Production methodologies applied to the fluid system outfitting on a construction and repair shipyard

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October 2018

Abstract - Due to the competitiveness of shipbuilding environment, shipyards try to optimize production efficiencies in terms of time, costs and quality and obtaining better results.
Modular Outfitting (MO) is an approach that consists in the installation of outfit systems on a structural block prior to shipboard erection. Traditional Outfitting (TO) consist in on-board outfitting installation on a building berth before launching or on-board after launching and as it allows parallel assembly of various outfitting systems. MO has the potential to reduce the assembling workload.
The dissertation scope is to compare the workload (expressed in Man hours - *Mh*) of a ferry vessel bilge's fluid system (Haksolok built in Atlantic Eagle Shipyard) assembly performed by TO *versus* MO.
Three questions are addressed regarding MO implementation versus TO in three selected bilge piping zones of higher complexity concerning: workload differences; layout changes and risk management
The workload, measured in *Mh*, used in the assembling procedure by MO, represented a reduction of 549 *Mh* or a gain of 74% *versus* TO.
There are advantages in the new layout concerning distance between work stations, space for outfitting activities and outfitting work flow hub creation.
A risk assessment was performed and the most critical risks were associated to: Design Process; Dimensional Control And Running Test in Shop Process; Module Transportation and Fitting on Block Process and On-block Assembly Fitting and Installing Process. The higher risk score regards Effective Schedule Coordination between Block and Module Block
To control the major risks a list of nine critical success factors was defined, being the qualification of the labor force and the update of the equipment, the most critical.

Index Terms - MO, Integrated construction, zone outfitting, systematic layout planning, risk management critical success factors, piping, outfitting

1. INTRODUCTION

Due to the competitiveness of the shipbuilding business environment, shipyards are always trying to optimize their production efficiencies in terms of time, costs and quality, or to do more with the same (or less) resources and obtaining better results.

One of the methodologies used to increase shipbuilding effectiveness is MO approach that consists in the parallel assembly of various outfitting systems.

The dissertation scope of work is to analyze a ferry vessel bilge's fluid system assembly performed by TO production methodology, their inputs and outputs and to compare them with the estimations of the equivalent parameters of fluid systems assembly performed by MO production methodology.

A Ferry type vessel (Haksolok) for the Democratic Republic of East-Timor is under construction using TO at Atlantic Eagle Shipbuilding (AES) shipyard and is to be commissioned in 2018.

This study was made in collaboration with AES.

The data, concerning the assembly, installing and fitting by TO used in this dissertation, was mainly collected from the AES pre-existing documents, from technical drawings and from field construction operations analysis. The data concerning MO alternative was based on information referred in the existing literature and on information collected on site from the production study (TO data).

This study addresses three questions:

- The workload differences between TO on-board approach and MO on-block approach.
- The potential layout changes required by the implementation of MO versus the implementation of TO according to Systematic Layout Planning (SLP) analysis.
- The risk management of MO implementation.

For each question, specific objectives were defined.

Regarding the first question, the primary objective was to compare the *Mh* used in production in the TO method with the *Mh* used in MO on-block method.

This analysis was circumscribed to selected bilge piping zones of higher outfitting complexity for which an increase in production efficiency could represent a significant decrease of workload.

The determinants considered for the workload calculation were the piping properties, namely: dimension, shape, location and position inside of the ship.

Regarding the second question, the primary objective was to compare the distances and routes of the existing TO layout *versus* the MO adapted layout.

Regarding the third question, the primary objectives were to identify and manage the risks associated to MO implementation, and to define the Critical Success Factors (CSFs) for effective implementation of MO approach.

Haksolok ferry vessel

The analysis for the implementation of MO approach was made upon a ferry vessel bilge's system, named Haksolok and built in AES.This specialized vessel was made to operate between islands, in small ports and piers, with shallow waters.

Table 1 summarize the general Ferry's characteristics, according to the information provided by the shipyard.

Table 1- Ferry's general characteristics

Characteristics	Measure	Units
Length overall (LOA)	71.3	m
Length between perpendiculars (Lpp)	59.34	m
Breadth Moulded (B)	12.6	m
Depth to Main Deck (D)	6.3	m
Design Draught (T)	3.6	m
Displacement (Δ)	1645	Ton
Cruising Speed	15	Knots
Pax	377	
Cars	25	

Regarding the outfitting method, during out the construction of Haksolok an on-board TO method was carried on through the entire construction process.

In TO, all the pipes sections and valves are transported to the ship's inner spaces (double-bottom, hull and other enclosed areas) after all blocks had been erected.

It is important to mention that, in MO, some equipment components such as pumps, valves and filters are placed inside the vessel's blocks before block erection.

2 STATE OF THE ART

2.1 Preliminary concepts on ship's life cycle

The ship's life cycle theoretical concepts are introduced because they will be used to define the identified risks of MO implementation Risk Analysis.

There are several ship's project life cycle model descriptions in the literature. This study adapted the Chapman and Ward [1] model that divides the project life cycle in to four major phases: conceptual phase, planning phase, execution phase and termination phase (that is a risk management orientated approach).

In this dissertation four ship's life cycle phases (figure 1) were defined in according to the location of its development:

A. Design Develop and Engineering phase corresponds to the merge of Conceptual phase and Planning phase as they are developed in a ship design office

B. Construction phase corresponds to Execution phase that is carried out on shipyard.

C. Operation and Maintenance phase corresponds to Termination phase is directly executed on board or on dock.

D. Scrapping phase performed in a scrapping yard, was added to the project life cycle due to its contribution to financial accounting (revenue).

