



# Introduction To Restructuring Of Mid-Tier Shipyard By Developing Rough Layout Concept

**Rafael L. Callamand A.**

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Supervisor: Prof. Dr.-Ing. Martin –Christoph Wanner, University of Rostock

Dr. Ulrich Kothe, Fraunhofer Institute of Technology

Reviewer: Dr. Prof. Tadeusz Graczyk, West Pomeranian University of Technology

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Traditio et Innovatio



Zachodniopomorski  
Uniwersytet  
Techniczny  
w Szczecinie

*Nadie sabe de lo que es capaz,*

*hasta que lo intenta*

*(Publio Sirio)*

*No one knows what he can do,*

*until he tries*

*(Publio Sirio)*

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## GLOSSARY

First to all it is important to define the meaning of different terms that will be related in the document.

1. DES: Discrete Event Simulation
2. PWBS: Product Work Breakdown Structure
3. HBCM: Hull Block Construction Method
4. ZOFM: Zone Outfitting Method
5. ZPTM: Zone Painting Method
6. PPFM: Pipe Piece Family manufacturing
7. SYSTEM: It is a separate set of components, which linked to each other.
8. COTECMAR: Corporación de Ciencia y tecnología para el desarrollo de la industria naval, marítima y fluvial (Spanish). Science and Technology Corporation for the Development of Naval, Maritime and Riverine Industries.
9. OPV: Offshore Patrol Vessel.
10. MODEL: Imitation of either real or planning system.
11. SIMULATION RUN: It is the image of behavior of a system in simulation model within specified time frame.
12. EXPERIMENT: It is empirical study of behavior of a model repeating simulation runs varying parameter.
13. ENTITY: Denotes either element or object within boundary of system e.g. machines, operators, and repairman. Entity works being performed in object. On the other hand, resource performs the work.
14. ATTRIBUTE: is the characteristic or property of an entity (machine ID, type of breakdown, time that the machine went down).
15. ACTIVITY: Transforming object's state usually over some time (repairman service time, machine run time).
16. DELAYS: Processes that take a conditional length of time in the system.
17. EVENTS: Change the state of the system (end of service of machine, machine breaks down).
18. QUEUE: It is set, used to model waiting.

## Declaration of Authorship

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## **ABSTRACT (ENGLISH)**

The irregular demand in ship types, besides, limited timeframe to deliver either navy or commercial ships play a great role in shipbuilding industry. Therefore, shipyards are trying to reduce delivery times also reducing production cost. The main goal of this master thesis is to develop proposals for restructuring workflow of mid-tier shipyard using methodology that [WAN 10-2] proposed, rough layout concept and discrete-event-simulation (DES).

In order to accomplish with this goal, brief explanation about ship production process is given, description of simulation used in this field. Besides, brief analysis of capacities in diverse software and capacities of the shipyard used as case of studies.

As introduction of this type of study, using as case of study a navy ship called Offshore Patrol Vessel – OPV80. The first existing condition was modeled and validated considering averages values for workstations. In order to get better understanding of production rate, assessing effect of each workstation on overall production process is done.

Following, using this existing and validated model was possible creation of various scenarios. Two scenarios were performed in endeavor to improve productions time. One of this scenarios deal with the inclusion of automation in production line and the other deal with layout of the workflow proposed to reduce the time used to move the material along the production line.

In this master thesis simulation analysis had shown how to evaluate either risk or impact of future investments or changes in production line, varying parameters and measure outputs. Furthermore, considering the influence of each parameter in the production line and bottleneck assessment.

**Key words:** Ship Production, Simulation, Mid-tier Shipyard, and Production Line.

## **ABSTRACT (SPANISH)**

La demanda irregular en los diferentes tipos de buques, además los limitados plazos de entrega tanto para buques militares como buques comerciales, juega un papel preponderante en la industria de construcción de buques. Por lo tanto, los astilleros están tratando de reducir los tiempos de entrega y de igual forma los costos asociados. El objetivo principal de este trabajo de investigación es desarrollar propuestas para la reestructuración del flujo de trabajo de un astillero mediano usando el concepto de diseño aproximado propuesto por [WAN 10-2] y simulación de eventos discretos (DES).

Con el fin de lograr con este objetivo, una breve explicación de la producción de buques es dada, de igual forma la descripción de la simulación usada en este campo. Además un breve análisis de las capacidades de los diferentes software y capacidades del astillero utilizado como caso de estudio. Como introducción a este tipo de estudios, usando como caso de estudio un buque militar denominado Buque Patrullero de Costa afuera – OPV80, la primera condición es modelada y validada considerando valores promedios para los diferentes talleres que conforman el astillero. Con el fin de tener una mejor comprensión de la productividad, la evaluación del efecto de cada estación de trabajo sobre todo el proceso de producción es asumido. Posteriormente, usando este modelo previamente validado, fue posible la creación de varios escenarios. Dos escenarios fueron desarrollados en busca de mejorar los tiempos de producción. Uno de estos escenarios incluye la automatización de la línea de producción, mientras que el otro incluye una variación el flujo de trabajo actual con el fin de reducir los tiempos de transporte del material.

Para este trabajo de tesis el análisis de la simulación ha mostrado como evaluar tanto el riesgo como el impacto de futuras inversiones o cambios propuestos en la línea de producción, variando parámetros y midiendo rendimiento. De la misma manera, considerando la influencia de cada parámetro en la línea de producción y el análisis de cuello de botella presentado.

Palabras claves: Producción de Buques, Simulación, Astilleros medianos, línea de Producción.

## 1. INTRODUCTION

During the last years variation in the global economy has been changing drastically, pushing different industrial sector to create new strategies in order to face those variations. The field of maritime is not separate of this problem; therefore different researches in the field of simulation models used for ship design and ship production have been developed to deal with this challenge. The idea behind of use of simulation model is either reduction of production cost trying very optimal design with less scantling for example, reducing the workforce and also trying new materials cheaper than current one, or increase productivity at low cost using numerous possibilities such as the way that the block will be assembled, how the ship will be split.

In the field of ship design with the use of CFD (Computational Fluid Dynamic) as simulation tool permit optimize the hull of new designs, analysis of impacts of new devices on the hull, and reduction of design cost just using towing tank test with very few models as well. In addition of, there are plenty of software packages that permit to simulate sea-keeping behavior, stability analysis using several load cases, also analysis of lifecycle of new designs in the very earlier stages.

Likewise in the field of ship production, Discrete Event Simulation models –DES have been growing very fast in the last few years derived from different industries such as automobile. In addition of, capabilities of new computers have now a day's permit several advances in the simulation field. Those tools are very useful because of the possibility to model a very complex system and test different parameters in direction to recognize the interaction between them; besides of cost reduction caused for the use of any mock up. The simulation tools have been analyzed for different authors, [ARA 08], where state different uses:

1. Analysis of internal interactions of complex system.
2. Variation of inputs and performance of total process or sub processes.
3. The knowledge getting during approach to create a model is very important because of can help to improve the system under study.
4. The simulation can be used to teach functionality of a system or to reinforce analytical methodologies.

5. The simulation can be used to anticipate the output and performance of a system even during design stage.

## 1.1. Problem Description

Nowadays, because of fluctuating demand of different ship types, most shipyards around the world face the crisis changing their strategies in favor to keep their business afloat. Therefore the main idea is to optimize current capacity, reduce risk for new investments, and moreover extend the range of ships to be built either for commercial or navy ships.

For that reason, Discrete Event simulation – DES methodology fit as cheapest way to assess production processes in shipyards. But this approach show up with some difficulties because of in production, the acquisition of the information related with the processes carried out in the shipyard play very important role to develop the simulation model; in the same way the time required to do it affect directly the decision making in the current projects.

## 1.2. Objectives

For this master thesis the main goal is to create Discrete Event Simulation - DES model (using coarse layout method), of a mid-tier shipyard, modeling current production process of the hull of Offshore Patrol Vessel – OPV, validating the model, and consider two scenarios in endeavor to improve production time.

The specific objectives of this master thesis were as follow:

1. Understanding production processes for this kind of shipyards. Presenting basis of ship production and the characteristics of this kind of shipyards.
2. Studying coarse layout method to be used in the model. Using the method proposed by [WAN 10-2] in the paper “long-term capacity planning in the shipbuilding industry”.
3. Identify input data required for simulation model. Using the information given by the shipyard related with the OPV project. This information includes drawings, tables, productivity rates, etc.

4. Creation of simulation model. With the software Tecnomatix Plant Simulation the model is created using the information gathered from the item above.
5. Validation of coarse layout method model. Taking into consideration the information presented by [SAR 01] and [RAB 09] about validation and validity of this kind of production models.
6. Generation of new scenarios to improve productivity in the shipyard proposed. Varying some parameters creating what if scenarios, assessing the impact in the production line.
7. Conclude with the analysis of best scenario, which disclose less impact and recommend its application into the shipyard.

### **1.3. Approach**

Using DES simulation tool to assess the productivity and relationship of each parameter along the production process. Using real information about productivity and projects already done for the shipyard. With that information create model about the production process using long-term capacity planning in the shipbuilding industry. Nevertheless, this methodology has its own strength and drawbacks such as availability of input data.

Time frame to build this model affects the dynamic of this business. Consequently, the use of very easy model reduces input data requirement and modeling time for. Those very easy model in other words, coarse models permit simulate production process assuming statistically information with the aim to evaluate the impact of current workflow and analysis of diverse scenarios that permit understand how can be possible create a restructuration of production processes in mid-tier shipyards with regard to enhance and face the challenge of the actual market.

On the other hand, fine models deal with all the information related with the production process, including logistics relationship, time for each activity under study such as transport time for the material, availability of cranes, time for accomplish activities, idle time, all the information required to extract from the real system. This kind of model takes a lot of time to create because of the readiness of the information necessary. This approach permits take

some decisions in operational level, even to solve daily problems that show up in the production line.

In conclusion those coarse models result very useful for shipyards, which have to deal with the strategic level assessing the impact of long-term decision. Fine models permit to know problems in operational level (short term analysis), either to solve problems or improve the productivity with very relatively small changes.

#### **1.4. Research Process**

During any research project there is or there are question(s) that must be answered by researcher, e.g. what is the information needed to figure it out and face specific problem? In interest to develop this master thesis following steps were held using the guide suggested by [KUM 05]:

1. Formulating research problem. Which is the main objective to be reached with this report?
2. Extensive literature review. Used to explain and understand this field of knowledge.
3. Developing objectives.
4. Collecting data. This means, input data in shipbuilding production process.
5. Preparing research design including sample design. In this case the simulation model.
6. Data analysis.
7. Interpretation of information gathered and conclusions.
8. Preparing of report (master thesis in this case).

## 1.5. Thesis Chapters

During the initial chapters an explanation of production process, passing by the explanation of the Discrete Event Simulation will be done, to give better perceptive as introduction of next chapters. The simulation model and scenarios assessment were the main objectives of the following chapters. With the purpose of give brief idea of the structure of the document there is an explanation of each chapter that correspond with report as follow.

Second chapter called theoretical foundations depict brief explanation of production processes in shipbuilding industry, explaining all related terms, decomposition of product Work Breakdown Structure – PWBS and generalities of the simulation giving an overview of the meaning of simulation itself, related terms in this field, drawbacks and strength of this models.

State of the art that is the third chapter, which will contain brief description of the mid-tier shipyard used as case of study including some characteristics, also explanation of benchmarking, carried out in the shipyard. As background the simulation model used to create the New Production Line – NPL developed for one of the partners of this shipyard. Besides of, an explanation about the process to select the simulation tool, supported with the bibliography, description of the software to be used, explaining briefly what is the philosophy behind, related terms, and how to do workflow using the interface of the tool. On the other hand, shown different steps followed to extract from the information available from the project and the values required to use in the model.

The fourth chapter addresses with conceptual explanation of the production process carried out in the shipyard. The conceptual model also is given using all information analyzed.

The fifth chapter deals with the creation of the simulation model that emulates the current system. Explanation how all data already gathered was used discriminating useful information with the aim to create the simulation model. Validation of the model following the steps according with different authors was done.

The sixth chapter includes “*what if scenarios*”, derived of the simulation model of the current production processes already built. Using these information consequent form the scenarios, evaluate the impact in the production process using new parameters.

Descriptions about data gathered using mid-tier shipyard as reference, and how the model was built. Besides of, how the simulation model will be developed and what kind of information will be waited after the model is validated.

Seventh chapter shown recommendations derived from the analysis of the scenarios carried out. At last but not least, conclusions were included in the chapter with the same name.

## 2. THEORETICAL FOUNDATIONS

The main goal of this chapter is to make a brief description of production processes in shipbuilding industry and brief explanation about the simulation used in this field of industry.

### 2.1. Explanation About Production Process In Shipbuilding

Traditionally, shipbuilding processes have been identified with operations and procedures to transform steel plates in ship's hull. Those actions include essentially mark, cut plates and profiles and welded in small pieces to form sub-blocks and blocks and those parts in turn form the hull.

Preliminary description of these processes are supported by Group Technology methodology<sup>1</sup>, [STO 96] Propose the methodology called Product Work Break Down Structure – PWBS, which is possible to identify interim products during building process such as small pieces, sub assemblies and assemblies greater and complex, giving the possibility to keep clear diverse production levels and production lines as well.

#### 2.1.1. *Decomposition of Product Work Breakdown Structure – PWBS*

This methodology establishes different levels inside of the production structure, given the possibility to classify the interim products<sup>2</sup> and gathering parts with common attributes. Using this methodology shipbuilding processes can reduce drawings, standardization, and reduction of man-hours as during the early design stages as production stage, afford with clarification between design, acquisition and production departments in the shipyard likewise, better usage of the shipyard capabilities.

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<sup>1</sup> According with [IND 98], Organization of work to take advantage of common process characteristics, while accommodating minor differences in material, geometry and size in order to bring the advantage of mass production.

<sup>2</sup> Assemblies, which can be, manage as though it were deliverable product. E.g. Block, Subzone, unit.

To have better understanding of the PWBS, one should become familiar with the four-product aspect, [IND 97]:

- System: A structural or operational function of a product, such longitudinal or transverse bulkhead, mooring system, lighting system, etc.
- Zone: Is the objective of production, such superstructure, engine room, etc.
- Area: This is the division of the product in similar type of work, and could be divided depending of features (flat and curve panels), quantity (the work of outfitting in the engine room), quality (requiring various grades of workers and facilities), and kind of work (such marking, bending, welding, etc).
- Stage: the partition of the production process, e.g. subassembly, assembly, erection, outfits on –unit, on block, etc.
- Material: used for production e.g. plates.
- Manpower: Human resources to be charged for production.
- Facilities: Equipment to be used for production such as buildings, machinery.

The components of this integrated approach are explained from the Figure 1, according with [STO 95]:

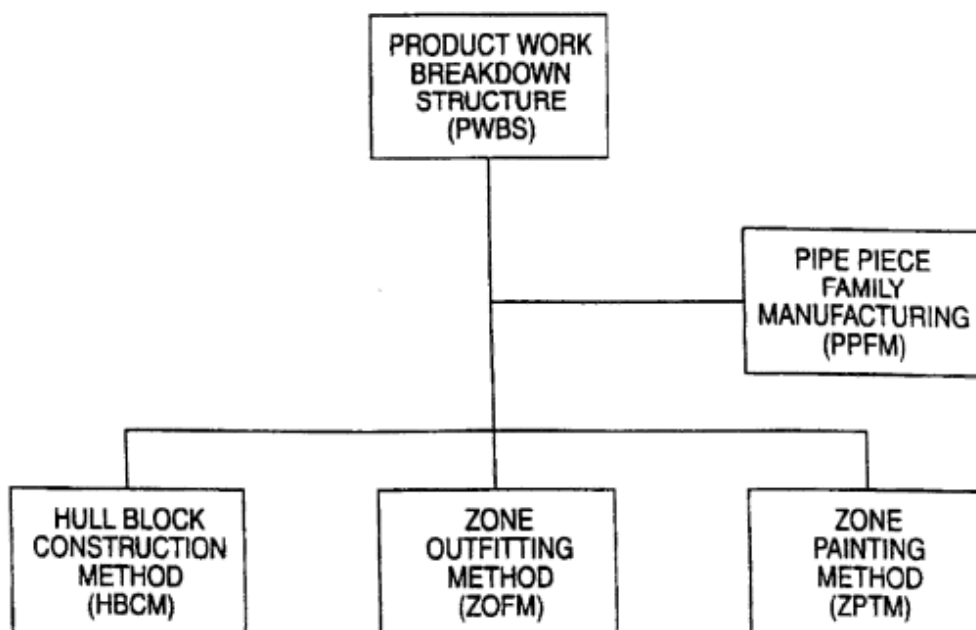


Figure 1. Components of Product Work Breakdown Structure. [STO 96]

### 2.1.1.1. Hull Block Construction Method – HBCM

Wherein hull parts, assemblies, subassemblies; blocks (zones are the goal) are built using the principles of Group Technology in organized production lines or workflow. The blocks division has the greatest influence in shipbuilding process, therefore, the designer has to take into account the same kind of outfitting and paint operation, and there should be similarities in volume weight, shape, etc. It is practical to plan hull construction in seven levels as shown in Figure 2.

