Study for implementation of Advanced Outfitting concept in a Mid-Tier Shipyard

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Szczecin (Poland), January 2018

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I, Michael Eyles Sanchez Blanco, declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research: **"Study for implementation of Advanced Outfitting concept in a Mid-Tier Shipyard".** I confirm that:

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ABSTRACT

Study for implementation of Advanced Outfitting concept in a Mid-Tier Shipyard

By

Michael E. Sánchez Blanco

Shipyards around the world are trying to create and strengthen competitive production advantages that guarantee their sustainable development in the regional and global market. The shipbuilding business continues demanding the design and implementation of new strategies to improve and maximize the ship production processes, allowing to reduce the cycle construction time for new ships and optimize the resources associated with each project.

This research proposes to demonstrate and explain the general aspects that should be considered for the implementation of "advanced outfitting" concept as a strategy in shipbuilding processes. At present, many small and mid-tier shipyards only install pipes on-block level in its new construction projects, leaving the installation process of the largest percentage of equipment after the ship's hull has been manufactured and assembled. The "advanced outfitting" process is a strategy currently used by the most modern shipyards in the world and allows the installation of the largest amount of equipment (machinery, pipelines, auxiliary machinery, etc.) in the earliest stages of construction, especially during the assembly of each block that compose the hull. The result of this investigation will become as a guide for any mid-tier shipyard to understand and implement the general concept of advanced outfitting techniques, and how to assess its impact on future shipbuilding projects. However, small shipyards could use this guide to understand this concept as well.

The document is focused on industrial purposes, not only to show the aspects should be checked to assess the level of outfitting processes in shipbuilding projects compared with global shipbuilding behavior and how to improve it, but to influence strategically to the mid-tier shipyard companies, proposing alternatives for achievement the future shipbuilding projects and support some decisions in terms of outfitting. Different sources of data and information were used, including fieldwork through observation, study of shipbuilding projects and interviews during internship time in CRIST shipyard (Gdynia, Poland), as a part of EMSHIP program, but also study of many documents related to ship production and outfitting technics.

The study shows and explains all the main necessary aspects to implement the advanced outfitting concept, from optimization of layout, until design and engineering aspects, production aspects, and project management. Also, some logistics aspects are studied to complement the different levels involved in shipbuilding strategy. Finally, a cost-benefit analysis was established to demonstrate the positive influence of advanced outfitting on shipbuilding projects and validate the hypothesis that this methodology could improve the productivity in mid-tier shipyards, reducing the cost and time for each project, and how it could impact the future shipbuilding projects.

Keywords: Advanced outfitting, outfitting process, ship production, shipbuilding,

1. INTRODUCTION

International shipbuilding business has continuously required the design and implementation of strategies that improve and maximize the ship production processes. This shall consider many organizational aspects as physical plant optimization (layout), human resources, organizational structure and technological capacities. Also, it must consider the possibility to acquire and implement new resources and tools, that allow to reduce the cycle construction time for new ships and optimize the resources associated with each project. All above mentioned aspects will benefit with high quality levels and high efficiency commonly demanded by the customers, and the high technical standards demanded by the classification societies.

Increasing productivity, competitivity and quality in their products, are strategies that generally are gathered in ship and design areas, business and commercial processes, acquisition and inventory control, and construction and assembly methods. It is inside this last area, construction and assembly methods, where some productivity terms appear, for example, group technology, assembly technologies, outsourcing and cross-trade contracts, and advanced outfitting.

This research will help to mid-tier shipyards to implement "advanced outfitting" concept as a strategy in shipbuilding processes. At present, many small and mid-tier shipyards only install pipes and structural outfitting on-block level in its new construction projects. The installation process of the largest percentage of equipment (outfitting that is part of ship's functional subsystems and systems as a cabling, propulsion plant, electrical plant parts, auxiliary systems, habitability modules, electronic systems, etc.) is left after the ship's hull has been manufactured and assembled.

Therefore, the hypothesis for this research is that it is possible to increase the productivity of shipbuilding cycle in any mid-tier shipyard based on the implementation of advanced outfitting concept. For this reason, the main purpose of this research is to establish and describe the general aspects that must be considered to implement "advanced outfitting" in that kind of shipyards.

The "advanced outfitting" process is a strategy currently used by the most modern shipyards in the world and allows the installation of the largest amount of equipment (machinery, pipelines, power grids, etc.) in the earliest stages of construction, especially during pre-assembly and assembly of each block that composes the hull. This process reduces the overall time of the construction project and brings advantages to the production cycle that are represented in cost reduction and better use of physical resources, working environment, high quality of finished products, among others.

The present document is the result of the research focusing in modern outfitting technics and processes implemented in high productive shipyards. It describes why and how could be implemented.

Likewise, this document is planned to be a guide for mid-tier shipyards to describe and understand the general concept of advanced outfitting techniques. General shipbuilding aspects should be taken into account for its implementation. At the same time, it is possible to assess the impact of advanced outfitting method on future shipbuilding projects.

This document is divided into the following groups:

Chapter 2 explains the research methodology, sources of data and the fundamentals about how and where were collected and analyzed data and documents considered for this research. The Chapter 3 is the theoretical framework where is explained the basics about ship construction process and in detail about outfitting processes from the production point of view. This chapter covers terms as Work Breakdown Structure (SWBS), Zone outfitting method (ZOFM) and Advanced outfitting concept, trying to arise and correlate outfitting processes with hull structural construction activities.

Chapter 4 gives an overview about CRIST S.A. shipyard (Gdynia, Poland), where most of the research was developed (internship), explaining some features about this company and its capabilities, and how the internship time was developed there. Then, in Chapter 5, it is presented a simple procedure to analyze and assess the current outfitting level in a mid-tier shipyard

Chapter 6 is the core of this research, the mains aspects that must be considered to implement “advanced outfitting” concept in a mid-tier shipyard are established, described and explained.

This chapter covers shipbuilding areas as facilities (layout), design aspects, engineering aspects, project management, ship production and logistics. The results of this research are condensed in this chapter proposing to be a guide line to create a main route or general map that leads to any mid-tier shipyard to a successful implementation process of this concept, considering its current outfitting level, capabilities, facilities and experience from previous shipbuilding projects.

2. RESEARCH METHODOLOGY

Different sources of data and information related to the topic of this master thesis were used to base, structure and validate the findings and hypothesis presented in this research. The scope and depth established for this research was considered taking into account the frame time of EMSHIP program, internship time and available data from studied resources.

2.1. Primary resources.

2.1.1. Fieldwork through observation.

During internship time in CRIST shipyard, some shipbuilding projects were observed, including fish carrier ships, trawler fishing ships, multi-purpose offshore ships, offshore structures, and other naval structures, analyzing specifically the outfitting practices carried out on them. The collection of data and information was performed on site (workshops, dock level positions and drydock) where outfitting activities are commonly executed. The field notes included the physical description of outfitting activities, and photographic record of advanced outfitting samples at CRIST shipyard.

2.1.2. Interviews in CRIST shipyard (open-ended questions).

Through daily conversations and interactions with project managers, engineers, designers and workers. All of them with long experience and high-level skills in shipbuilding projects and involve in current projects in this company. Knowledge and experiences about the best and modern outfitting practices were obtained, as well as the principal aspects related to advanced outfitting concept. This source allowed to get a qualitative description about this topic and clarify the theory found about it.

2.2. Secondary resources.

2.2.1. Literature reviews.

Official books, documents, reports, and previous researches related to shipbuilding projects, outfitting in ship construction, productivity in shipyards, and current global market of shipbuilding sector, were consulted and studied. Data from some of these documents were used for the established analysis and assessment of outfitting level porcedure, for example global shipbuilding benchmarking results. Likewise, theory and some fundaments about outfitting processes were used to founding and structure the framework of this thesis.

2.2.2. Web information (internet).

Web pages were consulted, especially those ones dedicated to shipbuilding sector, naval architecture, shipyard management and ship production. Official, governmental and well-kwon websites were selected to assure the reliability of data and information presented there.