Each of the vessel's life cycle phases listed above has a specific impact on costs.

A1. Design Development and Engineering

Conceptual Phase

The decisions taken at this phase are key cost determinants, because during this phase the main characteristics of the vessel are settled in order to meet the requirements of the ship mission and of the stakeholders (shipowners and authorities).

This set of characteristics will define the ship namely in what concerns dimensions, capacity, speed and shipyard construction support facilities. These decisions should be definitive. Any subsequent changes to these fundamental characteristics will determine substantial additional costs.

A2. Design Development and Engineering

Planning Phase

This phase includes designing of the vessel, planning of the strategy and allocation of the resources.

The designing of the vessel includes all the design steps, from basic design up to design evaluation and vessel's performance criteria.

The planning of the strategy consists of defining deadlines and milestones.

Finally, the resource allocation sub-phase incorporates the estimation of resources to be used, as for example: the quantity of steel plates to be used for the structural blocks manufacturing.

B. Construction Phase

This phase has an important cost impact magnitude that depends on the compliance requirements regarding:

- The ship design phase decisions and with guidelines respecting the established scope of the work
- The quality control guidelines and therefore, assuring that the manufacturing/sub-assembly/assembly of pieces, systems and structures are in accordance with the quality standards (ISO 9001)
- The established deadlines and schedule between ship-owner, classification society and shipyard

Any delay, namely due to correcting actions, potentially influences the start of ship's activity and its life costs.

C. Operation and Maintenance Phase

This phase influences the ship's life costs in a lesser order of magnitude then the previous mentioned ship cycle phases. Operation Phase corresponds to the period of the ship's life cycle on which revenues will be made. Therefore, without unexpected severe irregularities, the costs tend to be proportional to the ship's operating activity (length of legs, weather condition, and equipment's efficiency decrease due to usage).

Maintenance phase implies ship dry-docking and surveys, and as it implies the stoppage of the vessel, it represents additional costs on top of the costs of the maintenance and repair works (replacing of steel components, replacing of equipment and machinery, blasting, painting, tank cleaning, and others).

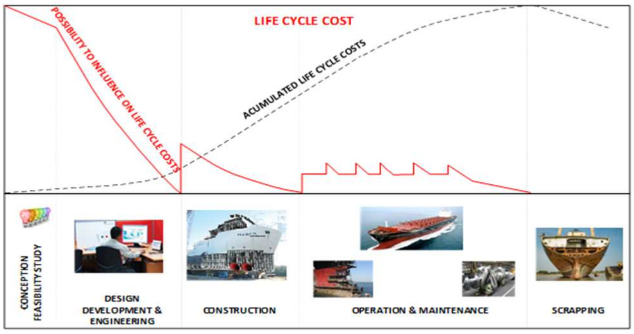

Figure 1 - MacGregor Cost influence curve/life cycle phase
Adapted from Gomes Lopes [3]

2.2 Outfitting

One of the most time-consuming activities in ship construction is outfit manufacturing, assembling and fitting.

This activity, is performed in almost every ship construction phase, which enhances costs across the whole construction process.

A. Traditional Outfitting (TO)

Traditionally, outfitting is a late stage process performed when the ship is on the erection berth or when the ship was on the pier after launching [2]. Outfit is assembled posteriorly to block grand assembly. Due to the space constrains resulting from the hull structure and vessel tanks, this process is carried in very confined spaces. This implies the usage of a large number of Mh for outfit elements transportation and fitting. Due to the space confinements many outfit units might have to be refitted which implies reworking, hence, wasting time, changing planned system layout and generating lower production indexes.

One of the methodologies developed to respond to the costly TO process was the MO approach.One of the methodologies developed to respond to the costly TO process was the MO approach.

B. Modular Outfitting (MO)

MO approach is an interim process of early sub-assembling of small components into modular units (modules) and to further away, assembling these modules in parallel with different specific stages of the ship construction process enabling construction time decrease [2].

This construction process also allows the implementation of the best layout for the systems function considering upfront the hull structure space constrains and reducing the need for on-board assembly adjustments. It however requires a larger space margin to pass through the equipment towards his berth.

As stated by Rubesa [2], "MO approach is based upon pre-outfitting in the workshop". This means that outfitting must start at an early design stage and must be integrated with the design (parallel design) of the numerous ship's areas, systems and structures. The parallel design of outfitting units is of the most importance towards the above-mentioned efficiency goal.

The implementation of MO implies that ship construction has to be managed in an integrated approach to ensure effective planning, coordination of the workstations and coordination of processes towards delivering the necessary output in a synchronized and timely manner.

C. MO advantages compared to TO

Baade [4] and by Rubesa [2] advocate that MO has several advantages compared to TO, namely in what concerns:

Workers productivity and efficiency increase

Outfitting costs and Mh decrease

Number of interface points within the labor force on-board decrease, which smothers the shipbuilding process

Modules manufacturing process related costs decrease, along with the number of built units, due to the implementation of standardized modules

TO requires fewer efforts in the early design stages but increases the costs on late construction stages (as a result of the number of Mh used) contrarily MO, requires more effort in early design stages but decreases the effort in construction late stages.

Rubesa [2] showed that MO reduces the costs and the amount of Mh, by demonstrating that "the labor costs on-board can be in average 3-5 times higher than the equivalent work done in the workshop or on platform".