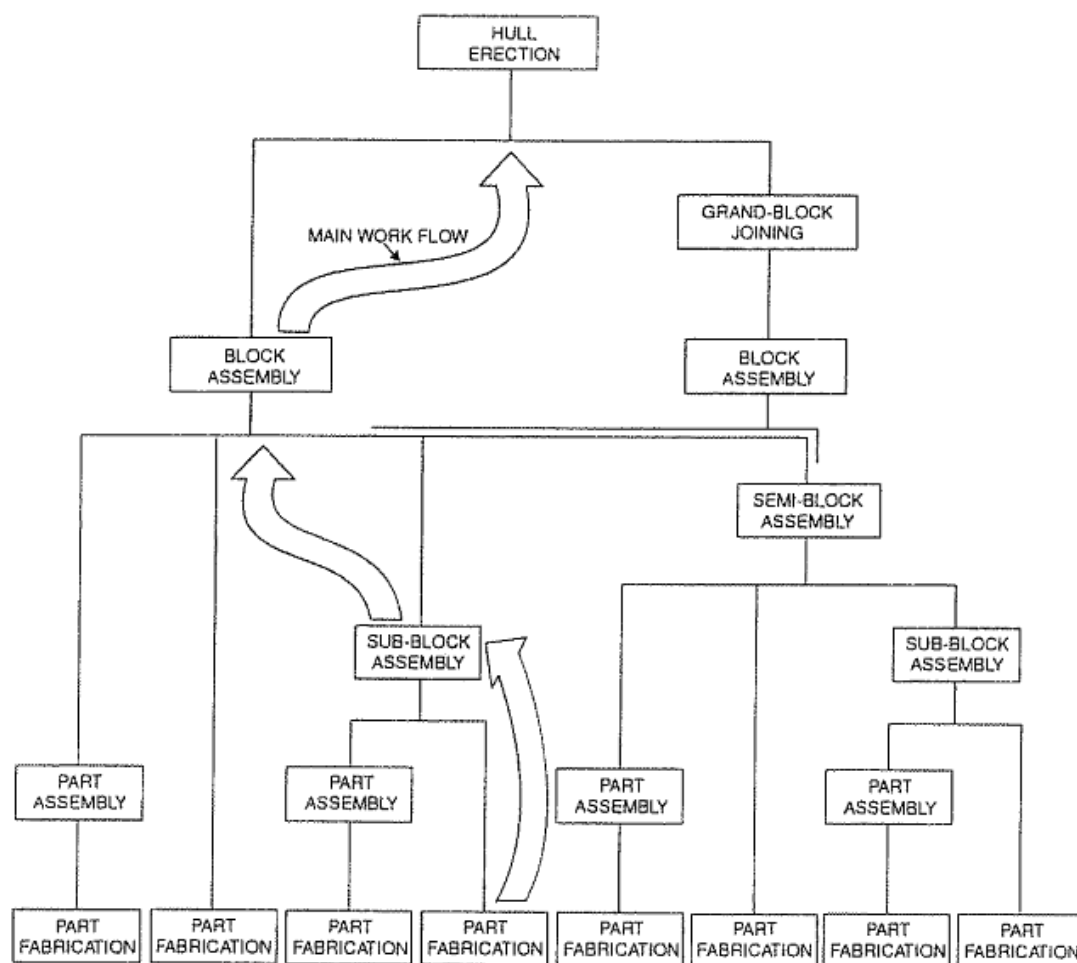


Figure 2. Hull Block Construction Method. [STO 95]

On the other hand, using flow according with [WAN 12], the configuration of parts manufacturing in the steel manufacturing sequence of a shipyard is shown as figure 3, where more specific explanation is given to have better understanding of the workflow of shipbuilding processes.

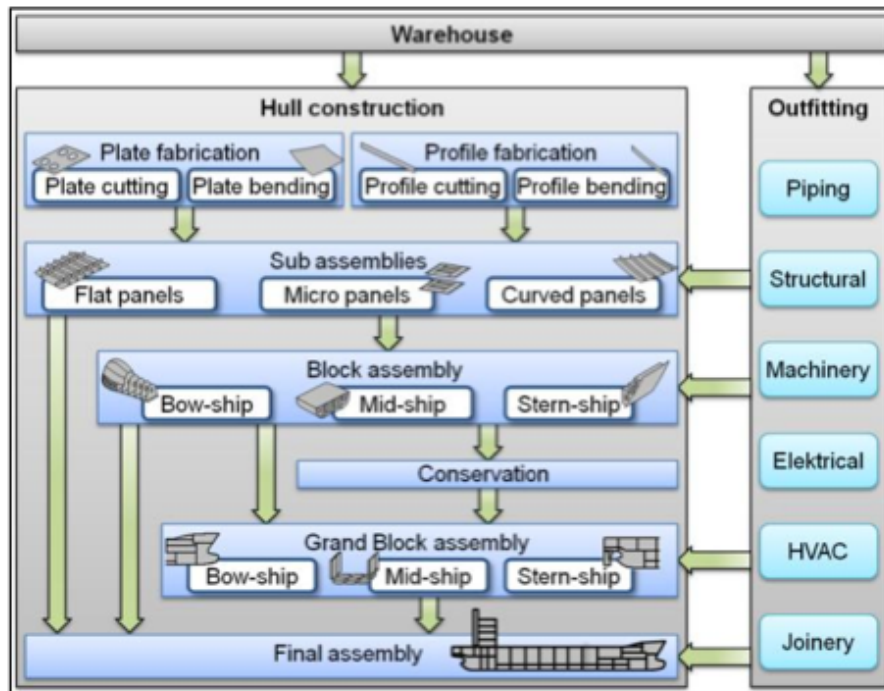


Figure 3. Steel Manufacturing Sequence of a Shipyard. [WAN 10-2]

Under this master thesis we will focus on Hull Block Construction Method – HBCM. Because of the complexity of the outfitting and painting process integrated with HBCM. Therefore the explanation of the HBCM methodology will be indicated.

#### 2.1.1.2. Pre-Fabrication

This is the first level in the block construction (HBCM), normally is carry out in specialized workshop with the require equipment and tools as shows figure 4. It is common practice that at this very first stage high levels of automation are present in order to reduce the fabrication time. At this stage cutting, bending and marking of the basic parts that make up the blocks are carried out.



Figure 4. Part Fabrication. [ITU 01]

### 2.1.1.3. Part-Assembly

The second manufacturing level corresponds to the part fabrication into small parts like Tee profiles, bracket welded with faceplate or flat bar shown in figure 5.

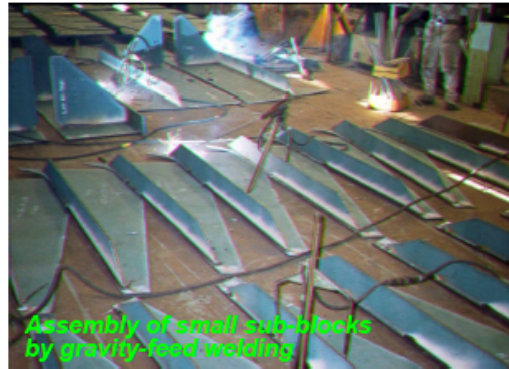


Figure 5. Part Assembly. [ITU 01]

### 2.1.1.4. Sub-Block assembly

This is the third level in the HBCM; parts, which can be welded with other parts in order to build up blocks, form it. These parts could be for example bulkheads, decks, etc. shown in Figure 6.



Figure 6. Sub Block assembly.  
<http://www.nenad-strbac.name.hr/>  
[Accessed on September 12<sup>th</sup> of 2012]

### 2.1.1.5. Semi-block, Block and Grand Block Assemblies

Different sub-blocks produce the semi-block assembly and parts assemblies, like the double bottom of a block, figure 7. The Block assembly is the most important part and also is reference for production control. Different semi-blocks welded in one unit form those blocks. Different blocks units form the grand block assembly, this part is also called zone.



Figure 7. Semi-block, Block and Grand Block Assembly

<http://www.watermarkpacific.com/newscontent.php?action=list&cid=55&pid=1&nid=95>

[Accessed on September 14<sup>th</sup> of 2012]

### 2.1.1.6. Hull Erection

At this last stage the total hull is building up using union of grand blocks, figure 8. Normally at this stage test of different compartments can be done. The level of outfitting at this stage is less and also welding parts because of the position and difficulty to get inside areas. Production time is very high compare with other stages.



Figure 8. Hull Erection

<http://www.watermarkpacific.com/newscontent.php?action=list&cid=55&pid=1&nid=95>

[Accessed on September 14<sup>th</sup> of 2012]

### 2.1.1.7. Zone Outfitting Method – ZOFM

Is derived by HBCM using the same logic, the outfit components are assembling independent of or on hull blocks. Therefore the ZOFM could be divided into six manufacturing levels as shown in figure 9.

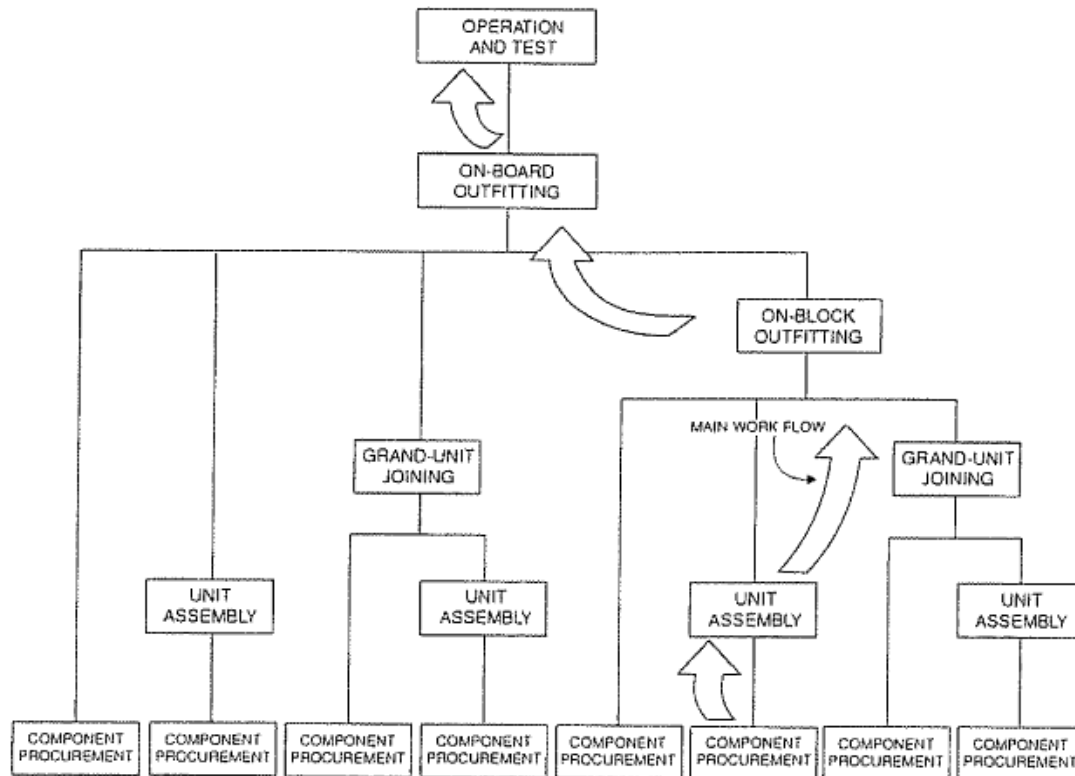


Figure 9. Zone Outfitting Method. [STO 95]

### 2.1.1.8. Zone Painting Method – ZPTM

The main idea is to proceed manufacturing levels by integrating painting with hull construction and outfitting processes. Painting is treated as another assembly process accomplished at each manufacturing level, as shown in figure 10.

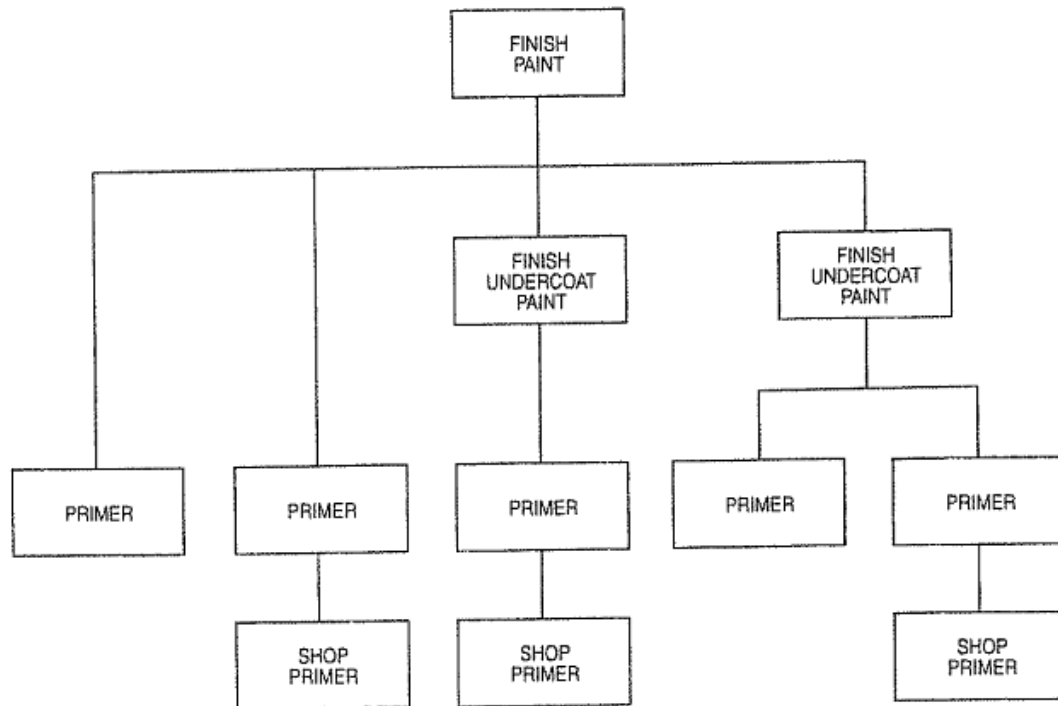


Figure 10. Zone Painting method. [STO 95]

#### 2.1.1.9. Pipe Piece Family manufacturing – PPFM

The aim is gathering wide range of pieces and conjuncts that use common elements forming families with the same attribute for production. Beside of this, test a covering of different type of pipes will be done in the same place of production in order to improve time of assembly. This process is comparable with HBCM, ZOFM and ZPTM; typically the PPFM is applied for seven different levels as shown in Figure 11.

The base of this methodology is possible to distinguish various stages or basic aspect of process as proposes, [AND 08]:

1. Sheet (or beam) metal treatment processes (conditioning, marking, cutting, bending).
2. Assembly, this process includes welding.
3. Handling. Moving and positioning the various blocks and subassemblies)

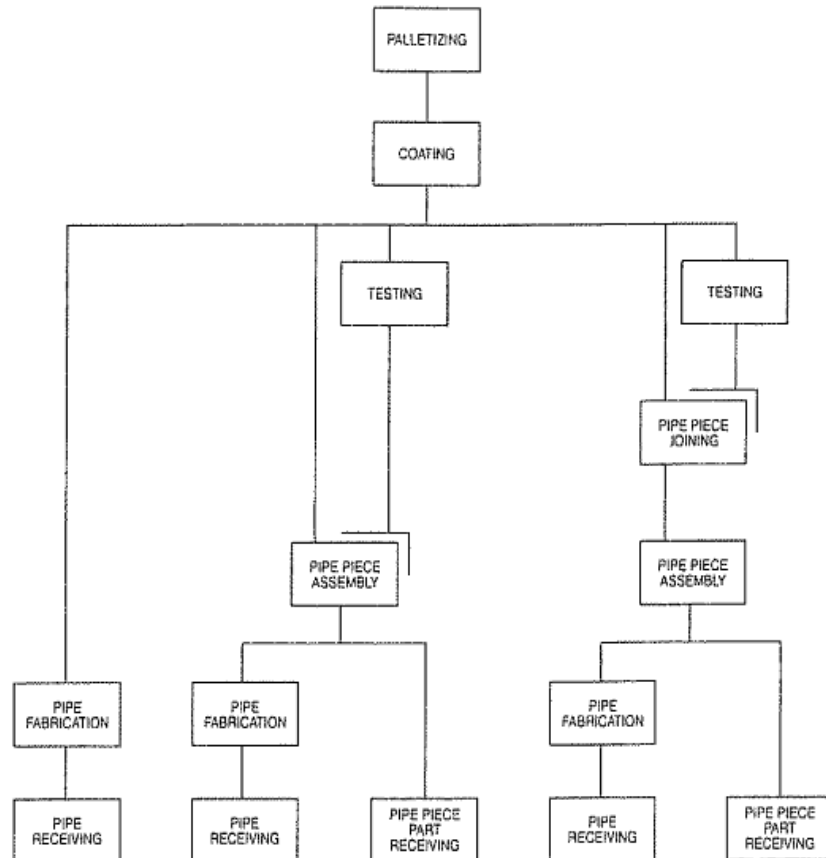


Figure 11. Pipe Piece Family Manufacturing method. [STO 95]

## 2.2. Simulation In Shipbuilding Industry

The complexity and interaction of the elements and processes involved in the shipbuilding process leave traditional static tools insufficient to provide results in this field. According with [KRA 04] state, the great number of variant parts and their dynamic effects can be shown and evaluated only by means of simulation. Capabilities of available simulation tools, already established in series production branches, have had to be extended according to the requirements of one-of-a-kind productions. The focus has to be set on the description of the product, resource and process structure, and the continuous product data flow to simulation.

Within the shipbuilding industry, simulation to control processes has been applied with following steps: Simulation scope, should take into account all dependencies and details of complex process and product, simulation model, production process can be split up in different phases:

1. Collecting material flow diagrams.
2. Collecting necessary product, process and project data.
3. Creating the simulation model of targeted production areas and relevant processes.
4. Comparing the simulation model with production process regarding the objective of the simulation project for validation & verification.
5. Simulation input/output which include static factors such as the system constrain are the information collected during analysis and data phases, process description, route scheme, facility data, generic methods;

In the same direction, time frame to build this model affects the dynamic of this business. Consequently, the use of very easy model reduces input data requirement and modeling time for. Those very easy model in other words, coarse models. On the other hand, fine models deal with all the information related with the production process, including logistics relationship, time for each activity under study such as transport time for the material, availability of cranes, time for accomplish activities, idle time, all the information required to extract from the real system.

Every change can be analyzed understanding impact of the total behavior of process. Otherwise, the simulation could be used to predict behavior of system during the design stage also assess functionality of every component. People that are using simulation get very advantageous outputs that depending of quality of the model and they could be very close to the real system. Moreover, is very important try to understand the drawbacks and strengths of this methodology according with [ARA 08], who affirm:

Strengths of this methodology:

1. It is possible to understand the importance of variables over a system.
2. Identification of bottlenecks is very important to evaluate how to get over them.
3. If very useful in design stage because of it is possible to have information about different layout concept without invest a lot of money e.g. new machinery.
4. With this model is possible run different proposals of information flow, arrangements of machinery, new organization without create any interruption in real system.
5. It is possible to evaluate outputs of a system to have very close information for planning future projects.

Drawbacks:

1. Simulation models require a lot of time and money to have very close model that permit evaluate real system.
2. Try to develop this kind of model is necessary special knowledge. Even if different expert in this field develop it model for specific system could be similar but not exactly identical.
3. Outputs are very complex because of inputs normally come from random variables. Therefore software simulation developers are working to create output easier to understand.

### 2.2.1. *Sort of Simulations*

In general way simulation is an emulation of a system, including its dynamic processes, in a model one can experiment with. It aims at achieving results that can be transferred to real world installation. In addition, simulation defines preparation, execution and evaluation of carefully direct experiments within a simulation model, [BAI 08].

This model can be divided either physical that is the scale of the system or virtual model, which permits use of software, figure 12. The first model present limited use and also more expensive, with the virtual one is possible to use it unlimited time and also permit creation of several scenarios to analyze.