3. THEORETICAL FRAMEWORK

To be able to talk about "Advanced outfitting", it is necessary to understand and comprehend some concepts linked to ship construction and ship production. In a general point of view, shipbuilding process involves different steps from the design stage considering the requirements and restrictions demanded by the owner or client, through fabrication, construction, tests, until the delivery process. Fabrication and construction processes include outfitting activities. Classically, outfitting tasks come after the structure of the ship has been totally performed, it means that the hull has been completed, but modern methods allow to complete them before that, improving the productivity of the shipyard and reducing the construction cycle.

To achieve advanced outfitting, nowadays, modern shipyards have developed high technologies technics and construction methods to carry out shipbuilding projects saving costs and time. These methodologies are linked to a concept known as "group technology", which is related with two work breakdown structures, system-oriented and product-oriented. The main goal of group technology is to classify and organize all work activities and sub-products according to similar features, regarding engineering technics, construction materials, construction and assembly processes, etc. At the same time, it is necessary to establish the correct sequences and hierarchies of these activities.

(Richard Lee Storch, 1995) Group technology improves the management system using technics as classification and codification of work activities and products. A comprehensive classification and coding scheme make possible to improve the inventory control, work scheduling, production information and manufacture processes.

3.1. Shipbuilding process & Zone Construction Method

Shipbuilding projects are divided in different processes or tasks. The output of most of these tasks is a provisional product (work package), which is an input for a subsequent product. Output is defined in terms of the number of work packages required. The total required output is the sum of all required work packages (Richard Lee Storch, 1995). These concepts of group technology and zone construction method, require a good planning and project management, to avoid delays and bottlenecks during construction time. As it was previously explained, group technology comes with the establish of work package sequences, and if there is any delay related to the production of any package, there will be other packages or areas that can be affected, numbing the general schedule.

According with some fundamental concepts of ship production (Richard Lee Storch, 1995), the ship project is subdivided into smaller geographical areas (zones), and at the same time, each zone is subdivided in groups, and consequently, each group is linked and associated with all resources necessary for getting some work packages. For example, a work package may include a portion of steel structure, a percentage of HVAC ducts, electrical components (cables, traces, panels), thermal insulation, etc. For this reason, a consequent effect of zone construction is to achieve the hull construction and outfitting simultaneously.

The final product or result of any shipbuilding project is the planned ship or floating platform, which can be divided totally or partially from the management point of view, into component parts. The system by which these components are subdivided in order to control the production or management processes is called a work breakdown structure (WBS). Work breakdown structures that are commonly used in shipbuilding projects are classified as systems or product-oriented (Richard Lee Storch, 1995).

3.1.1. Systems-oriented Work Breakdown Structure (SWBS)

Systems-oriented work breakdown structures are convenient for initial approximations and the initial design period. They are not appropriate for planning, scheduling, and executing a zone-oriented manufacturing process. All systems that compound the ship as entire entity are divided by groups (Richard Lee Storch, 1995).

Many shipyards have followed and applied for many years the system-oriented Ship Work Breakdown Structure (SWBS) established by U.S. Navy (Table 1), mainly for activities related to ship design, maintenance, logistics, management and training. The method defines the classification of groups using three-digit numeric code according to operational and functional approach of each system on board the ship.

Table 1. Ship Work Breakdown Structure - U.S. Navy.

SWBS Code - U.S. Navy
000. General Guidance and Administration
100. Hull Structure
200. Propulsion Plant
300. Electric Plant
400. Command and Surveillance
500. Auxiliary Systems
600. Outfit and Furnishings
700. Armament
800. Integration/Engineering
900. Ship Assembly and Support Service

3.2. Product-oriented Work Breakdown Structure (PWBS).

The common process to build ships or any floating structure starts from fabrication of parts of different dimensions (structural or mechanical components), and then they are assembly each other to produce temporal products (parts, subassemblies), later the last ones are combined to build bigger components (blocks) until getting the complete ship. For this reason, (Richard Lee Storch, 1995) the best technique to subdivide ship construction activities is to emphasis the processes on required parts and subassemblies (temporal products), following a classification scheme to subdivide work in accordance with common features and construction methods. Work Package Classification PWBS defines the shipbuilding process into three basic types of work: hull construction, outfitting, and painting (Figure 1).

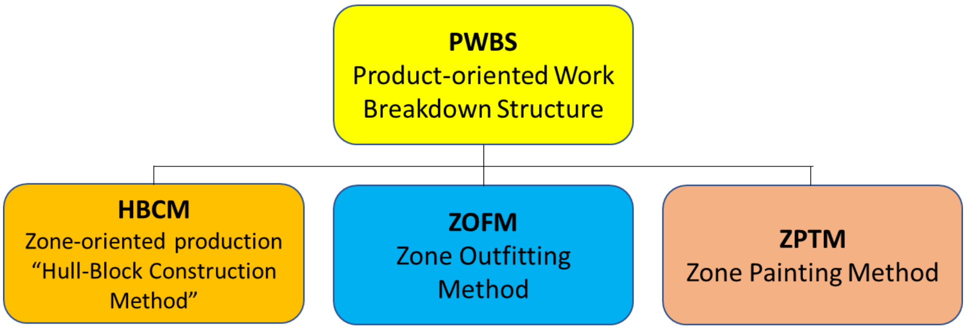

Figure 1. Product Work Breakdown Structure for ship production.

Zone-oriented production or well-known as Hull Block Construction Method (HBCM) is already being applied for hull construction by many mid-tier shipyard. In this method, the hull and superstructure are divided in blocks that are built independently, later are joint in a dry dock or land-level dock to complete the whole structure (Figure 3).

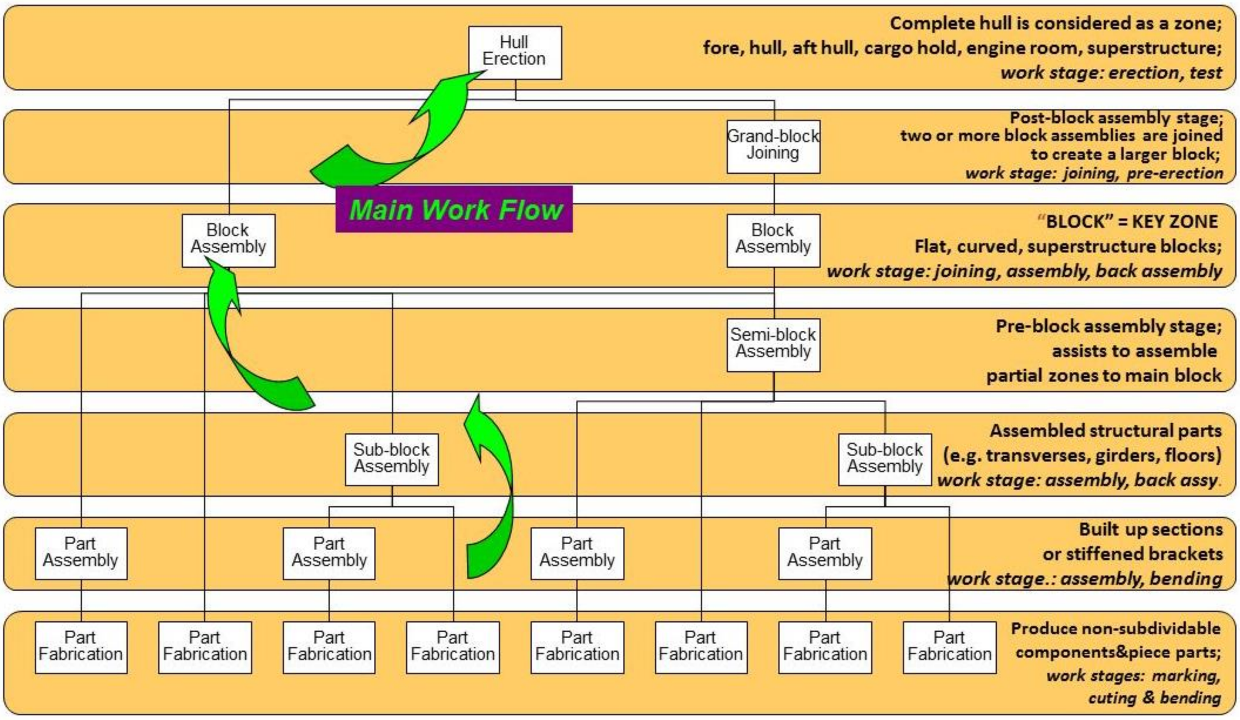

Figure 2. Hull block construction method flow. (source: http://lou.chirillo.com/shipbuilding-database/)

Figure 3. Hull block construction method. (source: source: fieldwork during internship at CRIST shipyard)

3.3. Zone outfitting method (ZOFM).

The zone outfitting method (Figure 4) makes possible efficiency advantages, through simultaneous hull construction and outfitting, is divided in three basic stages (Figure 5): on-unit, on-block, and on-board outfitting, and a substage for downhand outfitting on overheads when blocks are upside down. The zone outfitting method is a natural consequence of the hull block construction method (HBCM), because both employ the same logic. Shipyards which employ ZOFM assemble most outfit components independent of or on hull blocks (Richard Lee Storch, 1995).