To prepare the shipyard to deliver maximum added value of MO, activities must be planned and allocated to work stations in a specific way and resources distribution must be reallocated regarding the TO settings.

Gomes Lopes [3] illustrates in charted the difference of planning and resources allocation, between TO and MO, depending on outfitting process phase (figure 2).

Besides the positive points mentioned above, Baade [4] describes another advantage of MO is the capacity to simultaneously perform work on several systems in parallel, in a synchronized way.

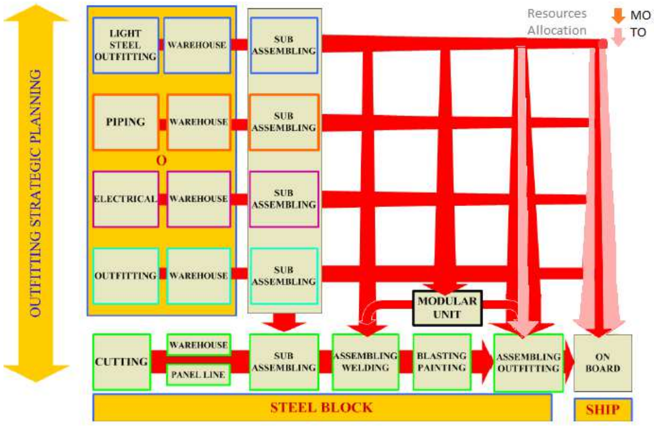

Figure 2 - MO vs TO resources allocation
Adapted from Gomes Lopes [3]

Even though, MO has multiple advantages, according to Rubesa there are also some disadvantages, such as:

- Design freedom decrease due to the space constraints on ship's inner parts
- Inner space requirements increase
- Heavier outfitting structures (due to modules structures) than in TO
- Precision requirements of detail engineering substantially increase to avoid rework

2.3 Systematic Layout Planning (SLP)

In this case, the implementation of MO processes required layout changes that were defined according to Muther's layout planning method [5].

Muther [5] stated that layout designing encloses a sequence of overlapping stages called the "Four phases of Layout Planning".

The SLP analysis which was developed on this study, only concerns overall layout selection therefore, it is mostly focused on phase II of SLP.

There are three primordial principles that constitute the backbone of a layout:

- Relationships - indicating the strength of the connection between things (Example: Relationship between steel shop and panel line)
- Space - indicating the physical dimensions of a thing
- Adjustment - optimizing arrangement to allow things to fit more properly

According to Muther [5] the selection of a new layout has to be made upon the three methods:

- Advantages and disadvantages weigh - the weight of the exposed advantages or disadvantages is rated in order to support the designer recommendation regarding the possible adjustments of the layout design
- Factor analysis rating – to address themultiplicity of factors that affect layout, a process of factor breakdown, named factor analysis was developed
- Cost comparison – Based on the following parameters: flow index, transport work and material handling

There are three fundamental tools that will enable a systematic data collection, a user-friendly representation of activities flows, a definition of the activities and space relationships. These tools also support the decision-making process of selecting the best layout among the several alternatives generated. These tools are: the Relationship Chart, the Flow/Activity Relationship Diagram and the Space Diagram.

2.4 Risk Management

Decision making process implies problem analysis that includes risk identification and risk response plans

The management of the project should also be based on the identification and prioritization of the favorable factors that are key to obtain results according to its goals.

The Project Management Body of Knowledge (PMBOK) [6] defines six risk managent major processes: Risk Managing Planning, Risk Identification, Qualitative Risk analysis, Quantitative Risk analysis, Risk Response Planning and Risk Monitoring and Control.

Guedes Soares and Gomes Lopes [7] suggested a methodology to estimate the impact factors of the identified risks that quantifies it in terms of: Quality, Cost and Time.

According to the Likelihood Impact relation four risk response strategies can be adopted: Avoidance, Transference, Mitigation and Acceptance.

Risk monitoring and risk control plan should also be implemented.

The management of the project should also be based on the identification and prioritization of the favorable factors that are key to obtain results according to its goals, named Crtical Success Factors (CSF's).

It is to be noted that this study will be based upon the risk identification process, the risk qualitative analysis and the risk response planning.

3. TO and MO - *Mh* comparison

3.1 Problem modeling

The scope of this chapter is to describe the comparison of effectiveness between traditional on-board outfitting method and the MO method, regarding work load expressed in number of *Mh*, allocated to the installing and fitting part of a bilge system composed by multiple pipe sections, valves and pumps.

The workload data of the system's section was obtained from the technical drawings provided by AES, regarding bilge system pipeline isometric and bilge system lines diagram.

The *Mh* used to assemble each pipe section depended on factors such as dimension, shape, location and position inside of the ship.

3.2 Analysis Methodology

For the study purpose, due to this extensive number of systems and components, it was defined that the production analysis would only be applied to the ship's bilge system and to selected groups of the pipe designated as MO zones.

According to Rubesa [2], MO, when compared to TO on-board, can have a potential impact on the assembly workload, reducing assembly time down to 3 to 5 times.

- Selection of the bilge system zones for MO

The selection aimed to identify the most complex assembly outfitting procedures, that are the most time consuming, for which the return of an increase of production efficiency could be translated into a decrease of the workload (expressed in *Mh*).

Two complexity parameters were empirically defined: 1) Highest quantity of elements per unit of space (m^3), 2) Space availability for fitting an outfitting module.

Based on the bilge's system isometric drawing 3 zones were selected for MO.