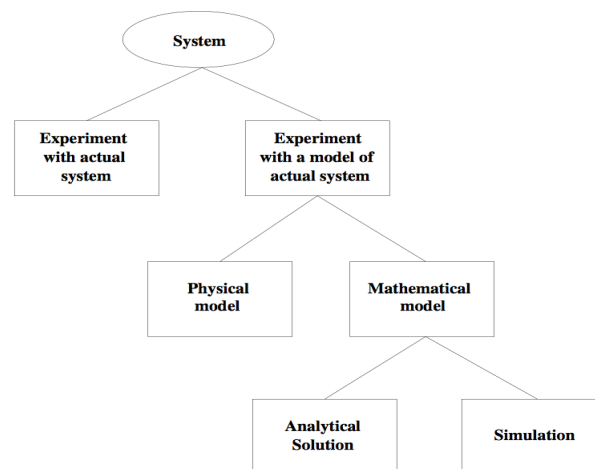


Figure 12. Ways to study a system.  
Simulation, Modeling & Analysis (3/e) by Law and Kelton, 2000, p. 4, Figure 1.1  
[Accessed on September 27<sup>th</sup> of 2012]

Behavior of a system changes in time; it is studied with a model of this system (simulation). To build this model is necessary to “Assume” some information respect of operation of this system. Normally these assumptions are formulas with logical, symbolical relationships between objects of the system. After the model is finished must be validated, this is the tune with the real system under study; it could be used to assess a great deal of scenarios about real system.

According with [ALB 10], there are different kinds of simulation but the main groups are three such as:

#### 2.2.1.1. Discrete Event Simulation

The DES utilizes a mathematical/logical model of a physical system that portrays state changes at precise points in simulate time. Both the nature of the state change, also time at which change happen mandate precise description. Customers waiting for service, the management of parts inventories or military combat is typical domains of DES – Discrete Event Simulation, figure 13.

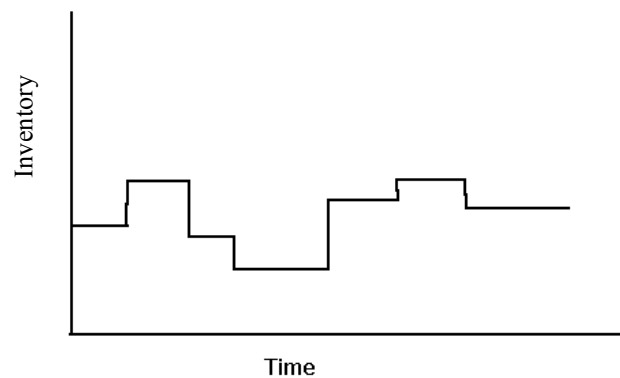


Figure 13. Discrete Event Simulation.

<https://engineering.purdue.edu/~engelb/abe565/week13.htm>

[Accessed on September 28<sup>th</sup> of 2012]

#### 2.2.1.2. Continuous Simulation

This kind of simulation uses mathematical models, frequently of physical system, which does not portray precise time and state relationships. The objectives of studies using such models do not require explicit representation of state and the time relationship. Examples of such systems are found in ecological modeling, ballistic re-entry, or large-scale economics models, figure 14.

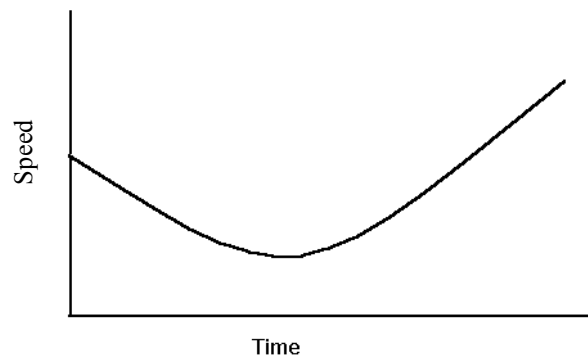


Figure 14. Continuous Simulation.

<https://engineering.purdue.edu/~engelb/abe565/week13.htm>

[Accessed on September 28<sup>th</sup> of 2012]

### 2.2.1.3. Monte Carlo Simulation

John Van Neumann and Stanislaw M. gave the name for this kind of simulation. They utilize models of uncertainty where representation of time is unnecessary. The term originally attributed to “a situation in which a difficult non-probabilistic problem is solved through invention of a stochastic process that satisfies the relations of deterministic problem”. A more recent characterization is that Monte Carlo is “the method of repetitive trials”. Typical Monte Carlo simulation is the approximation of a definitive integral by circumscribing the region with a known geometric shape, and then generating random points to estimate the area of the region through the portion of points falling within region boundaries. Figure 15.

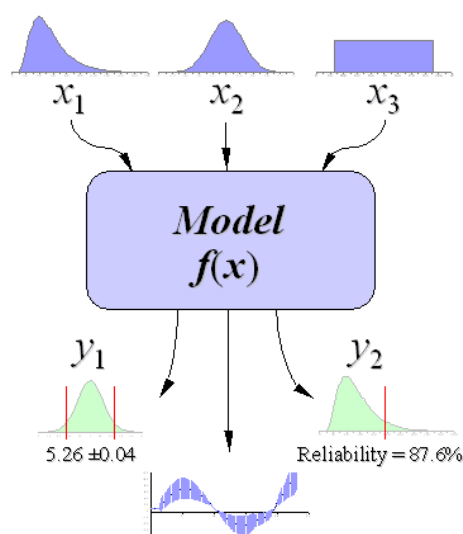


Figure 15. Monte Carlo simulation

<http://www.vertex42.com/ExcelArticles/mc/MonteCarloSimulation.html>

[Accessed on September 28<sup>th</sup> of 2012]

In the interest of have a better understanding; figure 16 shows approach of different kind of simulation are related.

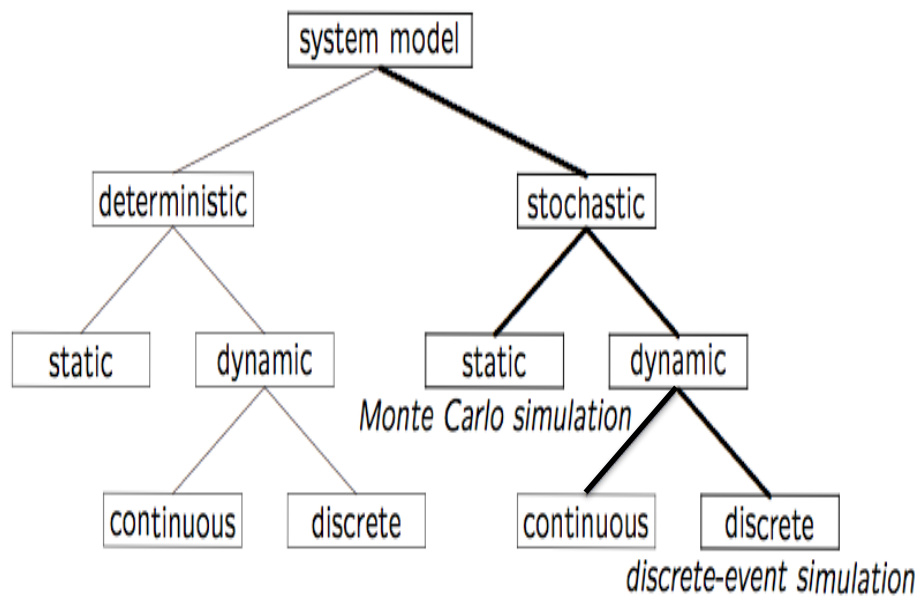


Figure 16. Model Taxonomy  
[www.cs.wm.edu/~esmimi/.../DESAFC-1.1.ppt](http://www.cs.wm.edu/~esmimi/.../DESAFC-1.1.ppt)  
 [Accessed on September 28<sup>th</sup> of 2012]

### 2.2.2. Course of Action to Build Simulation

Use of simulation tools involves different steps (flow diagram). Independent of problem or goals to be reached the processes remains constant. According with [BAN 10] the procedure is as follow:

1. Problem Formulation.
2. Test of simulation-worthiness.
3. Targets formulation.
4. Data collection and data analysis.
5. Modeling.
6. Execute simulation runs.
7. Result analysis and result interpretation
8. Documentation.

### 2.2.2.1. Problem Formulation

In the interest to face this stage, the customer (who will use the simulation), and the expert (who will do the model), will work together preparing the requirements for simulation. At the end those necessities should be written down in a document like technical specification or agreement.

### 2.2.2.2. Test of the Simulation-Worthiness

There are different ways to assess simulation-worthiness that can be written as follow:

- Many variables in the model. This mean lack of analytical mathematical models.
- When there are many factors to be considered, like in the ship production process.
- When the data are not available or inaccurate.
- Gradual exploration of the system limits.
- Repeated use of the simulation model.

### 2.2.2.3. Targets Formulation

This item depend of the shipyard (customer) because of different targets can be defined. Also there is main target that can be breaking down into sub targets. The definition of targets is very important step in order to address new scenarios in the simulation model. Normally the targets in this field are:

- Reduce the building time.
- Optimize the inventory.
- Diminish the idle time as for workers as for machinery.
- Support investment for new machinery.

At the end of simulation runs all targets must be gathered and analyze statistically. These assessments imply essential level of detail for the model.

#### 2.2.2.4. Data Collection

This stage requires maximum effort to get necessary accuracy to have the model very close to real behavior of the system. Data required can be structured as follow:

- System Load Data includes working plans, production orders, and transportation orders.
- Organizational Data is related with working time, shift scheme, workers, and machines.
- Technical Data, like layout, means of production, transport functions, routes, user time, capacity, etc.

#### 2.2.2.5. Modeling

This level includes model-building phase where the simulation model is building up and tested using required tool to transfer the concept into computational language. Once the model is ready must be compare with the real system behavior to evaluate relevance of the built model.

#### 2.2.2.6. Executing Simulation Runs

Test plan must be carrying out to validate the simulation model. In the same way, analysis of different simulation runs to estimate behavior statistically taking into account presence of random information during production process. Input and output data and underlying parameters on the model must be documented for each experiment.

#### 2.2.2.7. Result Analysis and Result Interpretation

The correct understanding of results from the simulation model influences success of the simulation study. E.g. outputs are contrary of assumptions made, it is necessary to check which parameters are responsible for this unexpected variation.

#### 2.2.2.8. Documentation

It is very useful for this phase create a report using the form of project report. This project report should provide with an overview of timing of the study and document the work carried out. The main goal of this report is the presentation of simulation results based on customer requirements, besides of, the conclusion of the study.

### **3. STATE OF THE ART**

The globalized economy requires that goods go from the production factory to the users. This means the use of mean of transportation. The shipbuilding industry holds the largest portion of the global transportation sector and is continuously growing.

In the following items a brief description about the mid-tier shipyard will be done, referring the benchmarking carried out by the research company FRAUNHOFER IPA. In the same way, the description of the simulation model already made in the shipyard, which include the production process of the production line, and the last item explain the selection of the software used to build up the simulation model.

#### **3.1. Description Of Mid-Tier Shipyard**

Keeping above brief explanation, those ships, which are going to carry all goods, necessitate to be built. The shipyard is the place, which according with its position permit easy access to water, e.g. along inland river, harbor, shoreline. And because of its workshops build the ships from the small up to the biggest size, either commercial or military. More over, some shipyards also carry on ship repair in the same place. Taking into account the difficulties that ship construction involves, numerous kind of skills are required such as naval engineers, naval architects, electricians, welders, etc. likewise, specialized equipment.

Those specialized equipment usually have specific distribution to facilitate the flow of materials and assemblies. There is no standard layout for shipyard taking into account that many shipyards were founded many years ago using the land available near to the water. Despite of, that the distribution for shipyard is not fixed, there are some typical features that those companies have to accomplish according with [MUH 12], such as:

- Locations on land for join up ships, along with associated means for getting the ship to the water, e.g. slipway system, synchro-lift, and dry dock, among others.
- Piers to mooring ships and carry on board works in order to finish them.
- Offices to support the activity e.g. cafeteria, nursing.

- Required shops to performing different sort of works like:
  - Steel marking, cutting and forming shop.
  - Steel assembly shop
  - Coating shop.
  - Pipe shop.
  - Plate shop.

On the other hand, this industry has a lot of competition. These oppositions forces shipyards to obtain comparison among competitors, in order to keep sustainability on the market. This assessment is called benchmarking. It is used worldwide and allows the processes and practices applied for individual shipyards to be compared to others and to international best practice. In the 3.1.1 item more detailed explanation of the method used has been included.

### ***3.1.1. Sketch of the Mid-Tier Shipyard under Study***

The Science and Technology Corporation for the Development of Naval, Maritime and Riverine Industries. – COTECMAR (for its Spanish acronym) is located in South America, Colombia in the city called Cartagena over the Caribbean Sea. It is a mix between governmental (Ministry of Defense through Colombian Navy) and commercial partners. COTECMAR as Science and Technology Corporation, is based on the university-company relationship, gives priority to research, development, application of new technology and the best business practices in order to contribute to the technological, social and economical development of naval industry in Colombia.

This corporation is oriented towards design, construction, maintenance and repair of as naval as commercial ships and artifacts is formed by different business line such as two shipyards (the biggest one with capacity to build and to repair ships until 3600 tons, the small one with capacity to do ship repair until 1700 tons), which are the backbone of the company, specialized workshops, design office, support offices, etc.

According with [FMI 07], this shipyard fit under the definition of mid-tier yards. Those kinds of shipyards typically employ more than 200 people but rarely more than 600. The market is for ships from small (20 m) to medium size (130 m). The yards tend to have lower levels of investment than the large yards and the overhead structure is generally lean with managers often having multiple roles. High level of subcontracting is common feature.

For this master thesis the study is focus specifically on the shipbuilding processes that are executed in Mamonal Shipyard. In order to describe the capabilities for fulfill those processes a panoramic view of the Mamonal shipyard is shown, where is possible to identify the workshops layout, dry-docks positions used to ship repair, likewise the workshops, dry-docks, mooring dock and other equipment required to build up ships. In the following items there are brief explanations of each workstation corresponding with the figure 17:



Figure 17. Shipyard layout.

<http://desarrolloydefensa.blogspot.de/2008/08/cotecmar-excelencia-en-astilleros.html>

[Accessed on September 27<sup>th</sup> of 2012]

## 1. New Production Line – NPL.

It is formed by pallets to store the plates after the shop prime application, pallets to store profiles and pipes, the CNC cutting machine (with plasma and oxy), bending pipe machine, Bending profile machine, pallets for pipe spools after bend and welded, cell to do hydrostatic test for pipes spool, cells for welders to build up as parts as sub assemblies, bridge crane and all the support for workers, figure 18.

Main dimensions:

- Length: 84 m
- Wide: 20 m
- High: 10 m
- Total area: 1.680 m<sup>2</sup>

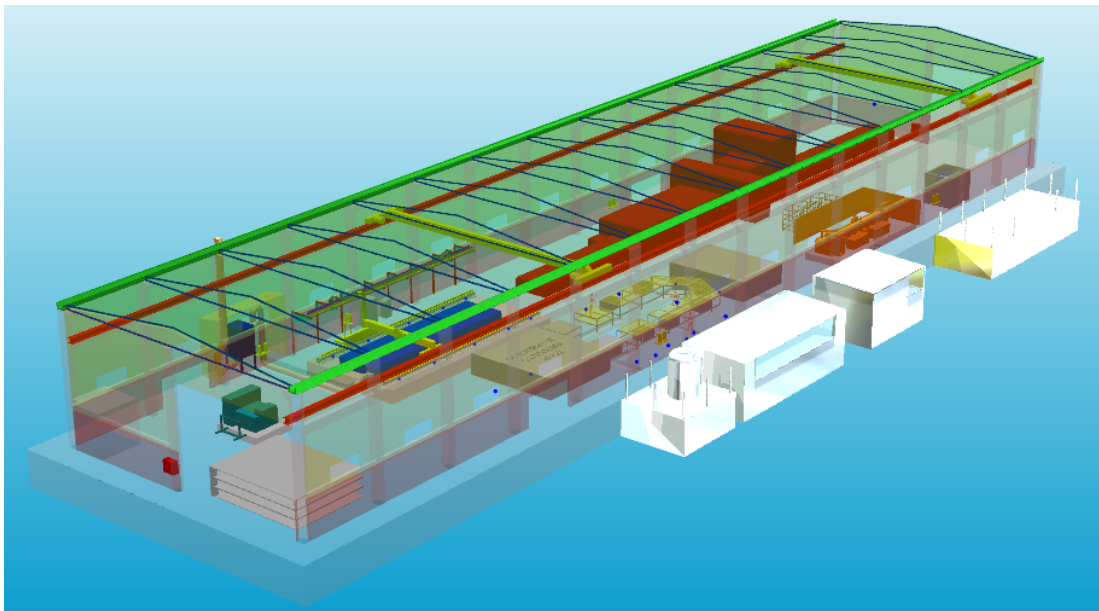


Figure 18. New Production Line workshop. [UNI 09]

## 2. Assembly workshop:

This workshop is used to join up panels and sub assemblies in order to form blocks, outfitting installation, sandblasting and painting of new blocks as well. This place counts with total area of 7920 m<sup>2</sup>, lifting cranes, required installation to supply welding, cutting and painting machines.

Main dimensions of principal zone:

Length: 120 m

High: 8 m

Wide: 46 m

Main dimensions external zone:

Length: 120 m

High: 8 m

Wide: 20 m

Figure 19 shows the assembly workshop drawing.

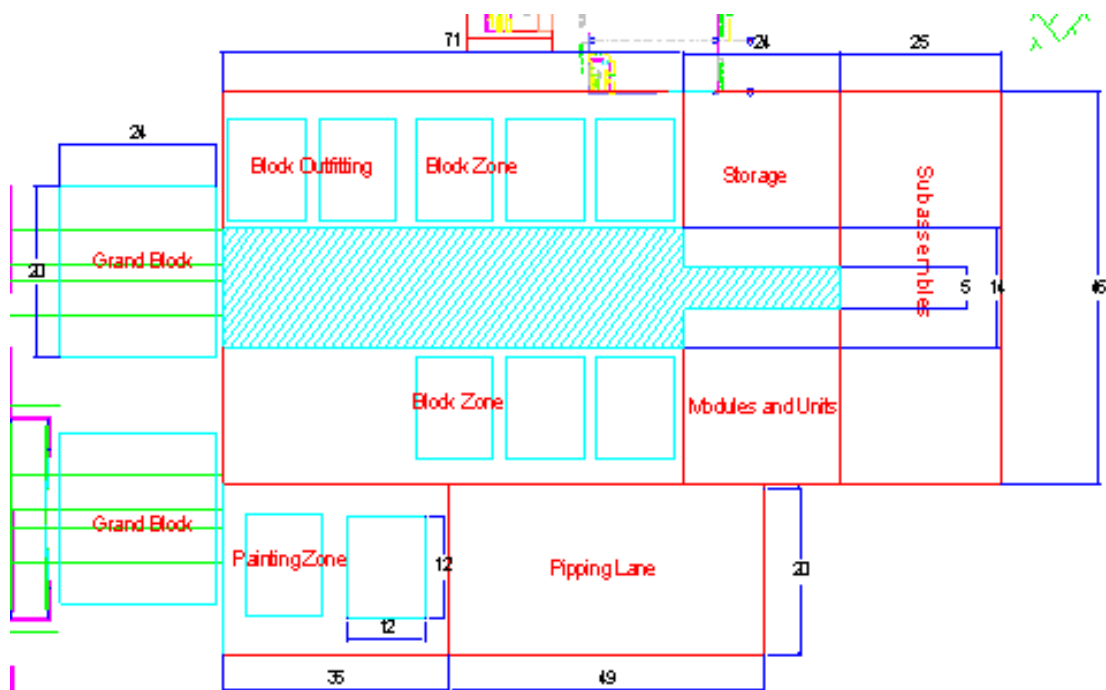


Figure 19. Assembly workshop. [UNI 09]

### 3. Hull Erection Zone:

This dock position is used to join the blocks, including the outfitting to create the called zones of the hull. The building of the ship hull is done on ground floor level. There is no output for more than one ship per construction point available. The erection is carried out at

the same place of the block erection. From this position is possible to move the hull to the water. Most of outfitting is installed as soon as possible. It depends on the available production information.