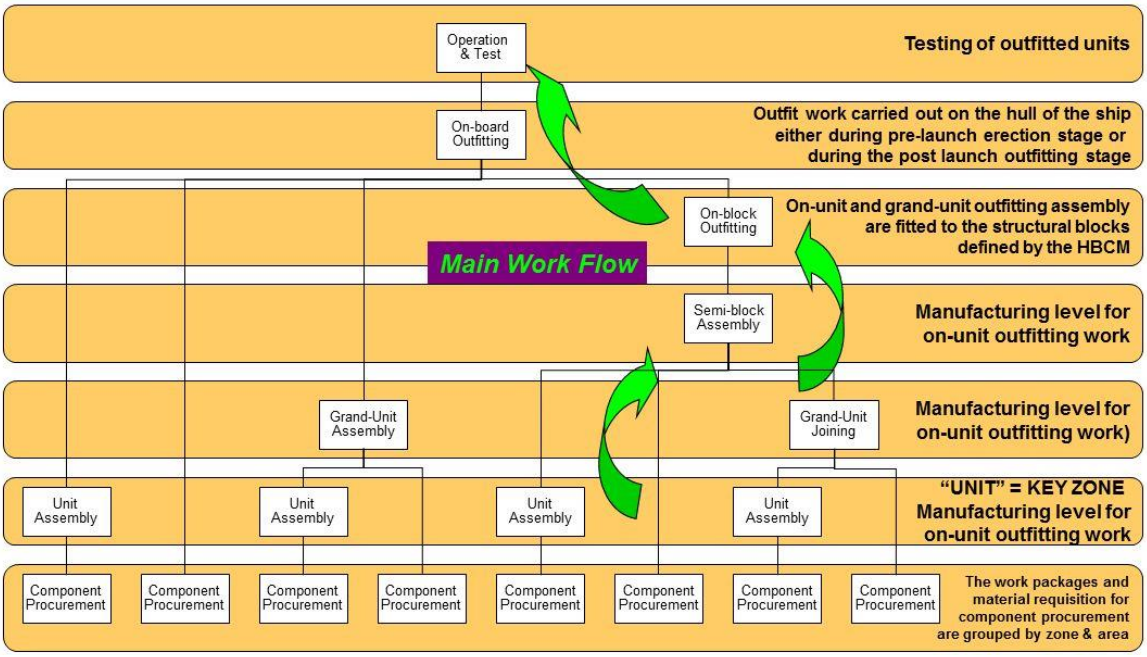

Figure 4. Zone outfitting method flow. (source: http://lou.chirillo.com/shipbuilding-database/)

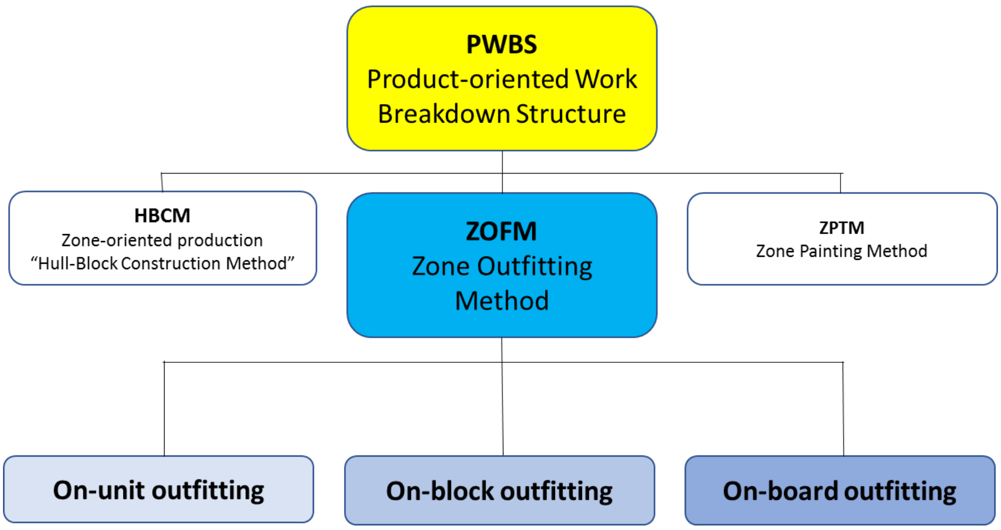

Figure 5. Zone outfitting method stages.

3.3.1. On-unit Outfitting.

This type of outfitting involves all the activities related to the constructing packages of equipment or packs of pipelines and other systems on a common foundation (Figure 6 & Figure 7). For “On-unit” outfitting the usual process is that the shipyard design office designs or procure ship’s outfitting before the structural designs to be possible assembled before in workshops and previously to the structure on which they will be installed being completed. The final idea is to have finished the outfitting units or packages to be possible their installation during the pre-assembly or block assembly process.

Figure 6. On-unit outfitting package. Pump-set for sea water system. (source: http://i2.wp.com/lou.chirillo.com/wp-content/uploads/2014/06/AVON02b.jpg)

Figure 7. On-unit outfitting package. Pump-set for sea water system (source: http://i0.wp.com/lou.chirillo.com/wp-content/uploads/2014/06/AVON02c.jpg)

Usually, the packages are incorporated with unitized foundations or support bases, corresponding equipment, even some accessories like small tanks, pipelines, controllers, electric cable, control systems, etc., and are completely painted and protected. Even, depends on the kind of equipment is going to be installed, the company requires to carry on some mandatory or special tests before the installation on-block. Some example of that are steering gear systems, HVAC packages, sewage treatment plants, sea water purifier plants, etc.

An example of this kind of outfitting is commonly used in Cruise ships building, for example, accommodation areas as cabins and toilets are designed like modules that are fabricated for the same company or outsourcing company. In some cases, it is possible to take out the module to be upgraded when the ship is on shipyard for maintenance.

3.3.2. On-block Outfitting.

This process consists on installing units or individual pieces of equipment (pipes, valves, foundations, tanks, electrical cables, ventilation ducts, auxiliary equipment, main engines, etc.) on a structural assembly or block before the hull is erected (Figure 8, Figure 9, Figure 10 & Figure 11).