- **Zone 1**- Located inside the Engine Room (ER) adjacent to the engine room's aft bulkhead (frame 23)
- **Zone 2** - Located inside the ER adjacent to the engine room's forward bulkhead (frame 39/40)
- **Zone 3** - Located inside the Auxiliary Equipment Room 1 (AER1) forward to the engine room's forward bulkhead (frame 43)

Every system element was identified with a four digit code (compartment, zone, element number, sub-element number).

- Calculation of outfitting assembly *Mh*

The calculation of the potential *Mh* gain of the bilge system assembly and fitting, resulting from the comparison between MO and TO, required the assessment of the workload of both outfitting methods.

a) Calculation of TO assembly *Mh*

The TO *Mh* values depend on four main factors:

- **Pipe Dimension** (Length and Normal Diameter -ND)
- **Pipe Shape**
- **Equipment Installing,**
- **Pipe Location** (inside the ship's compartments)

Concerning outfitting complexity estimation, the lesser degree was defined as the one corresponding to the pipes with the smallest dimensions (Nominal Diameter (DN) and length), with the simplest shape (less curves and branches) and located in the widest final position.

This pipe typology was used as the minimal complexity assembly value that was computed with the complexity incremental factors of the other pipe typologies (dimensions, shape and pipe location factors) according to predefined weighting coefficients

TO assembly *Mh* (*Mh*TO) corresponds to the sum of the pipe section's assembly *Mh* calculated in function of the pipe section's dimensions, shape (defined by the number of existing curves and branches) (*Mh*pip) and location, with the equipment fitting workload (*Mh*equip), as showed in equation 3.1.

$$\boldsymbol{Mh_{TO}} = \boldsymbol{Mh_{pip}} + \boldsymbol{Mh_{equip}} \tag{3.1}$$

Equation 3.1 was developed into the following equation.

$$\boldsymbol{Mh_{TO}} = Mh_{ND}.Length.(C_{cuv}.n_{cuv} + C_{brch}.n_{brch} + C_{loc}.C_{CGT}) + (C_{pumps} + C_{filters} + C_{valves})$$

C_{brch}	Branches coefficient
C_{CGT}	Coefficient to convert CGT of tankers to CGT Ro-Rovessels
C_{cuv}	Curves coefficient
$C_{filters}$	Filters coefficient
C_{loc}	Man-hour according to specific pipe section location
C_{pumps}	Pumps coefficient
C_{valves}	Valves coefficient
Mh_{brch}	Man-hours in function of existence of branches
Mh_{cuv}	Man-hours in function of pipe section shape curves
Mh_{ND}	Man-hours as functionof nominal diameter ND
Mh_{equip}	Man-hours in function of number of equipment
Mh_{loc}	Man-hours in function of section's location (inside the ship)
Mh_{TO}	Man-hours per pipe section for Traditional Outfitting
n_{brch}	Number of branches
n_{cuv}	Number of Curves

Concerning dimensions, the pipe section's length was directly obtained from the AES technical drawings.The TO *Mh*, as function of nominal diameter (*Mh*ND), was calculated by using as a reference, the values defined by Butler (2012) [8] for schedule 40 straight pipes according to the ND values.

The shaping workload was computed as function of the number of curves and branches weighed by empirical coefficients provided by Professor Gomes Lopes (C_{cuv} – 0.05; C_{brch} -0.2).

The equipment installing the workload was computed as function of the number of valves, pumps and filters weighed by empirical coefficients provided by Professor Gomes Lopes (C_{valves} – 0.8; C_{pumps} -1.2; $C_{filters}$ -1.2).

The pipe location the workload was computed as function of coefficient ($Cloc$) stated in the literature for tanker ships [8] together with a conversion coefficient (C_{CGT}) that had to be determined with the purpose of adapting the tanker ship coefficients $Cloc$ to the ferry ship specifications.

b) Calculation of MO assembly *Mh*

The calculation of the number of *Mh* used on installing, assembly and fitting of a MO process was based on the calculations that were made for TO.

As already stated and according to Rubesa [2], the value of assembly *Mh* associated to MO can be between 3 to 5 times smaller than the value of assembly time related with TO, or numerical expressed it represents respectively 0.3 (3) to 0.2.

Based on this reduction, it was assumed that the assembly *Mh* on shop would decrease linearly with the *Mh* in function of the pipe sections complexity.

In TO it takes more time to assemble pipes with larger dimension and several shapes (arising from the limitations to insertion, positioning and assembly in the on-board confined spaces) than to assemble simpler pipes. Thus, if there is the possibility of assembling the more complex pipes on a wider outside space it can be assumed that the reduction value of *Mh* in MO would be of greater magnitude in more complex pipe sections than in simpler pipe sections. For this reason, it was assumed that the highest value of *Mh* reduction of 0.2 would correspond to the *Mh* decrease of more complex sections and that the lowest value *Mh* reduction of 0.3(3) would correspond to the *Mh* decrease of simpler sections.

The following factors were considered to define the pipe sections assembly *Mh*: section's curves, section's number of branches, section's length and section's equipment (if any).

Data has been collected for each pipe section from the bilge system isometric drawings. This has enabled the calculation of a complexity score for each pipe section based on the sum of the partial complexity values of the pipe section's regarding curves, branches, length and installation of equipment relatively to the maximum possible value that each of these factors can assume.