#### 4. Transfer Zone:

This area has a frame of 90 m, moving through 156 m space to get different docking positions. This equipment permit move the ships transversally in order to blocked in the different positions. In the case that will be necessary this frame could be used as dry dock position as well.

#### 5. Syncro-lift:

This platform has the capacity to lift ships up to 3600 Ton; maximum draft is 5.8 m, length of 117 m and wide of 22 m. In formed by 15 pairs of syncro. This is one of the most important equipment's of the shipyard, because of the lift of the ships, which are going to repair or putted in the water.

##### 3.1.1.1. Benchmarking Study

The term benchmarking explained by [NAZ 07], is the standard method for collecting and reporting critical operational data in way that enables relevant comparisons among the performances of different organizations or programs, usually with a view to establishing good practice, diagnosing problems in performance, and identifying areas of strength. Benchmarking gives the organization external references and best practices based on its evaluation and working processes.

To develop this methodology there are several ways e.g. visit other shipyards and analyze theirs practices, Proprietary Benchmarking System. The main idea is makes comparison using some scale for reference. This approach can be used to general industry. Therefore the

use of First Marine International (FMI)<sup>3</sup> benchmarking system is shipyard specific, according with [FMI 07] state that provides with foundation for developing a performance improvement program that has the following steps:

1. Evaluate applied for technology and practices against international best practice.
2. Assess shipyard's current best practice rating.
3. Identify gaps and imbalances in technology used.
4. Establish shipyard's current performance and competitive position.
5. Identify areas that require attention, if overall performance is to be improved.
6. Determine product focus and required performance through market analysis.
7. Set future performance targets.
8. Define the overall characteristics of the shipyard that will allow it to compete in chosen markets.
9. Describe the processes and practices that will yield the required performance.
10. Generate a prioritized performance improvement plan.

The benchmarking system has been applied for more than 150 shipyards worldwide and has formed the basis of industry studies in the US, Japan, South Korea and Europe.

#### 3.1.1.2. Benchmarking of the Mid-Tier Shipyard

During the visit of the survey team, the ship repair at the Mamonal plant and Bocagrande plant were observed, making interviews with staff members (ship new building, ship repair, design, R&D, HR, sales).

The main objective was assessing the actual situation of the shipyard and to give some suggestion to increase the productivity of the shipyard. Because of the confidentiality in the results the shipyard has not permitted the use of specific information included among final report.

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<sup>3</sup> First Marine International Limited was formed in 1991 to provide specialist consultancy services to the marine industry. Among the clients are shipbuilders, ship repairs, governments departments and international maritime organizations.

The conclusion according with [KOT 12] was that this shipyard has an average level of technology under the international level, with gap between groups, what mean that the shipyard has to improve in those workshops with lower values, pushing total average to be more equilibrated.

The last point of view is the technological concept. There are a lot of manual works, that under the actual conditions this procedure seems to be cheaper for the shipyard. But COTECMAR in the near future wants to build frigates comparable to international competitors as like U.S.A or Germany. Therefore high standard of quality is necessary.

This high level has to be achieved with either big effort or rework. International surveys show a percentage of 30% rework for shipyard with manual production processes. The benefit of mechanization and automation is not the reduction cost for workers; it is the increasing of the static level of quality and the reduction of rework effort.

Just the final conclusion is related with the aim of reader has brief idea about the result for this benchmarking in the mid-tier shipyard used as case of study for this project.

### **3.2. Existing Simulation Model**

COTECMAR has developed during specific timeframe couple of years ago, a research project with the general aim to design and implement new production line – NPL. Integrating concurrent methodology, support tools to take decisions related with productivity as well to face the variation in the global market for shipbuilding. Including best practices of plant distribution for shipyards using groups' technologies. In the same way, simulation model for ship repair was made to assess processes under this system. Just the simulation model developed for new production line is analyzed due to the relevance in this master thesis.

This simulation model was developed using Arena software version 10.0, which is discrete event simulation software developed by System Modeling and acquired by Rockwell Automation. It uses standard flow diagram elements that represent processes. Connector

lines also used to represent relationship between processes besides of workflow of entities. This model took into account all possible restrictions and based on parts workflow.

### **3.2.1. Simulation models**

As result of the input data gathering, there are two simulation models with the difference in the resources used during the shop primer application. The first model uses a machine which process just plates, for pipes uses of sandblasting cabin are required. On the other hand, the second model includes one sandblasting cabin, in which is possible process either plates or pipes as entities. For this second model, three attributes were taken into account such as Sandblasting Time, Painting Time, and Dry Time. All those information were gathered from historical data from older projects.

The first entity used was plates. Therefore the panel line was model using two processes. The first one is about surface preparation (shop primer) and second one relate cutting. Because of the differences in shape, size, and plate thickness four attributes were taken into account for this entity. Such attributes were:

- Thickness: using statistical data in order to assess probability to have certain kind of plates.
- Cutting time: This is speed by length unit, depend of the plate thickness. This information was taken from cutting machine.
- Quantity: Indicate how many cuts have to be done in specific plate. This information was gathering from statistic of past projects.
- Cutting length: The length of the cuts in specific plate. Those values were gotten from regression using how many pieces result from one plate and plate thickness.

The second entity used was pipe. To model the pipe line four processes were used such as cutting, bending, assembly, and sandblasting. The follow attribute were used for each spool:

- Length: At the beginning all pipes have same length but this attribute change during process because of cuts.
- Mass: The weight divided by length of each pipe, this attribute depends of diameter.

- Diameter: Using U.S standard “ASTM”.
- Cutting length: This information is used to know the length of new pieces also length of the pipe itself after creation of the new piece.
- Bending: This information is related of how many bending will be done in one pipe. It used to have time for bending process.
- Pipe Weight: With this information control of stock after cutting process and before sandblasting.
- Area: This value is useful to find time of each pipe during sandblasting and painting.

In the figure 20, and figure 21 the representation of the simulation model using Arena software is shown with the aim to have better understanding of this model built couple of years ago.

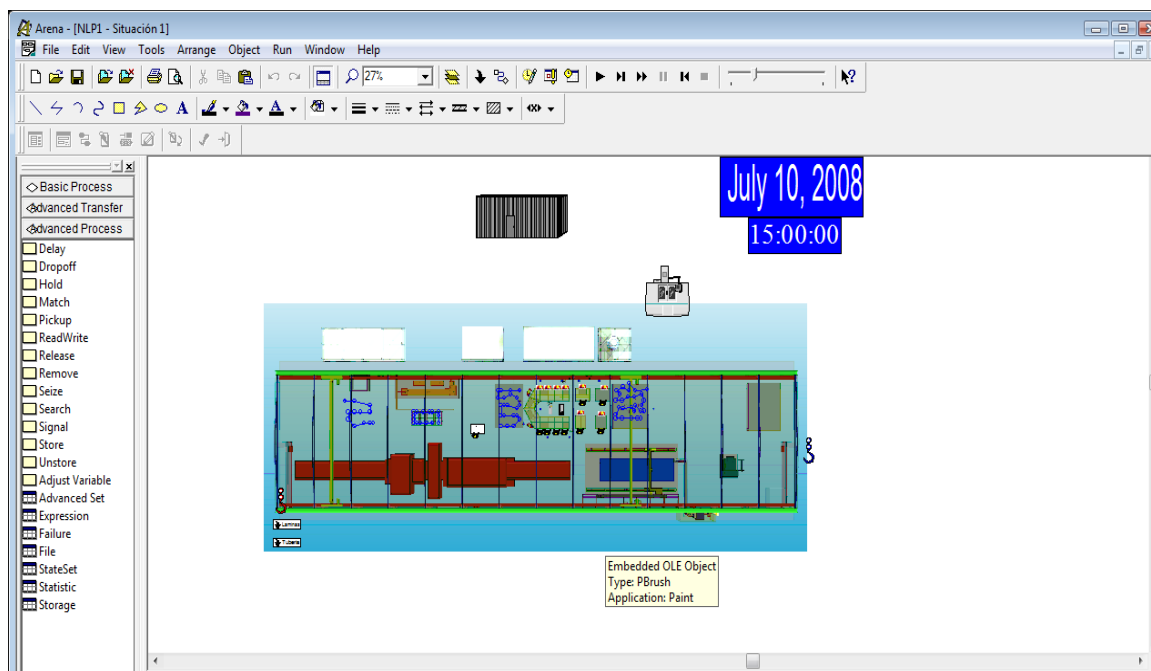


Figure 20. Simulation models 1. [UNI 09]



### **3.2.2. *Analysis of Existing Model***

According with the information analyzed for this model different conclusion can be written in this master thesis keeping the confidentiality of information collected from the shipyard under study:

- The simulation model was developed to analyze the new production line including workflow relate with all the process involving shipbuilding.
- With the simulation model the analysis of different scenarios to improve the production processes were carry out, using throughput of different kind of machinery like cutting plates, bending pipes, bending profiles machines among others.
- Diverse set up for new production line were assess to reduce transportation time, bottle necks.
- The model include algorithms, which include restriction due to this production processes, developed to optimize the use of resources.
- The model can evaluate different kind of ship to be built in order to give expected date to delivery.
- The model does not include differences between profiles and plates. This model identifies pipes and plates to run the simulation. Besides of this, there are no differences of the plenty of parts used to build a ship itself.

### **3.3. Selection of Simulation Software**

The simulation software allows users to build graphical representation of an application system and test it in a variety of scenarios to provide with better solution for problems in an organization [GUO 06]. This analysis depends of different items such as information available, the stage of the project, the aim expected.

The discrete event Simulation software is the most appropriate tool in order to assess the production process in a shipyard. Even that this kind of means are increasing in this field, but the use of this software still limited due to impractical time and cost associated with creating simulation models. Additionally, the system is built on existing simulation

software, resulting in applications that are complex, specific to a particular shipyard, and require experts to operate, [GUO 06].

At this moment there are different types of software in the market also literatures, which make comparison between them like [GUP 10], [CAP 10] using the multi-criteria-decision-making (MCDM)<sup>4</sup>. The method of MCDM used in those documents is the Analytic Hierarchy Process – AHP. This method rather than prescribing correct decision, AHP helps decision makers find one that best suits their goal and their understanding of the problem.

Using that information, where the alternatives for DES software were:

- NX-IDEAS (Integrated Design and Engineering Analysis Software), Now is PLM from Siemens ([http://www.plm.automation.siemens.com/en\\_us/products/nx](http://www.plm.automation.siemens.com/en_us/products/nx))
- Star – CD (<http://www.cd-adapco.com>)
- Micro Saint Sharp ([http://www.maad.com/index.pl/micro\\_saint](http://www.maad.com/index.pl/micro_saint))
- ProModel (<http://www.promodel.com>)
- Arena (<http://www.arenasimulation.com>)
- Flexim (<http://www.flexim.com>)
- Plant Simulation (<http://www.plm.automation.siemens.com>)
- Quest (<http://www.3ds.com>)

The conclusion about assessment of those simulation packages depending of the requirements, the cost of the license that any shipyard is able to pay, where the software Plant simulation is the most expensive, and time to develop production model. But even though this software has different advantages such as three-dimensional visualization, modules for optimization like the others, tools to check bottlenecks, and very good compatibility with programs from Microsoft's windows platform.

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<sup>4</sup> Approaches have been developed to support decision making problems, formalizing the trade – off between alternatives and fostering the transparency of the decision.

Taken into consideration those advantages and drawbacks the software to be used is Tecnomatix Plant Simulation. Besides of what was mention before, this tool has additional advantage because Flensburger Shipyard developed a simulation toolkit for shipbuilding (STS), reducing drastically the modeling time. The STS contains a large variety of simulation tool for material flow modeling, model management, execution strategies and output analysis. The tool can be easily implemented in all kind of simulation models. It is further developed and used within the international cooperation SimCoMar and the interbranch cooperation SIMoFIT.

### ***3.3.1. Description Of The Simulation Software***

Plant Simulation, software under Siemens group, it is a discrete-event simulation tool that permit to create computer dynamic models of complex system such as production systems, using icons that represents completely developed object. [BAI 08], declare that graphical interface is very friendly and is much convenient that programming lines either in Java or C++ environment.

The main advantage of this tool is that allows users to run experiments and what-if scenarios without disturbing existing production systems, on the other hand, in the planning process is very valuable to assess processes during design stage. Use of different analysis tools such as bottleneck analysis, statistics and charts let users evaluate diverse scenarios also impacts of new equipment in production line.

To have general understanding of this software, descriptions of the main components are done in this point. This is important to considerate philosophy behind of this tool. According with, [BAN 10], in plant simulation software standard classes can be divided as:

- Material flow objects
- Resources
- General objects
- Mobile objects
- Lists and tables
- Display objects

### 3.3.1.1. Material Flow Objects

Using the explanation of [BAN 10], mobile and static material flow objects are the basis objects of a model. They could be either static or mobile. The Mobile Units (MUs) represent physical or logical objects; these units are moving through simulation model by active or passive material flow. Active objects are SingleProc, ParallelProc, AssemblyStation, DismantleStation, Line, TurnTable, AngularConverter, Sorter and Buffer. Those objects actively transport the MUs along the connectors. Passive material flow objects are store, track, and TwolaneTrack. These objects do not pass the MUs automatically.

### 3.3.1.2. Resources Objects

These objects can be used to simulate employees that operate machinery, do repairs, to move parts. To use this resource is necessary to use other elements such as broker (mediates between suppliers and demanders of services), worker-pool (create the workers according with the information given), footpath (where the workers move between places and worker pool) and the workplace (it is used to connect an event of the machine with a request for a service)

### 3.3.1.3. General objects

The general objects are formed for different icons. The first is called, Frame, which is the base of all models. It is possible to combine various basic objects to an object with higher functionality. In this way is possible to build a model in several hierarchies. The object frame does not have its own basic behavior.

### 3.3.1.4. Mobile Units

Elements that imitate material in model frame and pass from object to object according with work flow. The source is the object that crates this MU, according with attributes given; on the other hand, at the end of the work flow the Drain destroys Mus. These Mobile Units are integrated by Entity (do not have basic behavior; the attributes are length and width). Container can load and transport other MUs, but it has not active performance. Used to

model palettes, and the Transporter Moves on the track with attributes such as speed, direction, capacity to carry, it has active behavior.

#### 3.3.1.5. Lists and Tables

The information objects are used to managing information and data. Those objects permit to create list of attribute for each active or passive object. On the other hand is necessary include statistics taking into account that production processes in shipyard does not lend to precise mathematical treatment, stochastic conduct does that the simulation has to be run several times to get the distribution of, for example, waiting times, failure in order to analyze a system, showing in tables.

#### 3.3.1.6. Display Objects

Display objects are used to show dynamic values (attributes, variables) during a simulation run. The values can be represented as a number or bar. The display shows numeric values in relation to the specific interval (between min and max).

## 4. TEST PREPARATION

The figure 22 shows all the steps required to build up the simulation model.

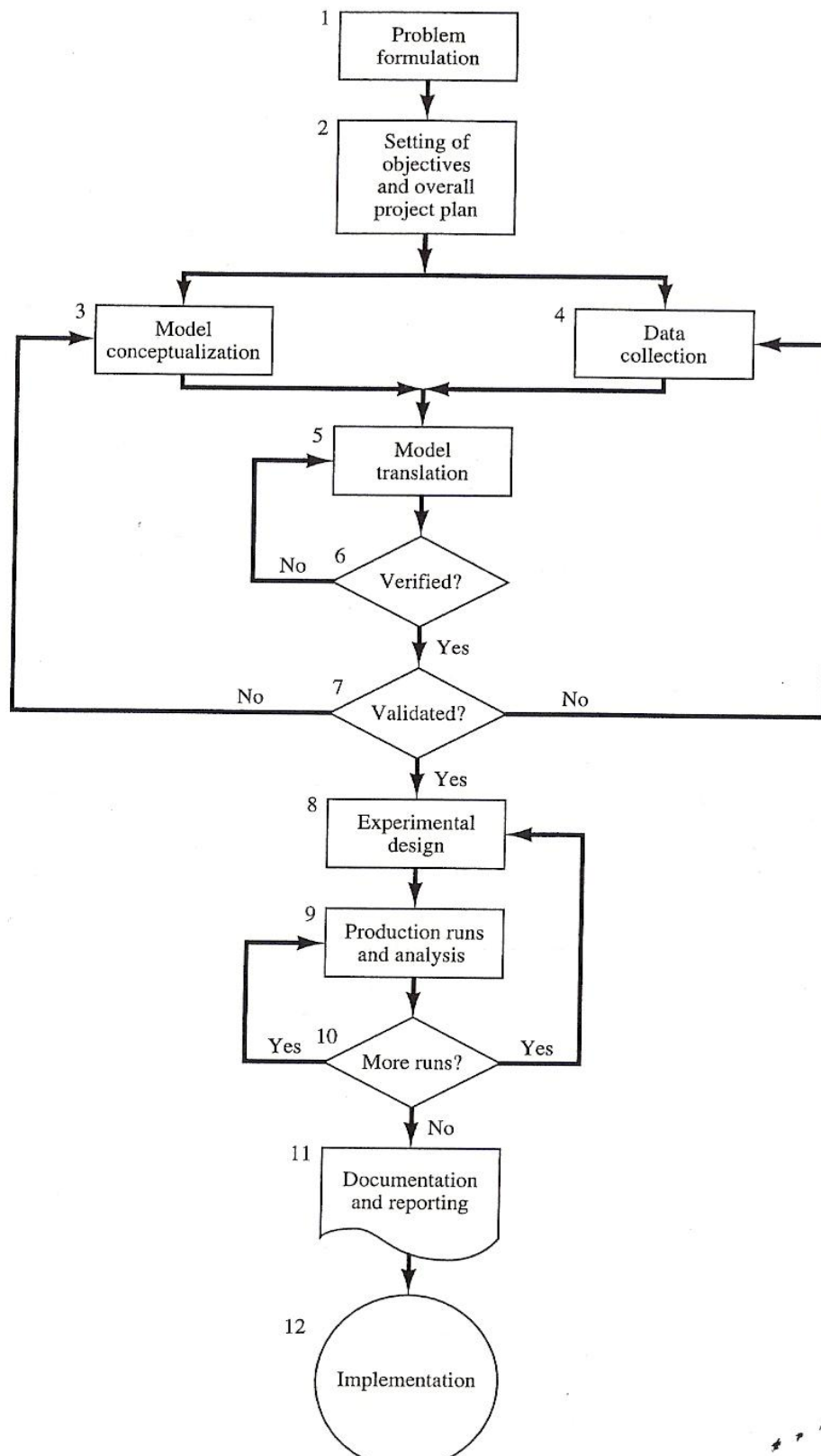


Figure 22. Flow diagrams to built simulation model. [ARA 08]

According with the explanation in item 2.2.1, in this document, In general way, simulation is the emulation of a real system, including its dynamic processes, in a model one can experiment with. In this chapter the main idea is to show all the steps required to gather all the required information to develop a model for production process in mid-tier shipyard, using simulation software selected in item 3.3 and explained in 3.3.1.