Figure 8. On-block outfitting sample. Pipelines. (source: http://i2.wp.com/lou.chirillo.com/wp-content/uploads/2014/06/AVON02k.jpg)

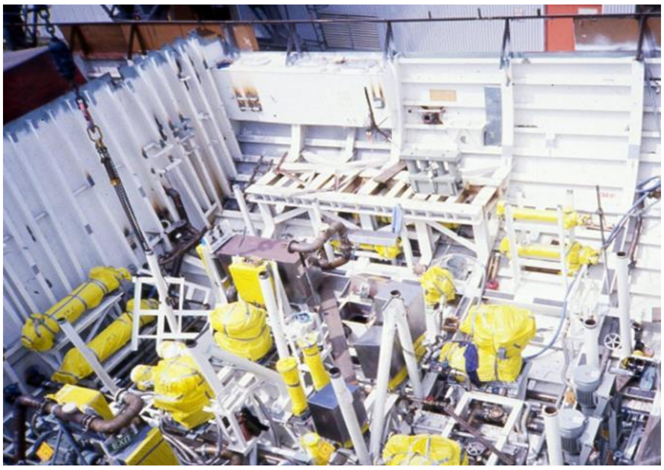

Figure 9. On-block outfitting sample. Pump room. (source: http://i1.wp.com/lou.chirillo.com/wp-content/uploads/2014/06/FRIG03c1.jpg)

Figure 10. On-block outfitting sample. HVAC ducts installation and cable trays. (source: http://kalyan-sg.byethost22.com/MPM-II/On-Block-Example-01.jpg)

Figure 11. On-block outfitting sample. Diesel Engine Installation. (source: http://gcaptain.com/isla-bella-worlds-first-lng-powered-containership-launched-at-nassco/)

3.3.3. *On-board Outfitting.*

For the common process of outfitting, complete units or individual pieces of equipment, pipes, accessories or single components of systems, are installed inside the ship when it is already erected. However, there are some variations of on board outfitting that are called on board advanced outfitting and correspond to some processes known as Open Deck or Blue Sky advanced outfitting (Lamb, Thomas, 2004), where a complete space or zone, for example engine rooms or auxiliary machinery spaces are left open. It means that the superior deck (top side of the compartment) is remained open until all the machinery, equipment, piping, or components have been moved into the compartment and installed. Then is possible to join the superior deck and the blocks above erected.

3.4. Advanced outfitting concept.

In ship production, advanced outfitting is a strategy that modern shipyards use as a part of shipbuilding processes (Figure 12). As opposite to the conventional or traditional outfitting process where the hull of ship is built and then erected on the dock, and the equipment and components (outfitting) that are part of functional subsystems and systems for the ship's operation, are installed only after the launching of the hull (floating), the advanced outfitting allows the installation of the most part of components (subsystems and systems) in the stage of pre-assembly or block assembly.

Figure 12. Shipbuilding process cycle including advanced outfitting. (Source: Terengganu Malaysian University – School of Ocean Engineering)

Historically, the advanced outfitting process as a technical ship production strategy came from Second Worldwide War II (WWII), where “pre-outfitting”, an early name for advanced outfitting, was a result from advanced pre-fabrication of ship (blocks) implementation, this link of both processes allowed the outfitting or equipment was installed while the assembly or block was being built. After that, this process was used extensively in the wartime shipbuilding yards in the U.S. and other countries.

Subsequently, the shipbuilding technology transference to the U.S. from Japan in the early 1970’s allowed the improvement of shipbuilding technics including the implementation of Advanced Outfitting strategy that later was applied for many shipbuilders around the world, especially the commercial shipbuilders that after implementing it, all reported significant reduction in build duration and savings of man-hours (Lamb, 2004).

As a result, (Chakraborty, 2017) it has been analyzed that the traditional process where it is firstly fabricated and completed the hull structure, and then, after launching, it is followed the process of outfitting installation inside the hull, takes extensive time. For this reason, to decrease the construction cycle time and improve the productivity in shipyards, the strategy of advanced outfitting has been established.

Nowadays, most of modern shipyards around the world have implemented and recognized that the use of advance outfitting in ship building reduces the time of the project and get considerable saving of money and resources associated to budget for each project.

Some studies have been carried out in topics relates to advanced outfitting strategy. Most of the information currently available related to projects, research or technical reports are focused in productivity, its impact over the cycle time in shipbuilding projects, its benefits on the project’s budget, low inventory costs benefits, etc., but there are not enough data related to how this technical process can be implemented in a current shipyard to optimize the layout or how to evaluate the viability to implement it (cost-benefit).

For the initial research related to this master thesis topic, were consulted different articles and websites that contain information and data about advanced outfitting strategy and some productivity and efficiency implications over the companies or shipyard when it is implemented.

Thomas Lamb from University of Michigan in 2004 wrote and article titled “The Advanced Outfitting Dilemma” (Lamb, 2004), where it is explained thorugh the investigation of different shipyards why some of them prefer to use the advanced outfitting approach and others not. It is explained for the author of this report using different considerations, for example, it was noted that some shipyards use subcontractors to complete the work in distinct stages, moving the most of outfitting responsibilities (or part of the ship, such as the machinery space or accommodations areas) over the subcontractors. In this case the shipyards expressed this strategy made easier the installation of outfitting avoiding interferences between shipyard workers and subcontractor workers performing activities in the same space at the same time, therefore it is possible to avoid the confusion over who is responsible for the space and decisions on priorities between shipyard and subcontractor workers.

Another important aspect studied by Lamb and that is a good support for this master thesis topic, is the differentiation about how the advanced outfitting process impact commercial shipbuilding projects versus naval or military projects. The costs and resources associated to shipyard labor, material, and subcontractor costs for typical commercial, cruise and naval ships were analyzed, as well as the typical breakdown of the labor for the traditional major functional areas, again for typical commercial, cruise and naval ships.

Lamb concluded that it is necessary to emphasis the changes from maximizing or implement advanced outfitting strategy about how best fits the shipyard and ship type is pretended to build. Also, some conclusion related to production, for example, the purpose for applying advanced outfitting is to reduce the building cycle, the building duration versus the time on building dock ratio, the outfit versus lightship weights ratio, and the amount of outsourcing all increase, some are benefits to implement advanced outfitting. Other conclusions were gotten in that study and they will be analyzed during the research period (internship) to support the master thesis topic.

Other document consulted is called “Outsourcing and Outfitting Practices” (Schank, 2005)and describes a research focused on understand and analyze the implications of implementing these processes (outfitting and outsourcing) in Ministry of Defense shipbuilding projects in the United Kingdom.

The main base of study performed by Schank and his group, was centered in the project planned by Royal Navy (UK) to produce two new aircraft carriers called the Future Aircraft Carrier (CVF), that will replace its three existing Invincible-class carriers. The two planned ships, which could be the largest warships ever constructed in the United Kingdom, were planned to be commissioned in the Royal Navy inventory during 2012 and 2015.

Schank analyzed different shipyards in the United States, Europe and United Kingdom, evaluating the level to which shipyards use advanced outfitting strategy, measuring the percentage of outfitting accomplished during early phases of construction, for example in processes like electrical power distribution tasks (installing cable), switchboards, and hangers. The results showed that UK shipbuilders realize lower levels of advanced outfitting than do most shipbuilders in the United States or European Union, not only for electrical power installation activities, even for a variety of different tasks. Likewise, it was explained that it is possible to plan for at least 80 percent advanced outfitting in most of shipbuilding projects that allow to produce super blocks outfitted before they are erected to complete the hull.

Also, Schank found that the lack of capacity of cranes to lift grand blocks into the dry dock or the lack of sufficient space to install advanced outfitting into the grand blocks are some practical limitations to the degree of advanced outfitting that could be improved.

The potential cost impact of higher levels of advanced outfitting was performed as well. Schank reported that all hot work should be completed as early as possible in the construction process, and before painting of the blocks or grand blocks. The second point was that, on every occasion possible, packaged assemblies and units versus the individual components should be used and installed in the blocks or grand blocks. For example, machinery units composed of structural foundations, equipment, and all pipe work and electrical work should be packaged and installed as a complete unit instead of building up the unit on the ship.

Another example showed was the case in cruise-ship industry and that is becoming more common in naval warships according to the author. The installation of completely fabricated cabins and accommodations areas as bathrooms, offices and galleys, it is very frequent practice today. Module cabins are typically built by outsourcing company or at workshops in a shipyard, and then lifted and set inside the assembled ship as a complete unit. The main shipyard job is to secure the cabin in place and connect the electrical lines, HVAC system, and other subsystems associated to this compartment (water, electronic lines, etc.). These modular cabins have replaced the initial practice of constructing accommodations areas with different components were installed separately inside the ship.

A third document was consulted, “Procedure for Estimating the Effectiveness of Ship Modular Outfitting” (Rubeša, 2011). The modular outfitting concept is explained by the author. The research considered different shipyards and various types of shipbuilding projects and concluded that modular outfitting is a strategy to reduce duration time of shipbuilding process and decrease costs associated to the project, even without making big capital investments for new facilities, machines and tools, and as a result there will be an increasing of shipyards’ competitiveness level. Additionally, the authors performed a new procedure for shipbuilding cost benefit measurement because of using the modular outfitting concept within the shipbuilding process, using a multicriterial decision process to evaluate a strategy for improvement of outfitting process with a precise indicator of impacts in cost reduction. Finally, it was suggested the enhancement of ship modular outfitting by introducing more standardization, unification and typification of ship modules, which allow a completely integrated structure and outfit construction.