The value of the complexity score, designated as pipe section's "f" score (f), was calculated as the sum of the values of the four above mentioned factors, equation 3.2.

$$\boldsymbol{f = fcuv + fbrch + flength + fequip} \tag{3.2}$$

Once each pipe segment's f was calculated, the corresponding *Mh* reduction rate R*Mh* was computed by linear interpolation, equation 3.3.

$$\boldsymbol{R_{Mh}} = R_{Mh_1} + \frac{R_{Mh_2} - R_{Mh_1}}{f_2 - f_1}.(f_2 - f_1) \tag{3.3}$$

In which:

- R_{Mh_1} and R_{Mh_2} are the value immediately above and below the section's RM h value
- $f2$ and $f1$ are the value immediately above and below the section's f value

Having calculated each pipe section's man-hour reduction factor R_{Mh}, the pipe section's MO assembly *Mh* could be computed by equation 3.4..

$$\boldsymbol{Mh_{MO}} = R_{Mh}.Mh_{TO} \tag{3.4}$$

Once every pipe section's MO *Mh* assembly value was calculated, a sum of all section's *Mh* was obtained in order to enable its comparison with the sum of the total TO pipe section's assembly *Mh*, as per equation 3.5.

$$\Delta\boldsymbol{Mh} = M\,h_{TO} - M\,h_{MO} \tag{3.5}$$

3.3. Results and Analysis

As previously stated, the calculations of the reduction in *Mh* from TO to MO implementation were based on the correspondence between pipe section (f factor) and *Mh* reduction rates defined on the literature [2].

f factor score was calculated for every pipe element, as per the above methodology, and then it was possible to define the complexity score range which contained all the values, within a range in which the maximum value corresponds to 3.1 and a minimum value to 0.

Considering that on the transition from TO to MO, complex pipes assembly time would lead to a greater improvement than simple pipe assembly times, it was empirically defined that a section with f =3.1 would lead to a five times decrease [2] and that a section with f =0 would lead a three times decrease [2]. This translates into a M_h reduction rate of 0.3(3) for the complexity value of 0 and a reduction rate of 0.2 to a complexity rate of 3.1.

Table 2 and figure 3 displays the results regarding the total difference between *Mh* used in the TO process and the used *Mh* in the MO (on-block) approach for the selected parts of the bilge system computed according to equation 3.19.

In figure 3, trendlines were computed for both curves. It is possible to observe that the trendlines functions of each curve do not intercept on the positive domain $f_1 \neq f_2, if\ x \in \mathbb{R}^+$).

One of the trendlines function characteristics that must be outlined is that both trendline functions diverges when the abscissa approaches infinity. This means that if the amount of pipe sections to be assembled and fitted increases, the difference between TO trendline and MO trendline will increase.

For the three selected sections of the bilge system it can be observed that by using a MO approach, about 26% of the assembling *Mh* used in the TO method will be spend, which in numerical terms, represents a decrease 548.80 *Mh* (a reduction of 74% of the workload).

This total difference of 548.80 *Mh* results from the analysis performed on the scope of this study that concerns only of part of a single piping system (bilge system), although it can be applied to all the piping systems and other outfitting systems.

A ferry vessel such as the "Haksolok" contains numerous piping systems that have more and heavier pipe sections than the bilge system. Therefore, it possible to extrapolate that the difference of both outfitting methods would increase.

Hence, it is valid to extrapolate that MO implementation could represent a significant decrease on the vessel's outfitting workflow.

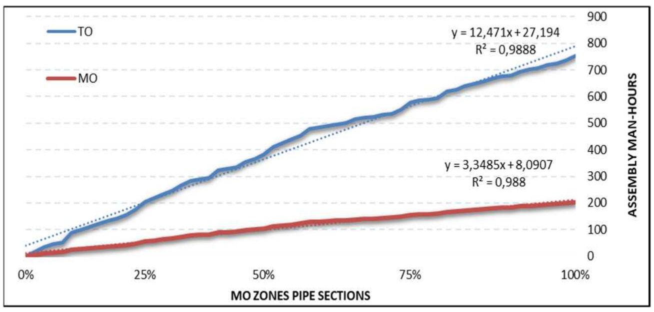

Figure 3 - *Mh* of pipe section assembly by TO or MO

Table 2 - Summed results of MO and TO assembly *Mh*

Total Results	**Mh**
Sum of Traditional on-board Outfitting	781.67
Sum Modular on-block outfitting	202.87
Difference between TO and MO	548.80

4. SYSTEMATIC LAYOUT PLANNING for MO

To analize the necessary changes in layout to adapt it to MO production, Richard Muther's Systematic Layout Planning [5] was the method adopted.

4.1 Problem Modeling

Considering the needs of MO units' construction, it was assumed that a new dedicated outfitting shop would be necessary. Therefore, three questions were formulated:

a. Where should the outfitting shop be located?
b. What implications would it have on upgrading costs for the existing buildings/shops?
c. What impact would it have on the flows of other shipyard's processes?

Regarding the first question, the biggest problem was the viability in terms of materials flow. Due to its high cost, the constructing of a new building shop was out of the question therefore; the implementation of a new outfitting shop should be on an existing facility. For the flow related reasons, this new shop should be as close as possible to the block assembly park, however it would important that the selected building would have the needed dimensions for the designated activity.

In what concerns the second question, there was a need to avoid significant added costs related to building's reworks.

Regarding the third question, the following described constrains were identified. The first constrain was that any change to the allocation of activities of the selected buildings should have a minimal impact on the rest of the other processes in the shipyard. The second constrain was that the shift of materials and equipment inherent the reallocation of function of the existing buildings, should not add significant costs.