## 4.1. Data Collection

Input data required is the most important task to build any simulation model. In this item is shown process to gather required information to obtain good model data. According with [LAW 09], two basic principles to obtain good model data and potential difficulties with data are:

Basic Principles:

- The analyst must be sure that data requirements such as type, format, amount, conditions, etc. must be very specific and easy to understand for people who will provide with information.
- The person, who is creating the model, needs to understand process itself, because of normally there are information related with the process outside of the data available. Without understand process, could be very difficult to extract useful information in order to model the process.

Common Difficulties:

- Data are not representative of what one already wants to model.
- The information are not appropriate neither type nor format.
- The gather information includes some errors during either measuring or recording.
- Could be presented some “subjective” deviation for some interest from one of persons involved in simulation.
- The data can be saved under unknown conditions.

Taken into account the information written above besides of state by [WEI 10], input data required for the simulation model are divided in three groups and were collected in following manner:

#### 4.1.1. *Product Data:*

This group includes all specific information related with the object itself, such as product properties, assembly sequence and the work force required. [WAN 10-2] established the steps to gather require data to build rough model using part families<sup>5</sup>. The figure 23 shows how the ship hull is divided using this approach in Bow, mid sections and Stern, gathering also characteristics of each part (block type).

Another advantage of this methodology is the identification of the workload of each workshop depending of the ship type. This mean, that a ship, which has more curve panel like tug boat will have more work this workshop compare with a container ship, which has more percentage of flat panels.

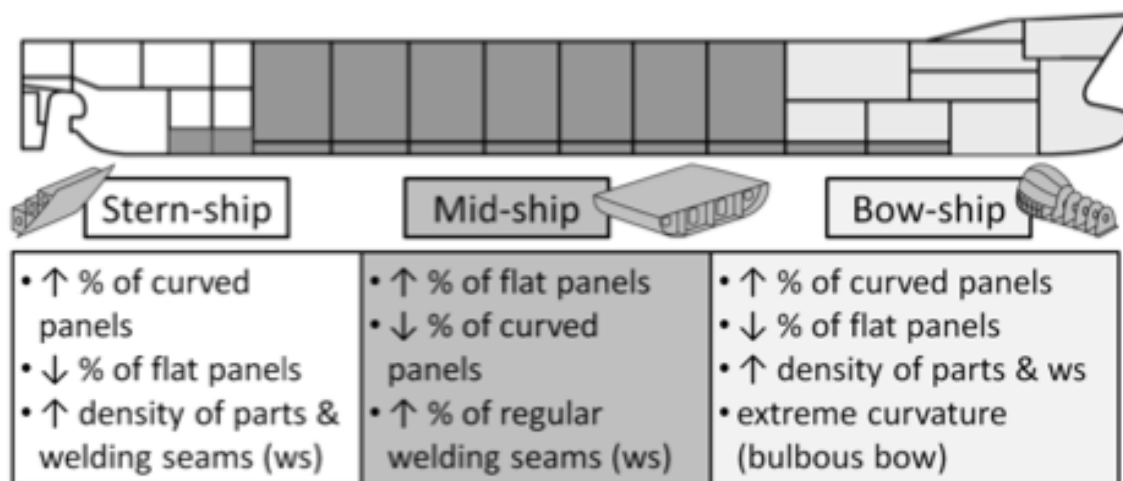


Figure 23. Partitioning of the ship hull and their characteristics. [WAN 10-2]

<sup>5</sup> "Part Families are group of parts with the same or similar manufacturing characteristics. This methodology is very common in the group technology approach as basis for the configuration of machine cells." [WAN 10-2]

To build distribution of the part families for our case of study, which is an Offshore Patrol Vessel – OPV, the ship was divided in Mid, Stern and Bow section, as figure 24 indicates this approach is used for this rough model for long-term capacity planning.

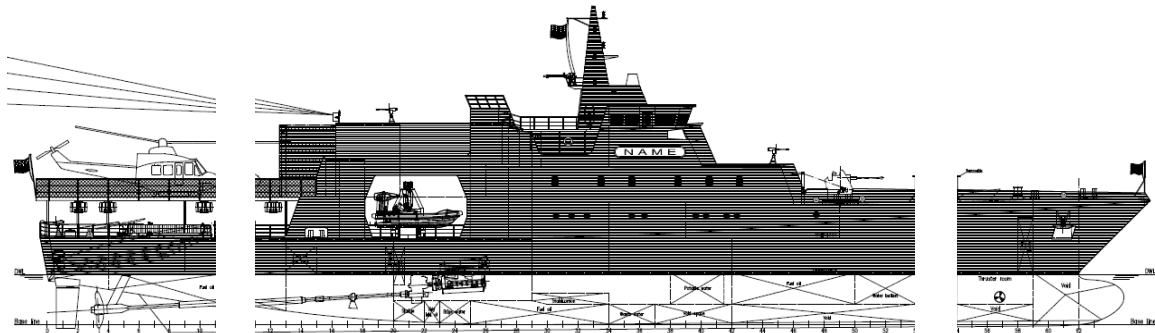


Figure 24. Zone division of the Offshore Patrol Vessel.

<http://www.fassmer.de/index.php?id=190>

[Accessed on November 12<sup>th</sup> of 2012]

With this division every block that belong to the ship’s hull has to be analyzed, such as capacity requirement for different working stations. The weight as reference is very usual in shipbuilding industry. Therefore, weight of the reference blocks is allocated to the proceeding production stages. The number of reference blocks is highly dependent on the product information available.

The ship hull of the OPV is divided in 19 blocks, table 1, 2, and 3 shown each block with the total weight including steel and profile, the outfitting is not taking into account during this master thesis. All the information was provide by the shipyard, which built this ship already.

Table 1. Weight allocation of blocks for stern part

	Stern-Ship		
Block Identification	1110	1120	1130
Weight (Ton)	7	31,5	31,7
Quantity	1	1	1

Table 2. Weight allocation of blocks for mid part

	Mid-Ship									
Block Identification	2220	2230	2320	2330	3410	3430	3510	3520	3610	3620
Weight (Ton)	65	33,4	60	35	22,4	53	17,5	25	13,4	20,1
Quantity	1	1	1	1	2	1	1	1	1	2

Table 3. Weight allocation of blocks for mid part

	Bow-Ship			
Block Identification	4720	4730	4721	4731
Weight	12	11,1	8,8	7,6
Number	1	1	1	1

In order to have better understanding about the procedure to gather all the information related with the material used to build the ship hull of the OPV, the procedure developed for one of the 19 blocks is shown.

1. The ship hull of the OPV formed by blocks. In the same way, assemblies form those blocks. Pre-assemblies form these assemblies. Plates and profiles form each pre-assembly. Those parts were identified and related to differentiated plates and profiles used. Figure 25 shows the well-known diagram of hierarchy that formed the ship hull relating all the components appointed before.

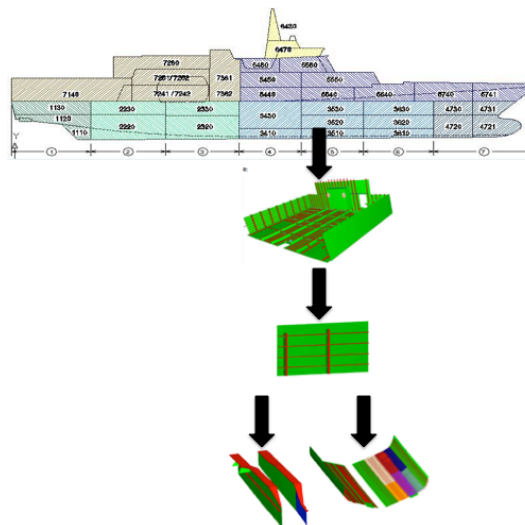


Figure 25. Hierarchy of parts in OPV80.

2. The first step was organized the information received from the shipyard, taken into account that this ship was already built, a lot of information related with production were available. This information was nesting, CNC programs, drawings, and list of parts that belong to the ship among others. Figure 26 relate the information used to gather the required information.



4. The step explained above was connecting with the part list known for each block. The problem with this part-list was that the information related was not divided for plates and profiles. Therefore the use of the drawing was very useful to understand at which group one part belong, e.g. bracket or profile made with plates. In the figure 28 the part-list used for the shipyard in its projects, the idea is to show that those list are very complex and the engineer has to go deep to understand the parts that compose each pre-assembly and how to obtain the information with the weight of either plate used or profile.

PART LIST - PZE80- 3530														
Blot	Sid	Weigh	Qualit	Ship	Nested on	Type	Area	Length	Widht	T	f	z	Assembly name	
1	3530	SB	4.48	A131	PZE80	00693410-07BU004	PLANAR PLATE PLANE	0.082	622.2	247.0	7.0	0	1	069_3-5-30
1	3530	SB	5.00	A131	PZE80	00693610-07BU002	PLANAR PLATE PLANE	0.091	689.0	268.1	7.0	0	1	069_3-5-30
1	3530	SB	5.40	A131	PZE80	00693610-07BU002	PLANAR PLATE PLANE	0.098	746.9	286.5	7.0	0	1	069_3-5-30
1	3530	SB	5.75	A131	PZE80	00693610-07BU002	PLANAR PLATE PLANE	0.105	796.3	301.7	7.0	0	1	069_3-5-30
1	3530	SB	15.86	A131	PZE80	00693610-07BU002	PLANAR PLATE PLANE	0.289	959.0	523.9	7.0	0	1	069_3-5-30-STR-X43S1
1	3530	SB	1093.67	A131	PZE80	00693530-07BU003	PLANAR PLATE PLANE	19.903	9648.5	2193.0	7.0	0	1	069_3-5-30-STR-Z6600-PAN
1	3530	SB	790.42	A131	PZE80	00693530-07BU006	PLANAR PLATE PLANE	14.384	9648.5	1497.0	7.0	0	1	069_3-5-30-STR-Z6600-PAN
1	3530	SB	801.62	A131	PZE80	00693530-07BU005	PLANAR PLATE PLANE	14.588	9648.5	1517.0	7.0	0	1	069_3-5-30-STR-Z6600-PAN
1	3530	PS	793.69	A131	PZE80	00693530-07BU004	PLANAR PLATE PLANE	14.444	9648.5	1497.0	7.0	1	0	069_3-5-30-STR-Z6600-PAN
1	3530	PS	799.85	A131	PZE80	00693530-07BU007	PLANAR PLATE PLANE	14.556	9648.5	1517.0	7.0	1	0	069_3-5-30-STR-Z6600-PAN
1	3530	CL	1137.79	A131	PZE80	00693530-07BU001	PLANAR PLATE PLANE	20.706	9648.5	2457.0	7.0	1	0	069_3-5-30-STR-Z6600-PAN
1	3530	PS	1094.61	A131	PZE80	00693530-07BU002	PLANAR PLATE PLANE	19.920	9648.5	2193.0	7.0	1	0	069_3-5-30-STR-Z6600-PAN
1	3530	SB	602.54	A131	PZE80		PLANAR PLATE PLANE	12.793	5205.6	2433.0	6.0	0	1	069_3-5-30-STR-BHCORR
1	3530	SB	42.24	A131	PZE80	00693520-08BU003	PLANAR PLATE PLANE	0.673	3369.0	202.5	8.0	0	1	069_3-5-30-STR-Z6600-Y4000S1
1	3530	SB	78.71	A131	PZE80	00693520-08BU002	PLANAR PLATE PLANE	1.253	6274.0	200.0	8.0	0	1	069_3-5-30-STR-Z6600-Y4000S
1	3530	PS	42.28	A131	PZE80	00693520-08BU003	PLANAR PLATE PLANE	0.673	3369.0	202.5	8.0	1	0	069_3-5-30-STR-Z6600-Y4000P1
1	3530	PS	79.43	A131	PZE80	00693520-08BU003	PLANAR PLATE PLANE	1.265	6324.0	200.0	8.0	1	0	069_3-5-30-STR-Z6600-Y4000P
1	3530	SB	78.67	A131	PZE80	00693520-08BU002	PLANAR PLATE PLANE	1.253	6274.0	200.0	8.0	0	1	069_3-5-30-STR-Z6600-Y1000S
1	3530	SB	42.24	A131	PZE80	00693520-08BU002	PLANAR PLATE PLANE	0.673	3369.0	202.5	8.0	0	1	069_3-5-30-STR-Z6600-Y1000S1
1	3530	PS	42.28	A131	PZE80	00693520-08BU003	PLANAR PLATE PLANE	0.673	3369.0	202.5	8.0	1	0	069_3-5-30-STR-Z6600-Y1000P1
1	3530	PS	78.76	A131	PZE80	00693520-08BU003	PLANAR PLATE PLANE	1.254	6274.0	200.0	8.0	1	0	069_3-5-30-STR-Z6600-Y1000P
1	3530	PS	462.68	A131	PZE80		PLANAR PLATE PLANE	9.823	5079.4	2433.0	6.0	1	0	069_3-5-30-STR-BHCORR
1	3530	PS	75.15	A131	PZE80	00693520-08BU002	PLANAR PLATE PLANE	1.197	5992.0	200.0	8.0	1	0	069_3-5-30-STR-Z6600-Y0
1	3530	SB	29.26	A131	PZE80	00693530-06BU001	PLANAR PLATE PLANE	0.621	2884.6	311.9	6.0	0	1	069_3-5-30-STR-X44S
1	3530	SB	34.86	A131	PZE80	00693520-08BU001	PLANAR PLATE PLANE	0.555	2992.0	200.0	8.0	0	1	069_3-5-30-STR-Z6600-X44S1
1	3530	PS	29.26	A131	PZE80	00693530-06BU001	PLANAR PLATE PLANE	0.621	2884.6	311.9	6.0	1	0	069_3-5-30-STR-X44P
1	3530	PS	34.86	A131	PZE80	00693520-08BU001	PLANAR PLATE PLANE	0.555	2992.0	200.0	8.0	1	0	069_3-5-30-STR-Z6600-X44P1
1	3530	PS	23.28	A131	PZE80	00693520-08BU001	PLANAR PLATE PLANE	0.371	1984.0	200.0	8.0	1	0	069_3-5-30-STR-Z6600-X44
1	3530	PS	4.49	A131	PZE80	00693410-07BU004	PLANAR PLATE PLANE	0.082	622.2	247.0	7.0	1	0	069_3-5-30
1	3530	SB	29.29	A131	PZE80	00693530-06BU001	PLANAR PLATE PLANE	0.622	2839.2	308.1	6.0	0	1	069_3-5-30-STR-X43S

Figure 28. Part list used for each block.

5. The information known for each block is used to divide the total weight used for profiles and plates. This is used to start definition of the workloads of the workshops. The first divisions to be appointed on are profiles and plates. Table 4, shown the information of three blocks from different parts of the ship, where the total weight of each block is divided in profile and plates used.

Table 4. Weight of profiles and plates for each block

	Stern-Ship	Mid-Ship		Bow-Ship
Block Identification	1130	2220	3630	4731
Weight	31,7	65	20,7	7,6
Number of Blocks	1	1	1	1
Plate Fabrication	24,8	53,49	15,05	6,26
Profile Fabrication	6,9	11,51	5,65	1,34

6. At the end of the analysis of all the information related before, that has been collected was divided in curve and flat parts. This division is done to analyze workload for each workstation in the shipyard, in order to have the input for the production system according with [WAN 10-2]. In the table 5, shown information gathered from the production information for reference blocks allocated in different parts of the ship hull as example.

Table 5. Breakdown of curve and flat parts weight for each block

Stern-Ship				Mid-Ship								Bow-Ship			
1130 (Block ID)				2220 (Block ID)				3630 (Block ID)				4731 (Block ID)			
31,7 (Total weight)				65 (Total Weight)				20,7 (Total Weight)				7,6 (Total Weight)			
Plate		Profile		Plate		Profile		Plate		Profile		Plate		Profile	
24,8		6,9		53,49		11,51		15,05		5,65		6,26		1,34	
Flat	Curve	Flat	Curve	Flat	Curve	Flat	Curve	Flat	Curve	Flat	Curve	Flat	Curve	Flat	Curve
14,01	9,34	4,79	2,10	28,54	17,82	5,49	6,01	9,71	4,22	3,34	2,30	3,12	2,79	0,50	0,83

\*All the weights are in Tons

7. The last step was to calculate the percentage of each part used to build the ship hull of the OPV80. The table 6 shows the percentage of the manufactured parts of the OPV80, based on the hull ship weight. The minimum and maximum value is used to have an idea of the variation presented for this kind of ships. Some values were changed in order to keep some confidentiality on the information received from the shipyard.

Table 6. Percentage distribution of manufactured parts of OPV80.