4. OVERVIEW ABOUT CRIST SHIPYARD S.A. (INTERNSHIP).

This research was supported by CRIST S.A. shipyard as a part of internship framework during EMSHIP master course. It is a large size shipyard (Figure 13 and Figure 14) placed in Gdynia, city that is part of three most important port cities in Poland, and located at southern cost of Gdansk Gulf (Baltic Sea). This company is one of the most important shipyards on the global and European market, specialized in shipbuilding projects, marine constructions and offshore structures.

Figure 13. Location of CRIST shipyard. Gdynia (Poland). (Source: https://earth.google.com)

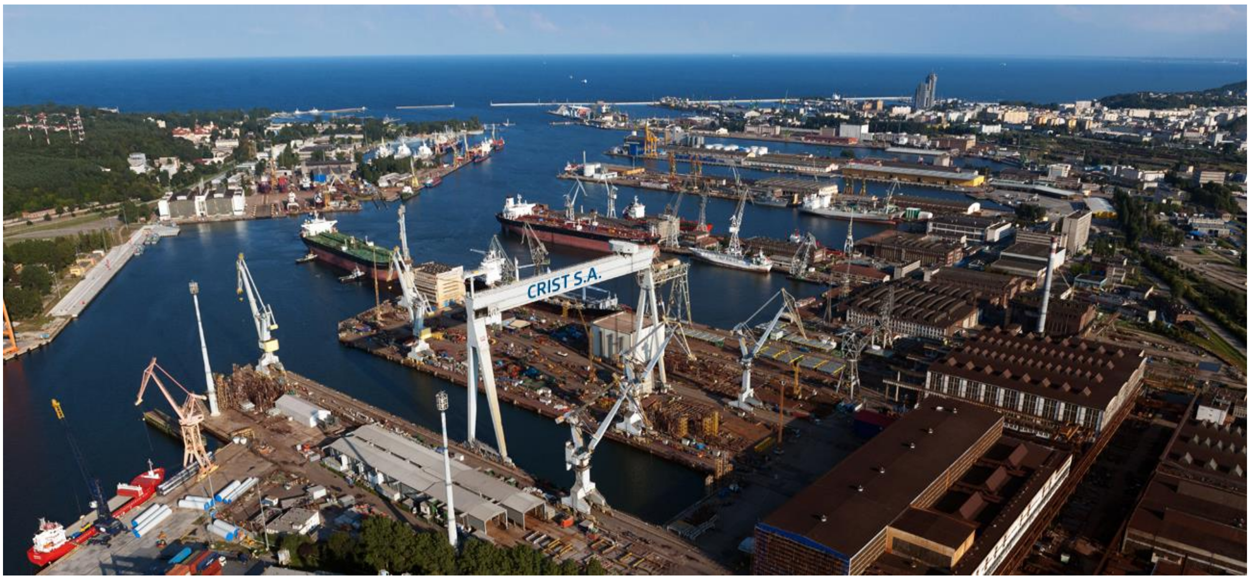

Figure 14. CRIST Shipyard in Gdynia-Poland. (Source: www.crist.com.pl)

Among its successful projects in Europe this company has constructed three high-tech ships for the installation and repairing of sea wind farms. Initially, the activity of CRIST S.A. Shipyard was focused on construction and repair of ships, steel constructions, fishing vessels and hulls for Ro-Ro type vessels. However, after the purchase of facilities of former Gdynia Shipyard in 2009, this company focused on offshore constructions, specialized coastal constructions and vessels for exploration of maritime resources. (CRIST, 2017)

This shipyard counts with a dry dock of dimensions 379 m length, 70 m breadth and 8 m depth designed for final assembly of floating objects (Figure 15), as well as big gantry crane (one of the biggest on Baltic Sea coast with 1000-ton capacity and 153 m span).

Figure 15. Dry dock at CRIST Shipyard. (Source: www.crist.com.pl)

Some of the shipbuilding projects carried out by CRIST shipyard are:

- Offshore industry: Off-shore structures, vessels and barges for installation of wind turbines, platform supply vessels PSV, anchor handling tug supply vessels (AHTS), off-shore construction vessels, platforms and units for installation of wind farms at sea, submersible objects, and foundations for wind turbines.
- Vessels: fishing vessels, tugs, ferries, container vessels and research vessels.
- Hydrotechnical structures: water gates and pontoons.

As it was explained before, part of this research was developed during the internship in CRIST, specifically within the Shipbuilding Project Management Department. Some projects of construction which were considered during the internship period including a multipurpose fishing vessel "Life Fish Carrier" of 80 meters length, trawler fishing vessels between 90 and 150 m length, offshore wind farm service ship, and other marine structures. Also, different workshops, drydock and production areas of this shipyard were checked, having the opportunity to interact with workers, technicians, engineers and specially with project managers, with the main idea to understand the layout and production flow of CRIST, including plate pre-treatment areas, cutting, welding and bending workshops, sub-assembly workshops, block assembly areas, hull erection areas (land level and drydock), painting workshops and the most important for this research “outfitting techniques”.

For this master thesis, some research activities related to general outfitting processes developed in CRIST, included programming, design, acquisition, checking and control of equipment in warehouses, and installation activities. At the same time, outfitting processes were studied with the support of designers (Naval Architects) focused in how outfitting is planned for shipbuilding projects, including off-shores structures, and how the production information is displayed to workshops and other production and logistic areas.

5. STUDY AND ANALYSIS OF OUTFITTINNG LEVEL IN A MID-TIER SHIPYARD.

5.1. Analysis and assessment of shipbuilding project schedule.

In this step the idea is to analyze and assess the planning and achievement of outfitting activities during construction cycle in any shipbuilding project (time, overlapping, resources control, etc.), based on shipbuilding schedules delivered by Project Managers who supervised the construction of new ships. The outfitting process should be evaluated considering the planned dates to carry out the insertion and installation of outfitting components, compared with the activities and progression of hull block construction.

It should be considered all groups of outfitting for this evaluation, including big and small machinery. As a result, it should be observed the following aspects for any shipbuilding project:

- Quantity of outfitting activities that were planned and carried out after hull block erection.
- Overlapping of activities related to outfitting procurement with hull construction tasks, which implies that installation activities would be performed after hull erection.
- Outfitting production information availability, which could generate installation processes were planned after hull completion.
- Outfitting activities carried out by subcontractors, not only for supplying, if not for installation and commissioning. It means that project managers had to manage a considerable number of companies, planning, controlling and organizing their working activities.
- Using of prefabricated modules, or design and construction of machinery units in shipyard's workshops. Quantity of machinery and equipment that were installed by components on-board and on-unit stages
- The time of construction from first plate cutting activity until delivery. Time of hull construction and erection has to be compared with time of outfitting activities.

Following the shipyard classification criteria taught by Aalto University (Finland) in its lecture "Shipyard Engineering", which is based on benchmarking system established by "First Marine International", organization specialist in consultancy about marine and shipbuilding industry, and the assessment made after analyzing shipbuilding project schedule, it is possible to place some mid-tier shipyards between two categories of shipyards: second generation and third generation (Aalto, 2017).

Second Generation: The method of construction changed to a unit or block building philosophy. The number of building berths reduced to two or three and much of the assembly work was carried out in large buildings. A limited amount of outfitting was installed prior to launch. Steel and outfit facilities remained separated with outfitting shops generally located adjacent to an outfitting quay (Aalto, 2017).

Third Generation: The separation of steel and outfit facilities continued. The assembly of steel blocks became mechanized and process lines were introduced for rapid steel assembly of the midship portion of a vessel. Blocks became larger, construction times reduced, and the number of building locations reduced. The level of outfitting prior to launch increased and there was some pre-outfitting of blocks (Aalto, 2017).

The thesis of improving outfitting methods and implementing advanced outfitting concept in shipbuilding projects, will allow to a mid-tier shipyard assessed between second and third generation, to be closer to establish a fourth-generation shipyard.