4.2. Methodology

As the Flow/Activity Diagrams and the closeness relationship rates were not included in the shipyard general arrangement layout drawings, it was necessary to create them.

For both TO and MO layouts, the time and the distance between the routes of the shops/buildings, were calculated and subsequently compared (table 3).

4.3 Shipyard's layout changes and results

To implement the TO layout and to simultaneously answer the three questions formulated, the changes should be as follows:

- **Change no.1** - Plasma cutting machine should be moved to a new location near the steel shop
- **Change no.2** - New outfitting shop should be placed

contiguously to where the plasma cutting machine used to be and the other shop where the old outfitting shop was
- **Change no.3** - Park to storage plates and steel profiles should be created near the plasma-cutting machine

The suggested changes were based on these reasons:
- **Change no.1** aimed to decrease the distance between the cutting and steel shop and therefore, to have a positive influence on the block manufacturing efficiency
- **Change no.2** was due to the fact that the place where the cutting machine used to be, was the one that better fit in terms of flow analysis for the new outfitting shop, because this shop is closer to the path that goes to the block assembly park
- **Change no.3** was due to the fact that change 1 had relocated the cutting machine near the steel shop that is further away from the reception park. There is a wide space near the new location of the cutting machine that could be reorganized to accommodate a closer steel storage park without significantly harming other production processes

As there were no available preexisting buildings near the steel shop area, change no.1 would imply the need for an extra building. In order to avoid high expenses, this building should be a pre-fabricated building that could be either acquired or rented. The alternative of a pre-fabricated building would potential reduce the costs of change no.1, comparatively to the construction of a new building.

The advantages and disadvantages of the layout changes were weighed and rated:
- For change no.1 (plasma cutting machine) the advantages of the suggested layout surpassed the advantages of the existing layout and the disadvantages were less (table 3)
- For change no.2 (new outfitting shop) the advantages of the suggested layout surpassed the advantages of the existing layout and the disadvantages were less (table 3)
- For the change no.3 (steel storage park relocation), advantages were identified with no disadvantages spotted and so there was no need to weigh against advantages

The major advantages of the existing TO layout are:
- a large workshop for steel cutting
- steel cutting workshop nearby the repair ramp

The major disadvantages of the existing TO layout are:
- cutting machine far away from steel shop
- cutting machine far away from panel line shop
- cutting machine far away from block manufacturing park

The major advantages of the suggested MO layout are:
- cutting machine nearby steel shop, panel line and block manufacturing park
- a larger outfitting workshops
- a hub point for all outfitting related processes
- closeness of the steel storage park to the new location of the cutting machine

The major disadvantages of the MO layout are:
- cutting machine further away from repair ramp
- added costs due to the renting/acquiring of a pre-fabricated building

The TO layout had an overall non-positive result when compared with the MO layout.

The disadvantages of the TO layout were associated with the order of magnitude of the distance between the location of the cutting machine and the location of the steel shop and panel line.and with the potential lack of space for the implementation of modular units assembly processes. On the other hand, this layout has the advantage of being located nearby the ship repair ramp.

Regarding the new suggested MO layout, the overall results were positive (table 3). For all the proposed changes most of the disadvantages are linked with the costs of equipment repositioning process and of infrastructure.

As advocated before, the transference of the cutting machine towards a new location, would imply the acquisition or the renting of a pre-fabricated building (because building of a new infrastructure would be over costly).

The equipment repositioning process also has some associated costs but those, when compared with the acquisition of a new infrastructure, have a smaller impact. The new suggested layout has various advantages.

Moving the cutting machine into the new location would reduce the transportation time of the cut steel plates towards the steel shop, the panel line and the block manufacturing park.

The increase of the available space for outfitting related activities due to the creation of a new outfitting shop, will also enable the suitable conditions for the implementation of more space demanding activities, as it is the case of the assembly of piping segments in modular units.

This space increment will also result in the reinforcement of the piping hub role of that shipyard's area. Concentrating all the piping activity on this area will create a logistic center that can supply all the construction needs both in ramps and piers.

Table 3 - MO/TO advantages *vs* disadvantages weigh

		Advantages (i)	Disadvantages (j)	Difference
Cutting Machine Position	Suggested Layout	11	9	2
	Existing Layout	6	11	-5
Wider Outfitting Shops	Suggested Layout	8	2	6
	Existing Layout	2	4	-2

The cost comparison study started by analyzing the existing TO layout in order to define a reference/control layout. The results obtained from this analysis provided the baseline values for the comparison with the new suggested MO layout.

Those results were exported from the software Proplanner and were used, both for flow index and transport work calculations.

The estimation of the definitive material handling costs would imply a more detailed analysis, that would require a high level of expertise, concerning the position and the working rate of several units inside the shops and the material handling methods (for plates, pipes, stiffeners, small sized equipment, large sized equipment, and other equipment and materials). Therefore, it was considered out of the scope of this master's thesis.

Two types of flow index outputs were obtained for both the existing TO layout and the suggested MO layout:

- **The Relationship Chart (RC)**
- **The Space Relationship Diagram (SPD)**

These outputs were generated for both the existing TO layout and the suggested MO layout.

Starting by the existing TO layout, it has been stated that every piece of material and equipment arrives in the reception park; thus, this park has type "A" relationship rates with several shops and construction sites (construction ramp and pier).

The shops and the facilities (construction ramp, block manufacturing park, steel shop, panel line and cutting shop) where the block manufacturing process is performed have type "A" and "E" relationship rates among them.