	Flat Panels Percentage	Curve Panels Percentage
Stern-Ship	20% - 28%	73% - 79%
Mid-Ship	54% - 62%	40% - 44%
Bow-Ship	44% - 52%	50% - 54%

\* Based on ship hull weight

#### 4.1.2. Production data:

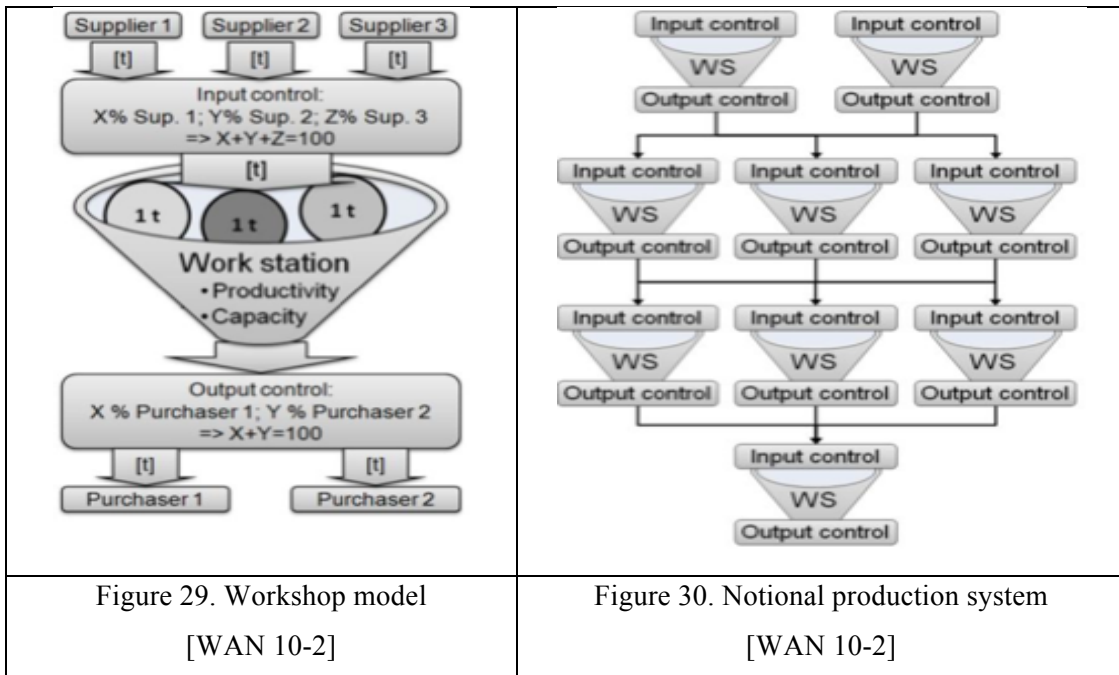
Production program data is related with futures contracts for ship construction including beginning and delivery dates. On the other hand, production system is related with available capacity and productivity of shipyard's workshops. For this last item the use of coefficients such as man-hours per ton of steel ( $P_h$ ), machine-hours per ton of steel ( $P_m$ ) as [LAM 02] established. The next steps were following in order to gather all the information related with the production data as follow:

1. The information used for this master thesis was modified form the original one because of the confidentiality. But some information is shown in the table 7, were different projects are related to have rough idea of the production probable for year.

Table 7. Projects expected by year.

Type of Ship	Length (m)	Breath (m)	Depth (m)	Quantity Per year
Tug boat	37,50	13,5	6,50	1
Barges	65,00	13,00	2,50	2
Naval Vessel	45,00	11,00	3,10	1
OPV80	80,00	13,00	4,50	1

2. The projects expected per year, gave it the estimated quantity of material that the mid-tier shipyard has to deal with in order to accomplish with the goal. For this master thesis the information used is related with OPV 80 and just taken into consideration one more ship for near future.
3. According with [WAN 10-2], a workshop is considered as a funnel with a given capacity and productivity, figure 29. Every workshop is equipped with an input and output control to regulate the material flow. Thereby a production system can be modeled based on this workshop system, figure 30.



4. Taken into account workshop's productivity that is crucial to the functionality of the simulation model; it is possible to control input and output for each one. Keeping material flow according with the real process. For this method, the reference ship's hull is separated into elements representing one ton of steel. This means if one ship hull weights 1000 ton, the input for production system is 1000 elements, without discriminate neither profiles nor plates. Table 8 refers some productivity coefficients of the shipyard based statistically from different projects. It is possible note that the coefficients did not discriminate how many welders have to be involve to get this value, because of this information is not essential for this rough layout concept.

Table 8. Productivity Coefficients for Shipyard

Workshop	Hour/Ton
<i>Work station for flat panel (workshop2)</i>	
Pre-assembly (midship section)	8,68
Assembly panel (midship section)	5,12
<i>Work station for hull erection (workshop2)</i>	
Midship section	25,00
Bow & Stern section	20,00

### 4.1.3. *Structural data:*

Comprise information about assembly area list, shift system for workers, service hours for machinery, and labor days during year among others. With this information is possible to create the restriction for time to be run the simulation model, because of this limit the daily schedule has to be including either for workers or machinery. Table 9 shows shift systems used in the shipyard. This information could vary from project to project, but for this analysis the use of this man – hours per day will be used.

Table 9. Shift system for man labor

Shifts per day	Hours per shifts	Working days per week	Working days per year
2	8 h/shift	5/week	241/year

Table 10 includes information related with the shift system used for machinery. This information changing depends either of the breakdowns presented during each project or variation of the projects developed during one year. For this simulation model there was not any breakdown for machinery during the time to be run, and the projects to take into consideration was described in the table 7.

Table 10. Shift system for machinery

	Kind of machine		
	Cutting	Pipe blender	Crane
Working days per week (days/week)	5/week	5/week	5/week
Shift Regime (Shift/day)	3/day	3/day	3/day
Effective Hours per day (hours)	18h/day	18h/day	18h/day
Working days per yard (days/ years)	330d/year	330d/year	330d/year
Machine time (hours/ year)	5940h/year	5940h/year	5940h/year

## 4.2. Data Preparation

Following the guide presented in the figure 21, the next step to create the simulation model is to generate the conceptualization model. [WAN 10-2], suggested an explanatory complete simulation model shown in the figure 31.

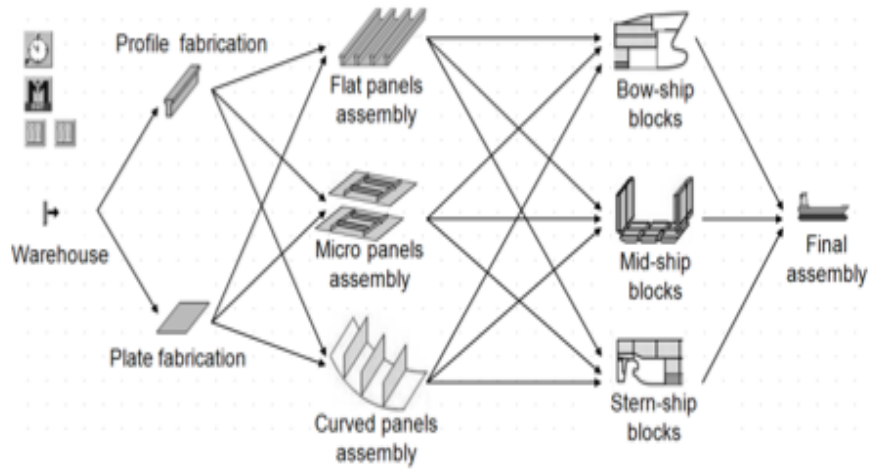


Figure 31. Explanatory Simulation model of a shipyard [WAN 10-2]

Taken into consideration the information above related, the following step is to represent the workstations along with their interactions. Figure 32 shows the main workshops of the shipyard, which are involved under hull ship construction avoiding all processes of outfitting.

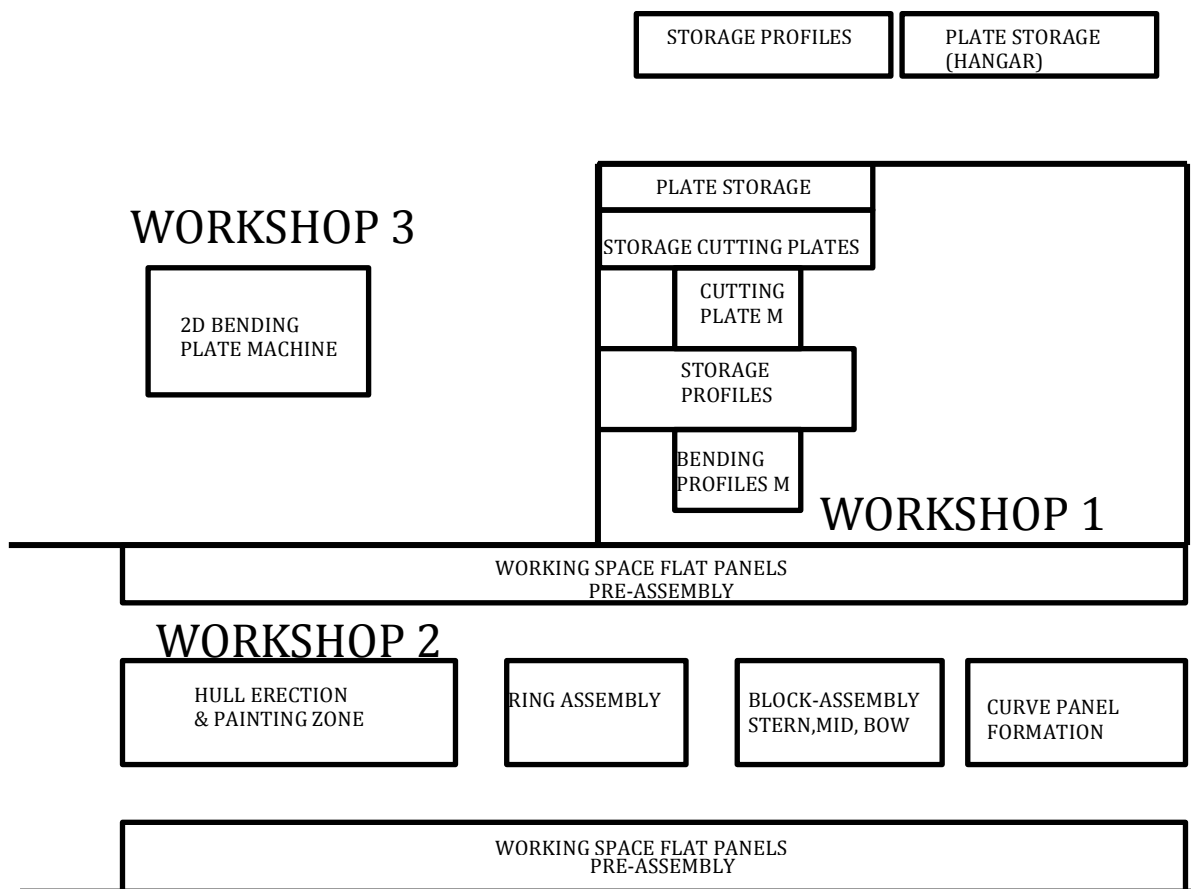


Figure 32. Shipyard Workflow

The figure 33 indicates the flow of materials for the mid-tier shipyard using the percentages of distribution of the OPV80 used to create this simulation model. The coarse model linking figure 31 and figure 32. The main difference respect with the figure 31, it is that this mid-tier shipyard does not use micro panel fabrication; therefore, this step was eliminated from the diagram.

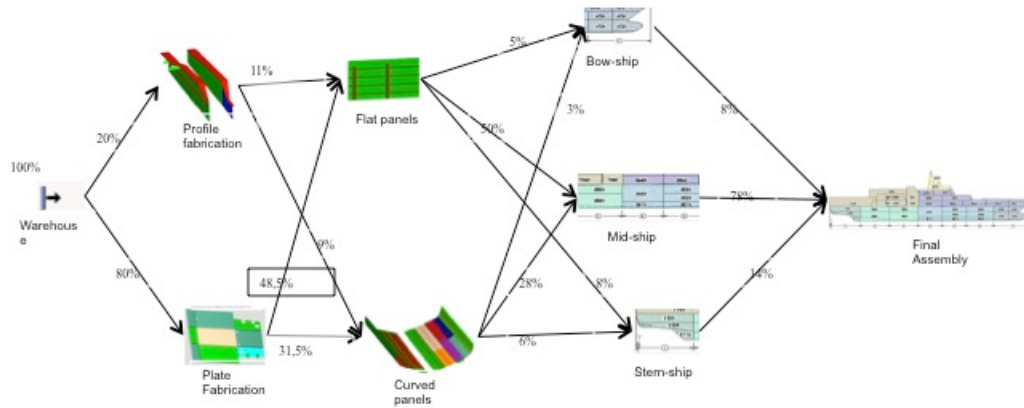


Figure 33. Flow of materials for OPV80

## 5. MODELING

In order to start developing simulation model one step is to determine, what aspect of real system has to be included in model and which other cannot be taken into consideration. This is related with the statement that models are not universally valid. Each model has to be designed for specific proposal.

On the other hands, the use of experts, people who are familiar with either process under study or similar process, with the aim to extract the most important aspect to be analyzed. In the same way, wonder which are the most important parameters, distribution and subsystems that have biggest impact over the system. One of the common errors during this process could be include a lot of details in the model. According with the recommendation of different authors, the idea is to start with coarse model and then include all required details to accomplish with the objective. Using this approach all the people working to build the simulation can understand easier main parameters of the real system.

Using the software chosen in chapter 3, Tecnomatix Plant Simulation 10.1, the simulation model for the shipyard is created, but for easier understanding the model is shown in linear workflow in order to appreciate the material flow passing through the workshops of the production line.

Tecnomatix Plant Simulation software works modeling hierarchically structured. In this manner, real system is broken down into its functional sub-systems. This approach permits decomposing the system with enough accuracy. [MUH 12] state “The individual objects and the operations within the objects are linked to an overall process. This creates a frame and with the objects and the frame various logistical systems can be modeled considering the input, failures and output parameters.”

## 5.1. Concept of the Current Scenario

Once all data are collected for modeling, the next step is to identify the connection of the material along the workshops finishing on the hull erection. With this diagram the relationship with predecessors and successors could be identified. According with [TRO 10], in manufacturing the acquisition of valid source information about main relevant characteristics and behaviors of manufacturing function is the key for simulation. Brief explanation for the shipbuilding process used in the mid-tier shipyards is given to have better understanding of the simulation model as follow.

1. At the beginning the material is received from the suppliers, who delivered the steel and profiles in different ways. According with this information the procedure to follow depend on the shipyard, they will remove paint or mill scale by blasting, and add primer. The typical process is to have plates and shapes loaded onto an input conveyor by forklift, crane and/or transfer car. After the material pass through blast machine and paint sprayer. The processing time for material treatment is a function of drying time, blast rate, and paint rate. This time will vary based upon what equipment a shipyard uses and the specific operational sequence followed, for example some shipyards apply primer paint immediately after blasting, while others works with clean plate.
2. Plate processing consists of cutting details parts from a raw plate. Could be used to cut just one piece or many from this raw plate. The plate is on the cutting table where it is cut using a CNC burning machine. Processing times are dependent on setup time, marking time, type of cutting head (i.e. plasma, oxy-fuel, laser, water jet), number of cutting heads on a gantry, plate thickness, length of cut, type of cut (straight, bevel, double bevel), number of pieces in a nest, and removal of parts. Material handling times are based on loading and unloading times. Normally the small parts and scarp are manually removed and placed on pallets.
3. Profile processing consists of cutting details parts from lengths of raw material stock such as I-beam, angle iron, flat bar, square stock, bulb, etc. Material is brought in using transfer car or crane onto roller tables, where layout for cutting is performed. After this process secondary operations are carried out such as beveling, notching,

bending, and/or punching. Processing time is a function of material transport (operational speed of transporter, distance), equipment-cutting times (cut rate depending thickness, length of cut), and number of pieces in a nest, marking time.

4. For pre-assembly and assembly of flat and curve panels the material is brought to the area used for those processes where the small assemblies are welded in order to create bigger panels, depending of the shape the material could brought from the curve workshop or cutting machine directly. The workshop has crane to move all the parts different position inside of the place. The processing time include the shape of the material, thickness, quantity of material to be welded, position required to weld, also include the quantity of personnel used to accomplish with the task.

For the last step includes the assembling of panels that conform different parts (stern, bow and midship), assembly of blocks (hull erection). For this task the processing time include the length of the welding, difficulty of the weld among others. The figure 34 depicts the production process described before using boxes to represent workstations. With this diagram the workflow is very easily identify.

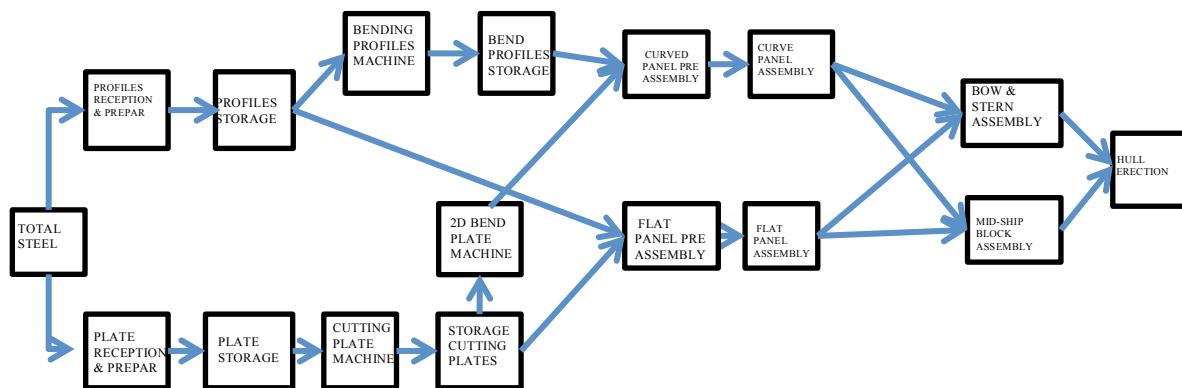


Figure 34. Block diagram of production process for shipyard

## 6. EXPERIMENTAL PROCEDURE

Using the flow diagram described in the figure 21, the next step in the direction of to build the simulation model of the production process of the shipyard, it is the model translation. This step has to be done using all the information gathered and prepared. In order to have better understanding of this simulation model using current situation, description of the procedure, parameter used will be done.

### 6.1. Model Description

The different workstations that forms all the system to build up the hull of any ship in the shipyard are described in terms of the values required to create the simulation model, this mean information about the time required to weld, cut. The model made in this document does not include information about the time for transporting parts between workstations, because of the availability of that information were not possible. According with the philosophy of the software (Plant Simulation) used, the description of the simulation model is done fitting standard classes as follow:

1. The Source: This object was used to imitate the behavior of the stock in the shipyard, where the material is stored for different projects. In the following table 11, the brief description about setting is done. According with the methodology used to build the model, each MUs (Mobile Units) is compared with one ton of material, indistinctly if they are plates or profiles. Therefore the time of 2h: 30m to produce each part are according with the process explained in the item 5.1 point 1.

Table 11. Setting of the source

Settings		
Operating Mode	Blocking	The generated MUs will be saved
Time of Creation	Number adjustable	Certain number of MUs will be produced
Creation Time	2h:30m	Each part will be produced according with the time, constant.
MUs Selection	Constant	Only one MU will be produced
Exit Strategy	Percentage	Depending of the weight distribution of profiles and plates for the OPV80.

2. Plate Storage: Using the buffer object, to simulate the pallets a long the production line. This object has the characteristics to store MUs, but depending of the capacity. For this model the use of infinite capacity was used, because of the lack of information related with this object in the shipyard. In the same way the MUs get the object according with the part distributions depending of the ship to be analyzed. Table 12 shows the setting used for the model. All the plates go to the cutting machine albeit is flat plate or curve plate.