Fourth Generation: Essentially steel and outfit facilities remained separated. Automated assembly of steel increased and multiple process lines combined under a single roof creating e factory style environment. Blocks became much larger and the level of pre-launch outfitting was maximized. The modularization of outfitting was used in all outfit intensive areas of the ship. Construction cycle times reduced, and a single high throughput construction point was normal (Aalto, 2017).

On the other hand, it was identified and analyzed as well, that the critical tasks which influenced shipbuilding projects in terms of outfitting were:

- the availability of outfitting production information.
- the outfitting procurement for block-outfitting activities.
- hull erection.

5.2. Analysis and assessment of current advanced outfitting level in a mid-tier-shipyard.

Through the analysis of different documents, as shipbuilding strategy, project master schedule, project reports, and others related to construction cycle, it is possible to get the approximated data to assess the level of advanced outfitting in any mi-tier shipyard.

Two approaches can be considered, one having as a reference some groups according to the ship work breakdown structures used for US Navy (Table 2), and other one related to typical outfitting groups in ship production. The following tables show the information that can be obtained through interviews and surveys developed by project managers, engineers, fitters, outfitting workers, and all people involved in outfitting activities in any shipyard.

Table 2. Table for evaluation of advanced outfitting level in a mid-tier shipyard, with reference on SWBS.

SURVEY ABOUT ADVANCED OUTFITTING LEVELS IN A MID-TIER SHIPYARDCASE	
Present level of advanced outfitting: percentage of advanced outfitting (on-block and on-unit) in relation with all planned outfitting activities	
WORK BREAKDOWN STRUCTURE	**%**
Sea water system	0-100%
Fresh water system	0-100%
Fuel oil system	0-100%
Lubrication system	0-100%
Ballast system	0-100%
Bilge system	0-100%
Firefighting system	0-100%
Sanitary system	0-100%
Hydraulic system	0-100%
Exhaust system	0-100%
Propulsion system (including engines)	0-100%
Steering gear system	0-100%
Gen-sets	0-100%
Ventilation (ducts and blowers)	0-100%
Air-condition (ducts and equipment)	0-100%
Cable trays	0-100%
Cables	0-100%
Electrics distribution panels	0-100%
Electronics (navigation and communication)	0-100%
Foundations	0-100%
Furniture	0-100%
Accommodation	0-100%
Combat and weapons system	0-100%

6. RESULTS OF RESEARCH: ASPECTS RELATED TO THE IMPLEMENTATION OF ADVANCED OUTFITTING IN A MID-TIER SHIPYARD

All aspects that were established as the main route to implement advanced outfitting concept in a mid-tier shipyard are described and explained. All of them are the result of this research and propose a detail guide to assess and implement advanced outfitting techniques.

As it was explained in previous chapters, the shipbuilding process includes different activities that could be gathered in two major groups, structural construction and outfitting installation. At the same time, outfitting implies a range of different kind of equipment according to engineering systems that were included during design stage and that allow the ship operates and achieves the mission for which it was created.

It was concluded that most of time outfitting activities (Figure 16) can be classified in the following groups:

- **electrical power distribution**: installation of main and auxiliary power switchboards, cable lines, trays for cables, transforms, frequency converters, battery cabinets, etc.
- **HVAC system**: installation of chilled water plants or main HVAC packages, air handling units, fan coil units, ducting, thermal isolation and HVAC auxiliary equipment as recirculating pumps, and fans for extraction and ventilation.
- **piping**: installation of pipes, valves and hangers for all fluid systems including fuel oil, lubricant, sea water, fresh water, sewage treatment, oil waste water, air, fuel for helicopters, etc.
- **auxiliary** machinery: installation of pumps, electrical motors, steering gear sets, desalinization plants, sewage treatment plant, refrigeration plants, fuel oil purifiers, etc.
- **main machinery**: propulsion sets, electrical generator sets, bow and aft thruster sets.
- **structural components**: installation of foundations for equipment or units of equipment, doors (watertight or not), ladders, handrails, covers for openings on decks, hatches, covers for manholes, windows or portholes.
- **deck outfitting**: cranes, winches, anchors, chains, working boats, etc.
- **surveillance, weapons and communication systems**.

- **habitability and working spaces**: installation of equipment and components for galleys, pantries and mess rooms, equipment and components for cabins and offices, equipment and components for bathrooms installed, equipment and components for wheelhouse and war-room.

A complementary activity is related to painting, that include the treatment of surfaces and application of paint on structural components as foundations for main and auxiliary equipment, ladders, mast, rail hands, cable trays, etc. For example, it is usually necessary to paint foundations before installing equipment, to paint cable trays before cable installation, to paint duct hangers before installing ducting, etc. Also, it is possible to paint some compartments or areas that have been outfitted in advance during on-block stages.

Figure 16. Outfitting groups.

On the other hand, for Navy projects and high technology ships, some components are not considered as a part of advanced outfitting due the sensitivity and care that must be taken during their installation. Surveillance and command control systems, weapons systems, and navigation and communication systems, are sensitive equipment that require special attention and most of the times they are installed after the hull and superstructure of ship have been completed. It doesn't mean that the project group does not have the opportunity of analyzing and deciding the possibility of installing some mechanical components (part of surveillance and command control systems, weapons systems and other systems previously mentioned) as advanced outfitting. In any case, the project group must study each case carefully.

For example, it would be possible the installation of mechanical gear for guns, cannons, missiles systems, etc., as advanced outfitting activities. Also, it could be possible to install sensitive equipment during on-block or on-unit stages having in account the following considerations:

- sensibility of equipment or components to high temperatures, humidity, dust and shock movements.
- possibility to install in advance some structural and mechanical components.
- possibility to install in advance foundations, cabinets or racks for automatic, monitoring and operational control.
- possibility to install electrical controls (cables and supply power devices).
- installation of equipment that would be more difficult to install after the hull has been assembled (sonar arrays, ammunition cargo racks and transport equipment, etc.).

In contrast, at the time to compare military shipbuilding projects with civilian, resulted that the quantity of outfitting is higher in military projects because the mandatory requirement of having redundant equipment. It means to have the back-up for each main system. For example, if the main fire-fighting system is operated with two electrical pumps located in one engine room, it should exist other two pumps placed in a different compartment with the purpose to be operated in case of main firefighting pumps cannot be operated because of any damage to them, explosion inside the compartment, fail in the supply electrical system etc. The idea is that the ship in any time, situation or sailing condition can operate its main engineering systems. Likewise, Navy ships are operated for a bigger quantity of people compare with civilian ships. The crew of Navy ship tend to be three to five times the crew on board a civilian ship of the same dimensions. For this reason, Navy ships usually have more accommodation areas, bigger galleys, more bathrooms, food store compartments, etc.

The difference in quantity of outfitting, its distribution and location along the ship, makes Navy projects more complex in terms of outfitting activities during shipbuilding periods. Most of the time the concentration of outfitting is higher in some areas in civilian ships, but in Navy ships, the quantity of outfitting is well distributed and dispersed along the whole structure.

To make possible the implementation of Advanced Outfitting method in a good level, any mid-tier shipyard should think about improving its facilities, production practices and methods currently used in shipbuilding projects, and make stronger the correlation and cooperation between the design, logistic and shipbuilding departments, allowing purchasing, acquisition, design, engineering, project management and planning process (Figure 17), to be integrated to maximize the using of economic resources, shipyard facilities and construction time.

Figure 17. High level of integration required for advanced outfitting concept.

In the following chapters are presented the general results of this research which were distributed in different groups, following the strategic areas of shipbuilding projects: design and engineering, management, production and logistic.

6.1. Aspects related to layout optimization.

The main objective would be to adjust lift capacity, hull's block management process (capacity to put upside down and right side the block or semi-block), storage (stand-by place), outfitting installation areas, and production information process, to fulfil the requirements for implementing advanced outfitting strategy. At the same time, as restriction for multi-purpose shipyards, it is necessary to continue offering maintenance, repairing and construction services for military and commercial sector.