Regarding piping systems, currently the pipes are outsourced and manufactured outside the shipyard. Hence in the shipyard they are merely assembled and tested on board. Additionally, if they have some type of damage in terms of surface treatment, they might also be blasted and painted inside the shipyard. Consequently, most of the pipe related flow in the shipyard occurs between the reception park and the construction sites.

A SPD for TO existing layout was created, using the data from the Relationship Chart. To avoid the diagram lines overload only "A" type relations were drawn.

Among the several changes suggested by the new layout, the creation of a new shop redefined activities flow, and determined new relationship rates that originated a new relationship chart.

Several relation rates can be highlighted in this new relationship chart (figure 4). First, the detach of a new outfitting shop that due to its new functions is now the construction sites pipes supplier. Hence this shop has now an "A" type relation rate with the block manufacturing park and with the construction ramp.

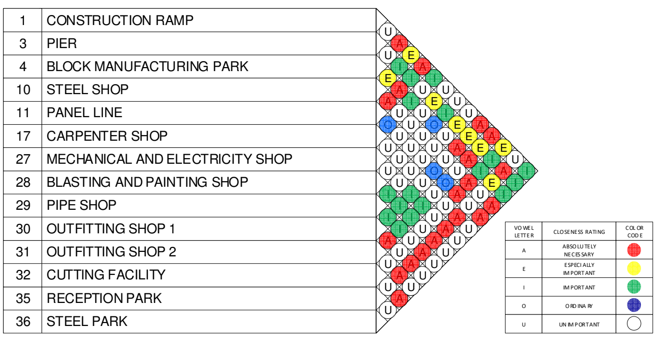

Figure 4 - MO layout relationship chart

In the existing TO layout, the steel shop and the panel line, were supplied by the reception park, with a type "A" relationship with the shops, while in the new MO layout receive their materials from the steel park, also with a type "A" relationship but within a significant shorter distance of 41 meters instead of 65 meters.

The results of MO layout transport work, considering the routes differences (table 4), showed that the outcome of change no. 1 and change no. 3 was a very significant reduction of traveling time when compared with the former TO layout. Looking in detail, the traveling time between the place where steel was storage in the TO layout and the place where it would be storage in the MO layout (near to the new cutting machine location), decreased by 37%. The traveling between the cutting machine and the steel shop had a remarkable decrease of 75%.

The changes between the existing and suggested layout would allow a smooth implementation of both, the module structure manufacturing and assembly process and the module assembly process.

In the case of the module structure manufacturing, the work flow gain margin from the repositioning of the cutting machine would depend of the number of parts and pieces to be cut, however, it is secure to state that it would be positive, when compared with the existing layout.

In the case of the module assembly process it is not possible to perform a gain margin comparison between existing and suggested layout because it is a new process that was not contemplated in the existing layout.

Table 4 - Traveling times between workstations

	Cutting machine position 1		Cutting machine position 2		
From	To	Travel Time (s)	To	Travel Time (s)	Relative Difference
Cutting machine	Pre- fabrication	93.08	Pre- fabrication	31.77	66%
	Receiving park (P1)	54.38	Steel storage park	34.21	37%
	Steel shop	99.02	Steel shop	24.35	75%
	Construction ramp	106.11	Construction ramp	88.01	17%

5. MO IMPLEMENTATION RISK MANAGEMENT

5.1 Scope of the problem

To assess the implementation of MO construction approach, Risk Identification, Qualitative Analysis and Risk Response and Critical Success Factors were assessed.

Risk Identification

MO approach is composed by seven different processes: 1. Design, 2. Module parts manufacturing, 3. Module assembly, 4. Dimensional control and running tests in shop, 5. Module transportation and fitting on-block, 6. Block assembly, fitting and installing and 7. Final trials.

The risks of each seven processes were identified and were numbered in a 2 digit code in which the first digit refers to the process number.

- **Qualitative analysis**

For the total of the 7 processes described, 27 risks were identified and their risk impact and risk's likelihood was assessed.

Once having assessed both the factor of risk impact and of risk likelihood, a final risk score for each identified risk was obtained. Risk score is the output that allows measuring risk, grading and representing it in an impact-likelihood table (Table 5).

- **Risk impact**

The total **Risk Impact ($\boldsymbol{I_{risk}}$)** was obtained for each identified risk by summing the impact ratings for Quality, Cost and Time factors that define the sustainability of the project (equation 5.1).

$$\boldsymbol{I_{risk}} = I_Q + I_T + I_C \qquad (5.1)$$

(I_Q - Quality factor; I_T - Time factor; I_C - Cost factor)

Once each risk had been rated, the obtained values (that could vary within a range from 0 to 9) were normalized into an impact rating scale from 1 to 5 that correspond to the impact categories of low (rating between 1-2), medium (rating equals 3), medium-high (rating equals 4) and high (rating equals 5). Normalization was performed by dividing each total impact rating by the highest rating value generated and then multiplying this value by five. The final result was rounded up to the unit.

- **Risk likelihood**

Likelihood was expressed in a scale of likelihood scores within a range of 1 to 5, that correspond to the likelihood categories of low (rating between 1-2), medium (rating equals 3), medium-high (rating equals 4) and high (rating equals 5). The likelihood of occurrence of each identified risk was empirically estimated.