Table 12. Setting of the Plate Storage

Settings		
Capacity	-1	Infinite capacity
Buffer Type	Queue	First in, first out.
Processing Time	1h:00m	Dwell time of a part in the buffer
MUs Selection	Constant	Only one MU will be produced

3. Profile Storage: This object is used to simulate the pallet to store profiles. Each MUs that get inside of this buffer is one ton of profiles that has to be join with the plates. The table 13 depicts setting used for the simulation model.

Table 13. Setting of the Profile Storage

Settings		
Capacity	-1	Infinite capacity
Buffer Type	Queue	First in, first out.
Processing Time	1h:00m	Dwell time of a part in the buffer
MUs Selection	Constant	Only one MU will be produced

4. Cutting Machine: This object is modeled using the SingleProc, to simulate all machines and jobs, which handle one part after another. According the the characteristics of the cutting machine of the shipyard the following setting was done, table 14.

Table 14. Setting of the Cutting Machine

Settings		
Processing Time	1h:30m	Time to develop the work on the part
Set-up Time	00h:45m	Time used to remove the part already worked and install the following
Exit Strategy	Percentage	Depending of the weight distribution of flat plates and curve plates for the OPV80.

5. Bending Workshop: For this workstation the use of the information related with the bending machine that shipyard is working with was done. The characteristics of this machine were used to do setting for the model, like table 15 shows.

Table 15. Setting of the Bending Workshop

Settings		
Processing Time	7h:00m	Time to develop the work on the part
Set-up Time	2h:00m	Time used to remove the part already worked and install the following
Exit Strategy	Percentage	Depending of the weight distribution of flat plates and curve plates for the OPV80.

\* The processing time include average quantity of workers to do the work.

6. Flat assembly: This workstation was modeled using SingleProc as well. As for flat assembly as flat pre-assembly workstations have used the same setting values because of the lack of the information to discriminate the performance to build up panels and pre-assemblies. This information was extract form the available form the shipyard, table 16.

Table 16. Setting of the Flat Assembly Workshop

Settings		
Processing Time	3h:30m	Time to develop the work on the part
Set-up Time	1h:30m	Time used to remove the part already worked and install the following
Exit Strategy	Percentage	Depending of the weight distribution of flat plates and curve plates for the OPV80.

\* The processing time include average quantity of workers to do the work.

7. Curve Panel Assembly: This workstation was modeled using SingleProc as well. As for curve assembly as curve pre-assembly workstations have used the same setting values because of the lack of the information to discriminate the performance to build up panels and pre-assemblies. This information was extract form the available form the shipyard, table 17

Table 17. Setting of the Curve Panel Assembly Workshop

Settings		
Processing Time	6h:00m	Time to develop the work on the part
Set-up Time	2h:00m	Time used to remove the part already worked and install the following
Exit Strategy	Percentage	Depending of the weight distribution of flat plates and curve plates for the OPV80.

\* The processing time include average quantity of workers to do the work.

8. Block Assembly: This workstation was modeled using SingleProc as well. Include average values about welding of different assemblies for stern, bow and mid-section of the hull. This information was extract form the available form the shipyard, table 18.

Table 18. Setting of the Block Assembly Workshop

Settings		
Processing Time	4h:00m / 3h:00m	Time to develop the work on the part
Set-up Time	1h:30m	Time used to remove the part already worked and install the following

\* The processing time include average quantity of workers to do the work.

9. Shift Calendar: This object permits to model the schedule, which is used for the shipyard, keeping in mind that the simulation model cannot run a long 24 hours of the day. Therefore the real working hour are used including the working days.

Shift Times											
Calendar		Resources		User-defined Attributes							
	Shift	From	To	M..	Tu	W..	Th	Fr	Sa	So	Pauses
1	Moorning	7:00	15:00	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	10:00-10:15;1...
2	Afternoon	15:00	23:00	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	17:00-18:00;2...

Figure 35. Shift Calendar

Using all the information explained before the creation of the simulation model for the current arrangement of the shipyard was done using the software already explained, Tecnomatix Plant Simulation 10.1. This snapshot shown in figure 36 depicts the arrangement used to evaluate steel processing involve under shipbuilding activities. Using the description of steel manufacturing process according with [NSRP 00], which gather the common procedure used for most shipyards, also clarifying that for this simulation model the average of the values founded were used. The goal of this approach is to gain more simplicity in the evaluation of the rough layout concept.

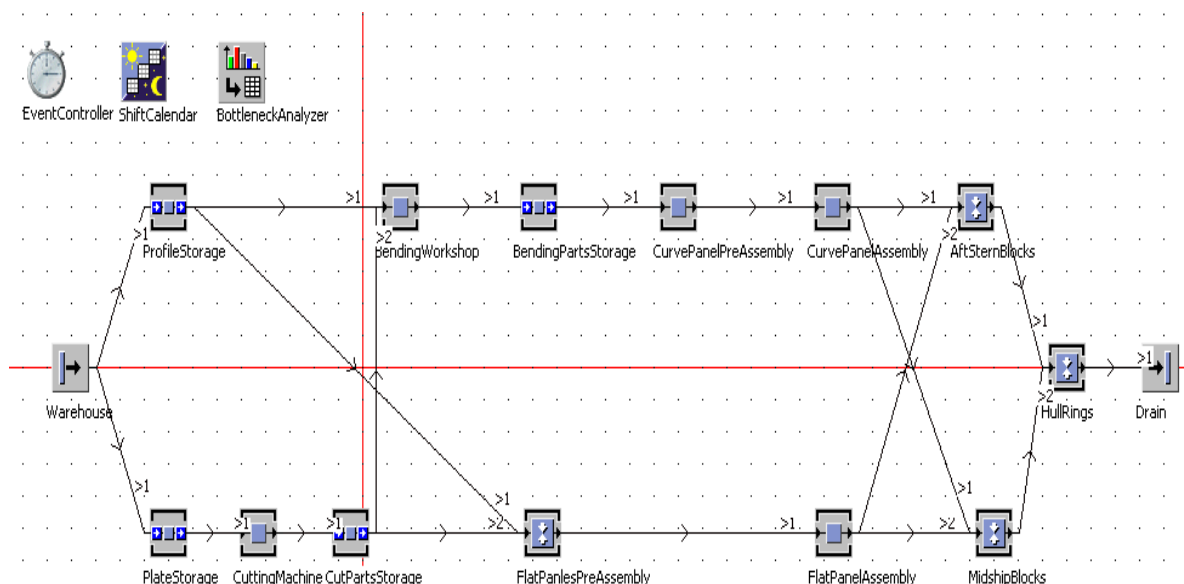


Figure 36. Basic Simulation Model for Mid-Tier Shipyard

## 6.2. Validation and Verification

Taken in to account that the simulation model is the representation of the real system is very important wondering if there is any relationship between this real system and the model. The terms used to describe those processes are called validation and verification.

Validation is referring to the correct creation of the model, determining is the model has some errors. Validation is referring to the process to determine if the model, like abstraction, is good representation of the system. Normally the validation is carry out through the model calibration, this mean that this is an iterative process comparing the behavior of the model against the real system and using the differences in order to improve the model.

This step is one of the most important during the model creation. Taken what was written by [RAB 09], “Simulation is an established method for production and logistic purposes. It is frequently used when decisions with high risk have to be taken, and the consequences of such decisions are not directly visible, or no suitable analytical solutions are available. This implies that correctness and suitability of the simulation results are of utmost importance. Wrong simulation results, translated into wrong decision proposals which are then implemented, can cause costs that are by orders of magnitude higher than the total cost of the simulation study.”

Different literature related this issue states that the verification and validation process has to be developed and the end of each stage of the simulation process, it is no task to do just at the end of the simulation process. In the same way, different author refers that this process is based on a subjective impression and defined by the user on the basis of his or her own acceptance. [SAR 01] propose four basic approaches for deciding whether a simulation a simulation model is valid or invalid. Each of the approaches requires the model development team to conduct verification and validation as part of the model development process.

- The model development team itself has to make the decision as to whether the simulation is valid or not. This kind of subjective decision is taken base on the results of various tests and evaluations conducted as part of the model development process.
- The second approach depend if the size of the simulation team developing the model is not to large, a better approach than the one above is to have the user(s) of the model heavily involved with the model development team in determining the validity of the simulation model. Using this approach the user can determine the validity of the model, also this method aids in model credibility.
- The third approach usually called “independent verification and validation” (IV&V), use a third party to validate the model This third party has to be independent of both the simulation development team(s) and the model sponsor/user(s). It is very useful when developing large-scale simulation models, which have one large or several teams involved in developing the simulation model. This approach require that the party, which is validating the model needs to have a through understanding of what the intended purpose of the simulation model is for.

- The fourth and last approach is using a scoring model (or weights), where the scores are determined subjectively when conducting various aspects of the validation process and then combined to determine category scores and overall score for the simulation model. This way is seldom used in practice, because of the subjectivity of this approach tends to be hidden and thus this approach appears to be objective, causing over confidence in a model or be used to argue that one model is better than another.

On the other hand, [RAB 09] proposes a set of essential criteria that form pragmatic base for the use in production and logistics projects, shown in the next items:

- **Completeness:**
  - Does the structural review point out missing requirements and information?
  - Which level of conformity does exist between requirements and model?
- **Consistency:**
  - Is the semantic context free of contradictions?
  - Is the structure of the documents, information model free of contradictions?
  - Is the terminology consistent?
- **Accuracy:**
  - Is the model free of visible faults and carefully built?
  - Is the level of detail appropriately chosen?
  - Are the scope of information and the granularity of data adequate?
  - Are the random distributions sufficiently precise and close enough to reality?
- **Currency:**
  - Are the information and data valid with regard to content and time?
  - Is the model valid with respect to given task?
- **Applicability:**
  - Is the model usable and convenient for the intended purpose?
  - Does the effort related to the model correspond to the given task?

- Is the model performance adequate?
- Is the benefit for the user distinguished?
  
- Plausibility:
  - Are the procedure, the background of information, and the model context traceable?
  - Are the results free of contradictions?
  
- Clarity:
  - Are the phase results understandable or comprehensible to the target groups?
  - Is the model building process understandable for the user?
  - Is the wording well defined?
  - Are the documents readable and understandable?
  
- Feasibility:
  - Can the requirements be technically realized?
  - Are the required project objectives achievable?
  - Is the project plan realizable in time?
  
- Accessibility:
  - Is there a continuous and unobstructed way to get to the needed information?
  - Are the information and data sources reliable?
  - Are time and effort for the process of information acquisition acceptable?

In order to follow one of the methods proposed above, for this master thesis was used the first approach proposed by [SAR 01]. “The model development team itself has to make the decision as to whether the simulation is valid or not. This kind of subjective decision is taken base on the results of various tests and evaluations conducted as part of the model development process.” Taken into consideration that for this master thesis the model development team is just one person. On the other hand to arrive to this decision the analysis of the simulation model was done responding the entire questions that [RAB 09] proposes as table 19.

Table 19. Simulation model validation

Question	Yes	No
Accuracy		
Is the model free of visible faults and carefully built?	X	
Is the level of detail appropriately chosen?	X	
Are the scope of information and the granularity of data adequate?		X
Currency:		
Are the information and data valid with regard to content and time?	X	
Is the model valid with respect to given task?	X	
Applicability:		
Is the model usable and convenient for the intended purpose?	X	
Does the effort related to the model correspond to the given task?	X	
Is the model performance adequate?	X	
Is the benefit for the user distinguished?	X	
Feasibility:		
Can the requirements be technically realized?	X	
Are the required project objectives achievable?	X	
Is the project plan realizable in time?	X	
Plausibility:		
Are the procedure, the background of information, and the model context traceable?	X	
Are the results free of contradictions?	X	
Clarity:		
Are the phase results understandable or comprehensible to the target groups?	X	
Is the model building process understandable for the user?	X	
Is the wording well defined?	X	
Are the documents readable and understandable?	X	
Accessibility:		
Is there a continuous and unobstructed way to get to the needed information?	X	
Are the information and data sources reliable?	X	
Are time and effort for the process of information acquisition acceptable?	X	

In the question related with the accuracy “Are the scope of information and the granularity of data adequate?” the response is negative because of the information used was general from the production processes of the mid-tier shipyard. The data required to build this simulation model was not very useful in some fields taken into account that the shipyard under study has not the information discriminate in the way that the model needed. But this obstacle was getting over it using the experience of the research company FRAUNHOFER IPA, which gave it some methodology.

On the other hand, the simulation model took the parameters given and the comparison between the real data and the simulation was made to check also the validity to use this model to create what if scenarios. The simulation model was validated using the production of ship hull of the OPV without outfitting during the timeframe used by the mid-tier shipyard. The discrepancy between the real and the simulated data was in the range among 5%. Which is very useful taken into consideration the lack of production information, also using this method of rough layout concept.

## 7. EXPERIMENTAL EVALUATION

The alternatives created must be determined after validation of the current scenario model. The decision related with which scenarios have to be modeled is function of requirements of the users, in order to response to any question that show up to improve productivity. This approach is called “What if scenarios”. With this methodology is possible to vary production plan, production equipment, if the shipyard is thinking about invest on new machine.

The scenarios considered in this analysis are related with the impact that new welding robot has in the production program, more over, the second scenario is considered about the layout of the material flow of the shipyard and what is the impact in the productivity.

### 7.1. Inclusion of Welding Robot in the Production Line

According with [TUR 11], Robots are used in a wide range of industrial applications. The earliest applications were in materials handling, spot welding, and spray painting. Although the automotive industry is the major user of robotic welding, the usage of robotic welding is also improving in the shipbuilding industry day by day. The two basic welding types in shipbuilding are spot welding and arc welding.

Arc welding robot is one of the most common functions in industry today. This process the electricity goes to the metal through the conduct increasing the temperature melting the metals to be welded. Automated welding has begun improving upon manual welding in the industry due to increasing speed, quality and throughput. In the field of shipbuilding inclusion of robotic welding is much safer and more cost-effective. The reduction of re-processes due to mistakes related with human factors won't come across with this method, figure 38. The main idea for this new scenario is include in the production line for the mid-tier shipyard a welding robot, shown in figure 38, in order to assess the impact of this machine of the all process.



Figure 37. Welding robot. [TUR 11]



Figure 38. Manual welding

<http://cfnewsads.thomasnet.com/images/large/515/515802.jpg>

[Accessed on 10<sup>th</sup> of January of 2013]

This scenario has included one change in the information compared with the current simulation model. This change was carried out in the processing time of the flat pre-assembly panel workstation, reducing at least 2 hour the time for the same work to be done. This change is without taking into consideration impact related with the reduction of the re-work, idle time because of welders. Table 20.

Table 20. Setting of the Flat Pre-Assembly Workshop

Settings		
Processing Time	1h:30m	Time to develop the work on the part
Set-up Time	1h:30m	Time used to remove the part already worked and install the following
Exit Strategy	Percentage	Depending of the weight distribution of flat plates and curve plates for the OPV80.

\* The processing time include average quantity of workers to do the work.

The figure 39 illustrates the percentage of work developed for each workstation used in the simulation model.

As result, the flat assembly panel workshop presents the highest value. One of the reason is the inclusion of the welding robot in the flat pre-assembly panel workshop, which made that the following station increase the quantity of work to be done. On the other hand, for the flat pre-assembly workstation, which the percentage has reduced considerably, this variation impact directly to the mid-ship block assembly workstation loading with more material in the time, but the performance is the same. Therefore this workstation is the bottleneck of this distribution.

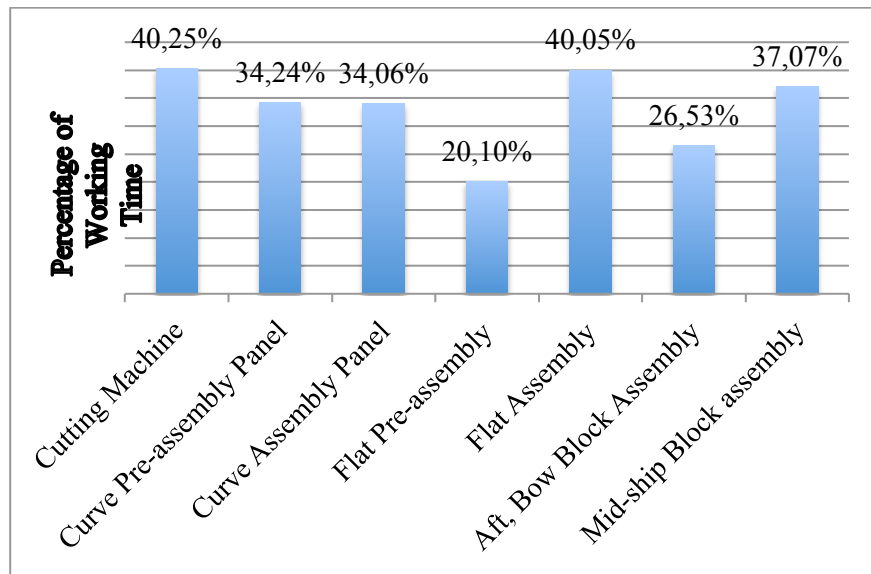


Figure 39. Working time in workshops for Welding Robot Scenario

## 7.2. Restructuration of the Current Layout of the mid-tier Shipyard

Normally, the production areas layout design process is with the aim to find optimal solutions for different activities with corresponding components. According with [MAT 09], this process implies the finding of spatial arrangement of such activities in given space, satisfying given preferences and constrains. More specifically, it is a complex and subjective problem, which includes evolving task dynamics, inadequate information availability, as well as uncertain and conflicting preferences.

Production areas in shipbuilding represent an especially interesting problem due to specific characteristics of the shipbuilding production process, which involves large products requiring wide production areas. Therefore, research in this field is linking with the following reasons:

1. Size and shape of the existing shipyards areas often unchangeable because of a shipyard is bounded by the sea for one side, and by urban settlement and/ or industrial facilities, from the other side.
2. Layout of the existing shipyard facilities is not usually subject to changes due to large-scale structures and already established related infrastructure.

3. Evolution of shipbuilding technology procedures imposes different demands and requirements on the production areas in shipyards. Such demands are difficult to implement because of the already specific constraints and limitations.

Due to the mentioned reasons, technological modernization within the existing shipyard has to be oriented to improving efficiency of using the existing production areas.

In this item the main idea is to assess the change in throughput because of change in the workflow layout using the reduction in the set-up time for flat panel pre-assembly, flat panel assembly, curve panel pre-assembly, and curve panel assembly at least half of the current time. This value was “assumed” based on the information of the workers from the shipyard. With this variation in the simulation model the new throughput is compared with the current throughput. The scenario assessed in this item does not take into account, neither time for transportation of each part, nor availability of cranes. This comparison is shown in the chapter 8, where it is the evaluation of the new scenarios taken into consideration for this analysis.