It was explained that "Advanced Outfitting" strategy implies to carry out outfitting activities during earlier stages in the ship construction cycle (on-unit, on-block, or on-grand block stages). For this reason, most advanced outfitting activities require to be accomplished in enclosed or protected production facilities to have a good environment or atmosphere that allows to minimize the risk to affect the component or device during its installation. However, other advanced outfitting tasks can be performed outdoors (Figure 18), but of course, it will depend on the assessment and analysis performed by production department.

Figure 18. On-block advanced outfitting. Installation of a gen-set. (source: fieldwork during internship at CRIST shipyard)

Following are presented some aspects established during this research, and that could be considered to optimize current layout:

- **Warehouses**: space for storing equipment and their components. It is necessary that these areas are placed in a correct or proper position related to shipbuilding work flow to have a good access during installation processes. The storage capacity should be able to manage either big quantities of small parts (pumps, electrical motors, electrical components, furniture, etc.) or large and heavy items (engines, gen-sets, propellers, reduction gears, etc.). For example, in CRIST Shipyard, warehouses are organized in such way that each project has its own storage sector or area for outfitting, avoiding confusions, mess and waste of time when project managers and technical teams develop checking and collecting tasks.

- **Workshops**: area for assembling and construction of components. In this case, the idea to implement advanced outfitting comes with the concept of unitization. Through unitization, some components (outfitting) are installed in common support or foundation, typically know as on-unit outfitting, and later are installed on-block as only one component. For this reason, workshops should be improved in terms of lift capacity, handling materials equipment, space, tools for fitting and installation activities, etc., to facilitate the construction and assembly of outfitting units.

- **Outfitting assembly areas**: it is necessary to have more and better environment for outfitting installation activities on sub-block, block or grand block. The main idea is to guarantee the protection of components from bad weather or extreme conditions. It should exist sufficiently space to carry out the outfitting activities in parallel with the construction of ship structure. Accomplish advanced outfitting tasks in good production facilities permits the equipment and its components to be installed in the best way, with better results and less re-work tasks. At the same time provides better working conditions to outfitting fitters, for example comparing the case of installing some equipment in a confined space after the hull is completed versus do it on-block stage with better and easier access to that compartment. This relocation of outfitting activities implies the reduction of work on board the ship and make the areas cleaner after this. For example, CRIST shipyard sometimes uses temporal (portable) covers to protect blocks in outdoors areas and be easier the installation of outfitting and other structural activities.

- **Lifting capacity**: the weight of non-outfitted block compare with outfitted block is higher due the equipment installed in advance, so capacity of cranes to lift semi-block, blocks or grand blocks into the hull assembly area or hull erection zone, should be according to the weight of outfitted block. Likewise, it is necessary to calculate the lift capacity to put from upside down to right side and vice versa, the block or semi-block previously outfitted, and the same time the dimensions or size of each block.

  One complementary strategy to fulfil the lifting capacity limits in case that the shipyard cannot improved the current one, is to modify the block division from the design point of view, in order to make the outfitted blocks be lifted with the current capacities. However, this task could take more time and make more complex the production cycle. Thus, it would be necessary to adjust all production information from the design office.

6.2. Design and Engineering aspects related to advanced outfitting.

Shipbuilding (production area) and ship design departments are strongly linked, and design department mainly works for shipbuilding department. Consequently, designers must consider production technics, shipyard limitations and capacities, and shipbuilding strategies before producing information for construction. The design department should be trained and oriented to understand the implications of advanced outfitting over production activities, taking them into account during the complete design cycle.

Following the methodology of zone outfitting method "ZOFM" (Richard Lee Storch, 1995), the objective will be to break down outfitting tasks into packages, trying to maximize the labor on-unit and on-block zones. For this reason, at the time to think about advanced outfitting, the design department should contemplate all engineering systems contained in each block or zone. Figure 20 show a good example of high level of advanced outfitting where different components and equipment related to different outfitting groups, have been installed on-block stage. This block corresponds to "USS Chafee" DDG 90, Arleigh Burke-class guided missile destroyer (Figure 19), United States Navy unit commissioned in 2003. It is possible to observe pipelines, valves, cable trays, auxiliary and main machinery, electrical panels, etc., installing in the same block, previously to the hull erection.

Figure 19. "USS Chafee" DDG 90, Arleigh Burke-class guided missile destroyer. (source: http://www.cpf.navy.mil/news.aspx/010442)

Advanced outfitting concept requires higher level of technical and design information flow. The main objective in this area would be guarantee the delivery of data, drawings, material lists and all information related to outfitting as soon as possible, in order to allow planning, production and management departments, organize all the activities associated to that, including outfitting procurement, assembling and installation, all of them in parallel with the hull structure construction, focusing on all the work activities (structure and outfitting) of some particular block at a particular time according to the block construction and sequence established. Design department should have in consideration that delays in delivery of production information will affect production plans and management process.

Figure 20. Main Engine Room #2 of DDG 90. This unit contains the complete main machinery (two LM2500 gas turbines and their reduction gear) and generator #2. Total weight approximately 480 tons. (source: https://www.hazegray.org)

Block outfitting construction drawings must be more specific and accurate related to materials, dimensions, location and sequence for installing equipment. Mistakes and wrong data can cause difficult changes, re-works, re-designs, and more labor work, even much more when these mistakes are visible after the hull was completely assembled. In this way the design department, from the conceptual design until contract design stage, must has into account the advanced outfitting concept in all design process. The main information for each block should detail foundations, pipelines, structural outfit, HVAC ducts, cable trays, cable lines and panels, insulation, main and auxiliary machinery. Most of them with the help of isometric drawings and 3D tools (Figure 21) that allow a spatial location for fitters.

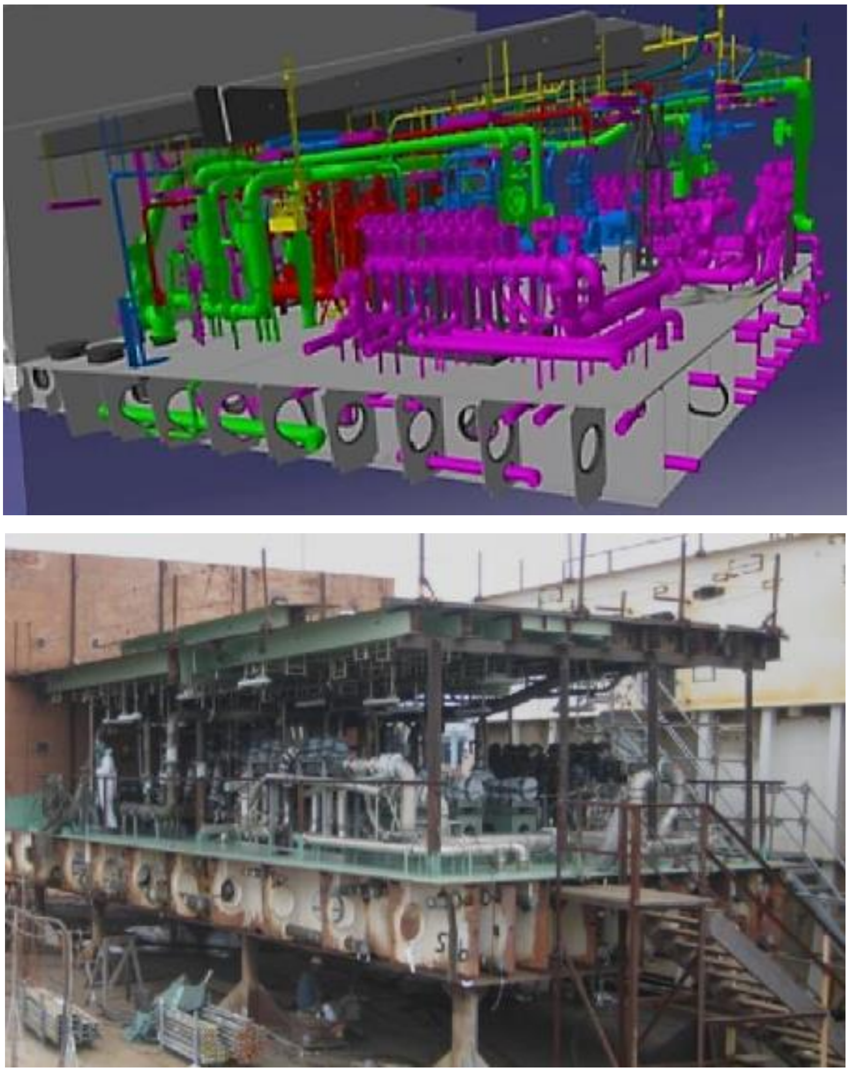

Figure 21. 3D model vs physical product. (Source: Huntington Ingalls Industries)

Some instructions related to advance outfitting that must be indicated and oriented by the design department are:

- Detailed drawings and part lists to manufacture outfitting units in workshops.
- Construction, location and installation drawings of foundations and structural reinforcements for outfitting on assembly unit or on-block.
- Penetrations for pipelines, cables and HAVC ducts.
- Data as weight, dimensions and 2D or isometric drawings of outfitting (including outfitting units manufactured in workshops or pre-fabricated units contracted by outsourcing) to be installed in advance. Placement drawings for outfitting installation must be ready and available at the same with hull structural drawings.