- **Risk Assessment in function of Risk Impact and Likelihood**

The risk assessment was based on the impact-likelihood risk score results, computed by equation 5.2.

$$RiskScore = Likelihood \,.\, Impact \qquad (5.2)$$

In this dissertation's impact range is between 1 and 5 points, which is a linear function of the PMBOOK impact scale values of 0 to 0.1.

For each of these two dimensions of risk assessment, the rating values were categorized in low (rating equals 1); medium (rating between 2-4) and high (rating equals 5). No color scale was adopted for the Impact-Likelihood scores.

The range of values of risk score computed according to equation 5.2 is from 1 to 25 points.

- **Risk response**

The response for each of the identified risks was according to risk score (impact-likelihood relation) that was represented in green for Acceptance (A), yellow for Mitigation (M), orange for Transfer (T) and red for Avoidance (I).

- **Critical Success Factors (CSF)**

CSFs were selected considering their potential to reduce the risk of the identified risks.

5.2 Results analysis

The MO most risk affected processes were: Process 1 (design process), Process 4 (dimensional control & running test in shop), Process 5 (module transportation & fitting on block), Process 6 (on-block assembly, fitting and installing process).

From the 27 identified risks, 3 that were scored above 20 points were the most critical and 24 had a risk score below 20 points (3 of them below 3 points).

We will only address the 4 most critical risks that were:

Risk 5.5 – "schedule coordination between block and module block failure" had the highest risk score (25 points) and it was the only risk that has to be contained by an avoidance response. This Step of the Transportation and Fitting On-Block process must be carefully planned, checked and identified risk corrective and preventive measures must be implemented.

Risks 1.5, 6.1 and 6.2- had high risk score (20 points) and should be handled by transfer response. These factors had to be covered by entities outside the shipyard. The risk factor is high and the attempt to mitigate could jeopardize parts of the overall outfitting process.

To each identified risk a response was developed.

The highest scored risks were 5.5- Schedule coordination between block and module block failure,
1.5- Inadequate working plans, production and detail drawings), 6.1- Parts out of dimension and 6.2- Parts out of shape (see table 5).

Table 5 - Identified risks likelihood-impact table

		Impact Factors				
		1	2	3	4	5
Likelihood Factors	5	2.2	2.1	5.6	6.1; 6.2	5.5
	4	2.4	2.3	6.5	1.2; 4.2; 5.4	1.5
	3		5.1	3.3; 3.4	6.3; 6.4	4.1
	2	1.4		1.3	7	1.1; 5.3
	1		5.2			3.1; 3.2

The list of the selected nine critical success were selected in function of the risk analysis. This CSF's were defined by Moura and Botter in reference [9].

F1: Application of CAD systems for project development
F2: Supplier inclusion in project production design phase
F3: Production planning in advance to the suppliers
F4: Delivery schedule in compliance control mechanisms
F5: Standardization of supplier provided parts/ equipment
F6: Partnership in research and development area between the shipyard and the suppliers
F7: Partnership in research development area between the shipyard and the universities
F8: Presence of qualified labor force
F9: Equipment and machinery technological update

F8 and F9 are the most outstanding because of their influence on a large number of the identified risks, including risk 5.5, which is the most hazardous identified risk.

CONCLUSION

Regarding the comparision of *Mh* of TO vs MO question the study suggested that by implementing the MO approach, the number of *Mh* used in the assembling procedure could be reduced by 549 Mh, which represents a gain of 74% when compared with TO

In what concerns layout changes due to MO, it can be concluded that there are more direct and indirect advantages resulting from the new suggested layout namely in what respects distance between work stations, space for outfitting related activities and outfitting work flow hub creation.

It should be enhanced that the positioning of the cutting machine near the steel shop (using a pre-fabricated building) and the creation of a new steel storage park nearby the steel shop will represent an improvement in terms of traveling time. The route traveling time between the cutting machine and the steel shop, on the new suggested layout, enables a trip reduction of 75% when compared with the trip time of the existing layout

This newly suggested cutting machine position will also decrease the traveling times for the panel line by 66% and for the construction ramp it has a reduction of 17%.

Another important matter is the location of the new steel storage park. The repositioning of the site to storage the steel plate and steel profiles will result in the decreasing of trip's time between the park and the different buildings. Comparing with the existing layout this advocated alteration will bring a traveling time decrease of 37% on the route towards the cutting machine.

An important benefit of the creation of a new outfit shop would be the setting up of an outfitting hub with simplified routes of network of the work flow derived from the centralization of outfitting related activities in a single shipyard zone which reduces the work flow routes dispersion.

The major disadvantage of MO layout is that it generates additional costs to rent/acquire the pre-fabricated building to host the cutting machine.

The most critical risks identified, were related with the design process, with the dimensional control and running test in shop process, with the Module Transportation and Fitting on Block process and with the On-block assembly fitting and installing process. The higher risk score regards risk 5.5 - Effective Schedule Coordination between Block and Module Block identified risk (Module Transportation and Fitting on Block process) that must be managed by an avoidance response that implies its careful planning, checking and implementation of corrective and preventive measure.

To control the major identified risks a list of nine critical success factors was defined: F8 and F9 are the most outstanding because of their influence on a large number of the identified risks, including risk 5.5 which is the most hazardous identified risk.

The risk management analysis performed shows that this profitable outfitting methodology can be implemented, although it carries critical risks that must be addressed. Strong planning, quality certification, scheduling margins and investment in labor force qualification and training would be factors that would reduce the risk factors of this outfitting approach.

If implementing MO approach, the shipyard should therefore incorporate the described CSFs in their strategic objectives and monitor performance accordingly.

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