Table 21. Setting of the Flat Assembly Workshop

Settings		
Processing Time	1h: 30m	Time to develop the work on the part
Set-up Time	1h: 30m	Time used to remove the part already worked and install the following
Exit Strategy	Percentage	Depending of the weight distribution of flat plates and curve plates for the OPV80.

\* The processing time include average quantity of workers to do the work.

According with the figure 40 mid-tier shipyard current layouts is shown in order to have better understanding of the proposal. The red lines illustrate the current workflow presented for cutting plates. Even that for this master thesis the time for transportation was not taken into consideration in one calculation, the set-up time to start the job was taken.

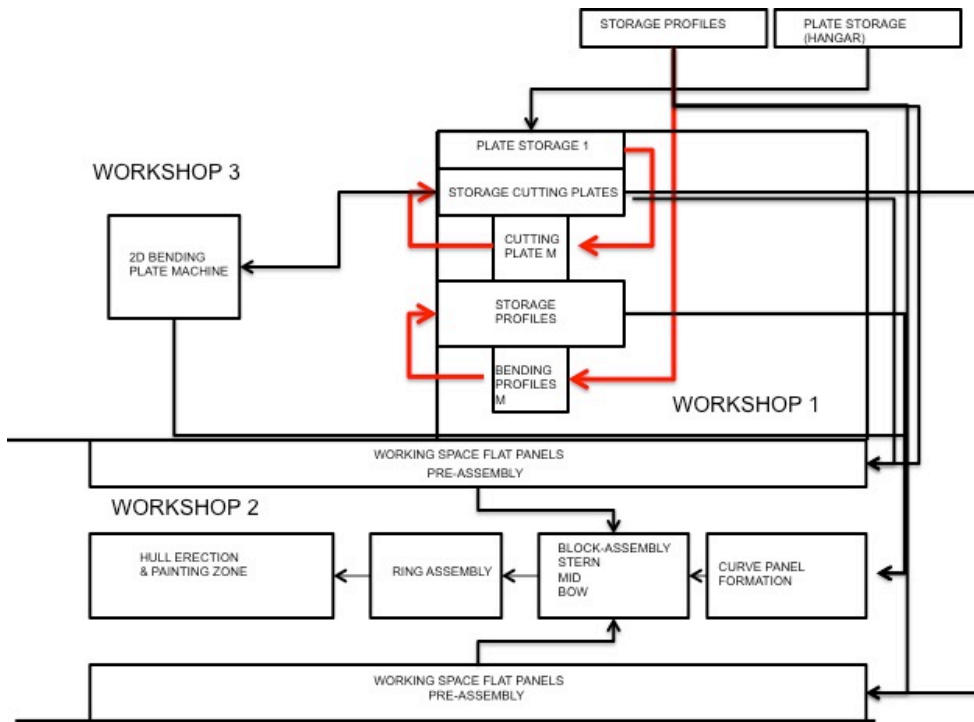


Figure 40. Mid-tier shipyard current layout

The figure 41 depicts the proposal for the layout, that is small change inside of the production line, given smooth workflow for material.

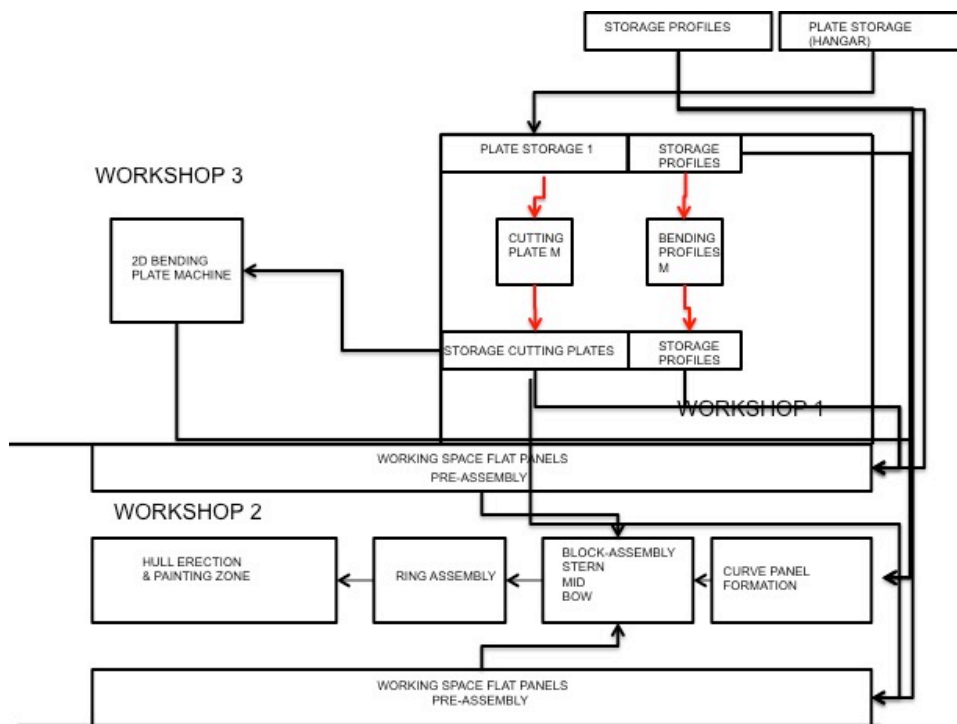


Figure 41. Mid-tier shipyard proposal layout

The figure 42 describes the working time for this proposal, where the variation of the percentage is clear reducing the load for the block erection. According with this figure the most charged workstation are the pre-assembly and assembly for both flat and curve panels.

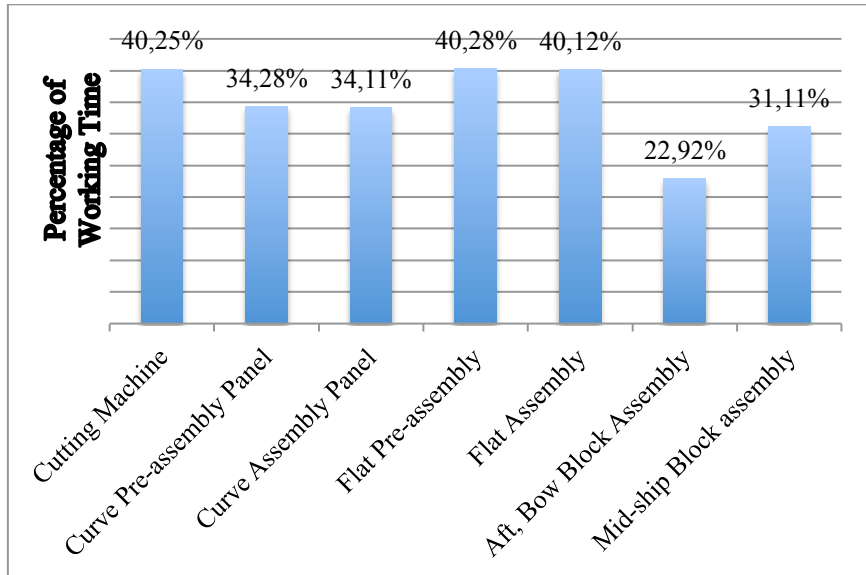


Figure 42. Working time in workstations (using different workflow)

## 8. DERIVATION OF RECOMMENDATIONS FOR RESTRUCTURING

In this item the comparison of all the results was done in order to have the complete panorama of the two scenarios already assessed and the current scenario to see the changes in the working time and load for different workstations.

Figure 43 represents the working time for each workstation taken into consideration for this simulation model. It is visible the differences presented when the weld robot is assessed because of the impact in the flat panel production. With the new workflow recommended the working time for both workstations to produce blocks is equilibrating.

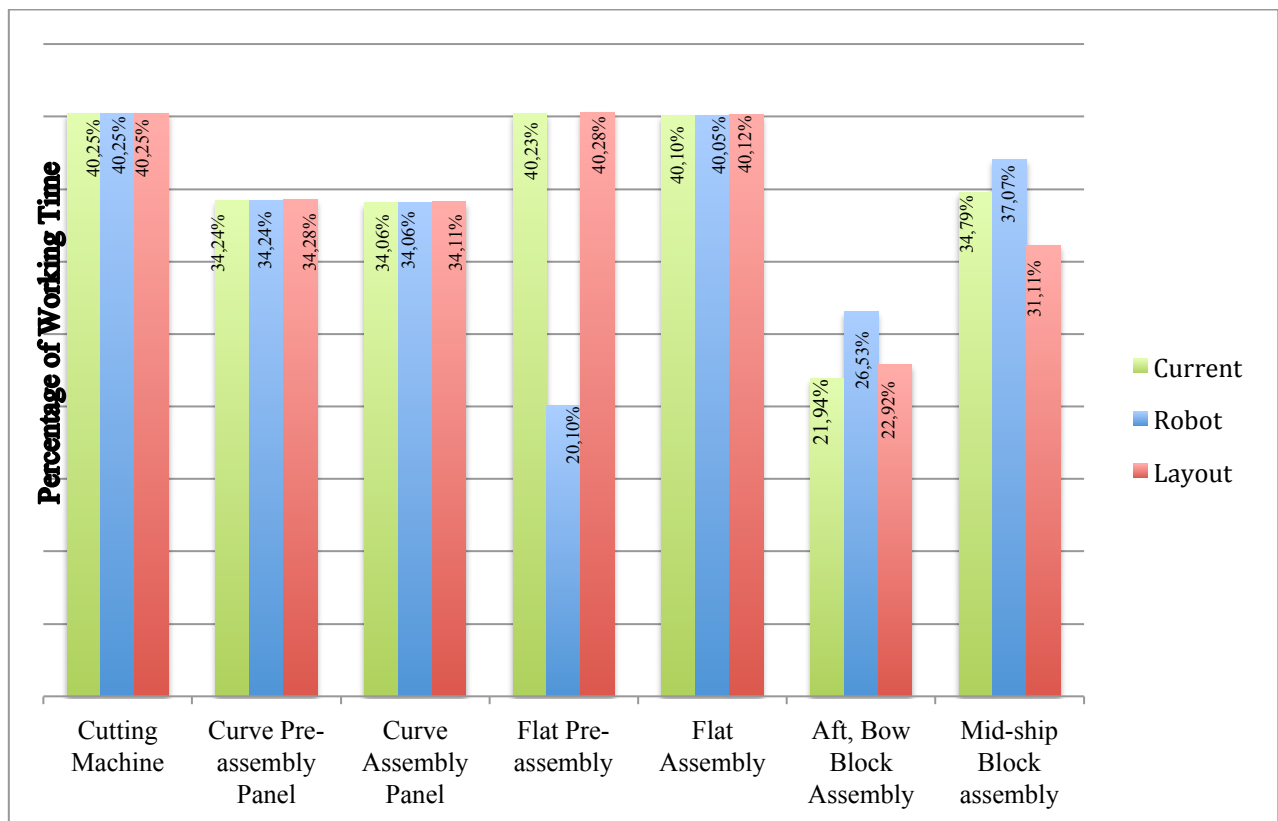


Figure 43. Comparison between scenarios

According with the figure 44, the comparison of the results of the different simulation runs can be concluded that the results of the simulation of the real model correspond to 95% with the results of the reality. This can be explained with the use of a coarse model and the associated decrease in detail. Also modeling requires a detailed database that existed in this

thesis only in the form of assessments. In order to achieve a higher reliability of the results, a more detailed database for the creation of the model would be needed.

The simulation experiments showed that the implementation of a welding robot in the flat pre-assembly workshop causes an increase in throughput of 12%, which is due to the shortened processing time. In addition, due to the increased level of automation, an almost constant quality of the components can be achieved which can be ensured only by qualified personnel in manual processes. In order to make a decision on the purchase of a welding robot a cost-benefit analysis has to be performed.

Regarding the layout optimization the simulation has shown that the optimized design of the material flow in the flat assembly workshop causes a slight increase in throughput of about 2%. Since the proposed layout is based on existing structures, the change would be implemented without any further investment.

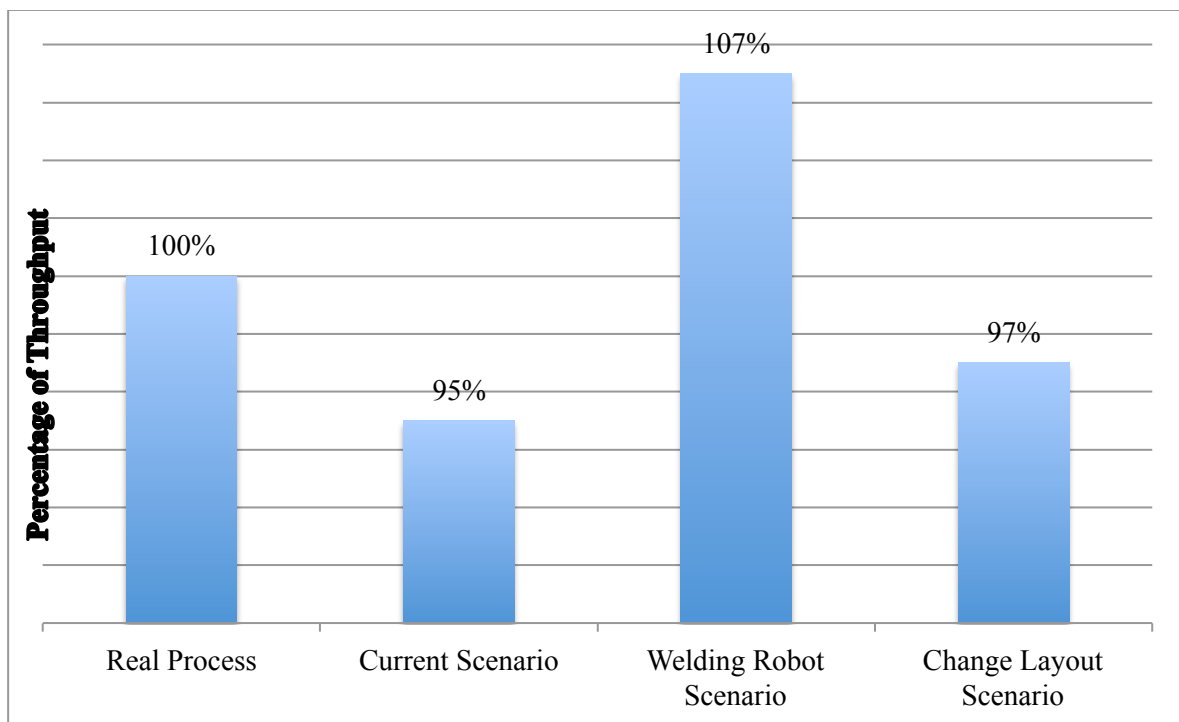


Figure 44. Throughput comparison

## 8.1. Recommendations

1. The improvement of this simulation model permit the mid-tier shipyard have very powerful tool to evaluate any change to be done in the future to the production line. Also the impact of different ships in the time frame, given very useful tool to programing dry-docks positions.
2. The use of this tool is very useful to estimate the impact of different machinery that the shipyard wants to include in the production line, before to do it, knowing the impact of any of those, before to spend any money.
3. The enlargement of this simulation model including all the processes involved in the production such as design, logistic or any other support unit, to calculate the impact in the throughput of any project that the shipyard is working on.
4. Even that this kind of tools called DES are very powerful, it is necessary to be careful because of the result depend of the quality of the information gathered and also the interpretation of them. Sometime during creation of this kind of models some information is missing and the model team has to take some decision based on their experience. This mean inclusion of subjective information.

## CONCLUSIONS

1. This master thesis shown the use of rough layout concept to create the simulation model of mid-tier shipyard, evaluating the current production line, validating this model. Using this model changing some parameters permit the analysis of different scenarios to understand the variation of throughput.
2. Creation of this very rough model of the mid-tier shipyard used, as case of study was very challenging because of the amount of information required to create the distribution of weight of the ship hull of the OPV80 was very high. Besides the information gathered from the productivity of the shipyard was very difficult because of the confidentiality of this kind of information.
3. The use of this tool such as Discrete Event Simulation – DES shown its capabilities to face with this kind of problem, where a mathematical model is very difficult to build. With the use of this tools in the field of shipbuilding, permit the creation of model according with the necessities, this mean for long-term capacity planning the approach of rough layout concept used present the benefits, because of it is straightforward and easy to understand for people, who does not have very deep knowledge in this sort of tools.
4. The creation of simulation model of the shipbuilding processes, permit either the evaluation of current scenarios or design of the well known “what if” scenario or any invest in machinery. This information could be the support of the decisions that the high level of a shipyard has to take during project, without risk the production that it’s working, reducing the cost.
5. During the development of this kind of project the understanding of the all processes involved, gave really useful advantage to have enough knowledge to advice the company in the future plans to improve its capabilities, because of the strategic perspective permits this support to the board of directors of a shipyard.

6. The use of new equipment in the production line such as weld robot, include some changes also in different fields like design. The design has to be appointed to production using this kind of equipment, because of the design of very complex shape limit the use of the robot.
7. The use of state of the art equipment bring great amount of training, preparation and also spare parts that permit reduce as much as it can the block time due to damage. On the other hand the preparation of different workers to program that equipment is very important because of this activity is very complex and time consuming.
8. The software tool used for the development of this master thesis, permit experiment with student license, which allow up to 80 objects for the simulation model. This option was enough to build up the model, because of the methodology used reduce the objects to be modeled, in the same way, was very useful because of the learning time was using this license avoiding disturb the industrial licenses that belong to the research institute.

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


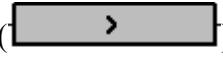



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


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## APPENDIX A1



In order to have general understanding of the software used to create the simulation model called Tecnomatix Plant Simulation 10.1, the following explanation of the different icons used in the model will be done.

Material Flow Objects:




-  SingleProc, which accept exactly one Mu from its predecessor, processing and transferred to its successor.
-  ParallelProc: Same behavior of SingleProc but with more than one places.
-  AssemblyStation: Add part to the MU; facilitate the simulation of assembly operations.
-  DismantleStation: Take away parts from the MU, facilitates modeling dismantling operations.
-  Line: Transport MUs along the route with constant speed.
-  TurnTable: It is used to turn the MUs along the track.
-  Sorter: Receive certain amount of Mus and move them in different order.
-  FlowControl: Is always positioned between two or more objects and define the flow behavior.

-  Buffer: Can keep Mus until the capability has reached or can give characteristics like first in first out.
-  Source and Drain are the boundaries of the model (Used to create and destroy Mobile Units respectively).
-  Track: Simulate transport routes.

#### General Objects:

-  The connector as the name itself explains connects objects and frames.
-  The EventController coordinates the events during the simulation.

#### Mobile Objects:

-  MUs represent the material that flow from object to object within the frame. After creating new MUs, they move through the model and remain at the end until they are destroyed.
-  The container can load and transport other MUs. It has not active basic behavior of its own. The container is transported from object to object along the connectors or by methods. Useful to model boxes or pallets.
-  The transporter moves on the track with a set speed forward or inverse. Using the length of the track and the speed of the transporter, the time the transporter spent on the track is calculated.