- Information about when and where (in which stage and zone) outfitting could be installed in advance.
- Sequences for installing equipment on assembly part or on-block, in such way that access and work location be comfortable for insertion and installation processes, including instructions for installation when assemblies, sub-blocks or blocks are upside down and then right side. Also, it is important to have in consideration some features of each outfitting component, particularly its spatial location, connections (penetrations and links with another equipment or system), kind of material, weight, dimensions, geometry, distance with reference to other components, and position.
- Revolution direction for main machinery (engines, gen-sets, gear boxes, thrusters, electric motors, etc.) and flow direction for ducting and pipelines.
- Instructions for transporting outfitted blocks or assemblies (hook or loading points), including calculation of center of gravity.
- Establish a coherent block construction sequence according with advanced outfitting activities scope.

A good example about advanced outfitting concept during stage design is the general arrangement or layout for machinery rooms. Nowadays it is more and more used equipment as package units (machinery or piping) or pre-fabricated modules, and for machinery rooms construction, advanced outfitting demands for designers the decision to use them or not. Of course, the use of certain unit or machinery unit or packages should come after thinking about the access and space for fitters and installing tools, and the required conditions by crew for operation and maintenance activities in these compartments.

For example, the last version of MEKO warships produced by German company Blohm + Voss, were built with high quantity of machinery units (modules), not only for engineering systems on board the ship, if not for operational or missional systems designed as portable and interchangeable modules (Figure 22 and Figure 23).

Figure 22. Blohm+Voss MEKO® A-200 Class Frigate. (source: www.thyssenkrupp-marinesystems.com)

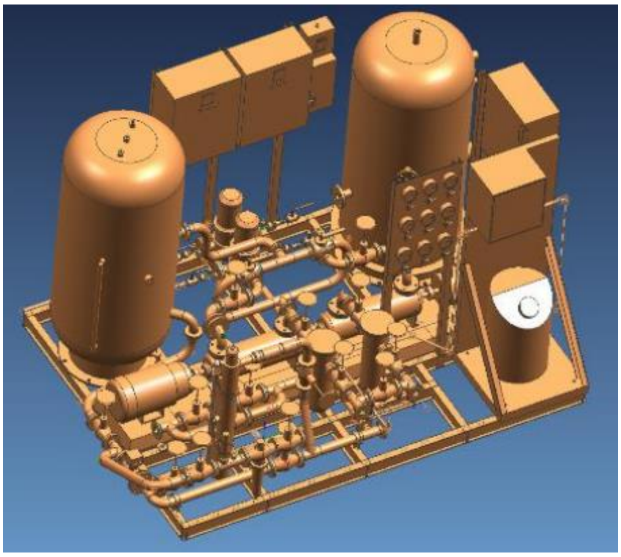

Figure 23. Fresh water unit installed on MEKO Flex warships (TMS, 2014).

Sometimes it is possible to install equipment or components on the assembly unit, of course, depending on the structural space, quantity of systems converging on the same space, geometry of installation area, and kind of equipment to be installed. After assemblies have totally been built from the structural point of view, these one can be turned right side to start the installation of the outfitting. For example, if the assemblies are sufficiently large (Figure 24), especially if these ones correspond to zones such as machinery spaces or pump rooms, can be easily turned to perform outfit installation, particularly those containing machinery or components on flats surfaces where pipework and other components can be fitted on the underside of the surface in the upside-down position and then turned it to right side position to install equipment above the surface. These outfitted assembly units can then be assembled into a block and additional outfitting can be installed as well. (Eyres, 2012).

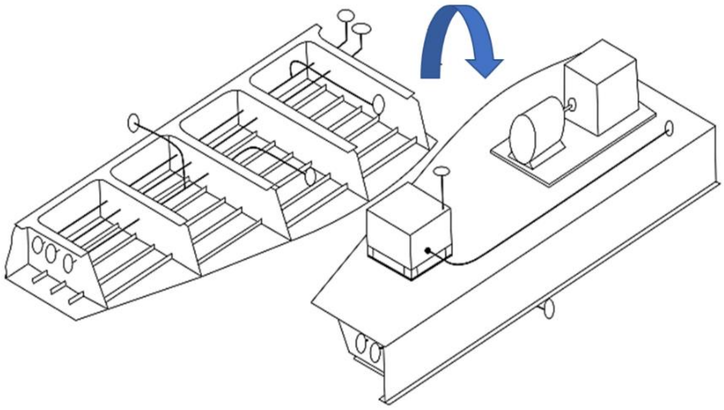

Figure 24. Assembly unit outfitted on both sides (Eyres, 2012).

For the same case, design and shipbuilding department should work together for foundation design and construction orders. Occasionally, moving or repositioning a component on an outfitting unit, can make easier the installation of all the equipment in a common foundation and simplify its assembly. Likewise, sometimes it is difficult or impossible for crew to have access to certain components in a machinery unit because their position.

6.2.1. Machinery and piping modules.

Design and build units or modules, allow to carry out outfitting assembly tasks in workshop instead of on-board, generating more benefits in terms of efficiency, working conditions, quality and costs. Typically, these units or modules are built in a workshop (by the shipyard or outsourcing company) and later they are installed on-block or on-board. In general, if the design department in a mid-tier shipyard wants implement machinery or piping units in future shipbuilding projects, complementary to the previous explanations, should have in account the follow design aspects and considerations:

- Grouping of equipment according to main system and complementary sub-systems. For example, to build in a common foundation as be possible, components related to fuel oil transfer system (valves, pumps, re-circulating pumps, filters, oil-purifiers, etc.), considering the better sequence for operators and people who do the maintenance.
- Arrangement of equipment installed in common foundation in such way that installation and connection with the main systems on board can be possible and easier.

- Arrangement of equipment installed in common foundation in such way that the extraction, change of parts and components, diagnostic and maintenance can be possible and easier.
- Design that can be homologated with next shipbuilding projects. For example, some outfitting units designed for next a determined series of ships can be used later in other projects. The important point is the arrangement because the size and capacity of the equipment can be modified according to the requirements.
- Vibrations aspects must be checked avoiding resonance and malfunctions when the components are working together.
- Points for lifting, transporting and installation. It must be considered the gravity center of the total unit.

Pipelines can be grouped in modules for specific systems where usually is possible to converge valves, filters, by-passes and other components which functionality is complementary each other, at the same place. For example, manifolds for ballast or fuel oil transfer systems (Figure 25), or pipelines converging to sewage treatment plants, are possible component to modularize.

Figure 25. Manifold designed in a common foundation. (source: http://jordan-engineering.co.uk/api-products/choke-manifolds/)

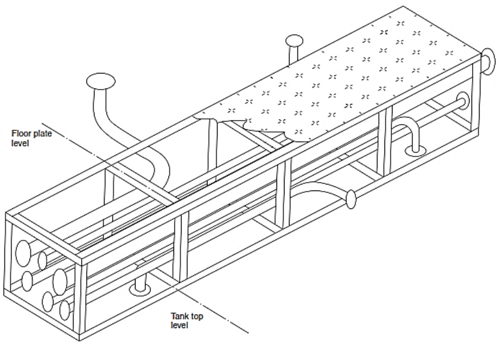

Figure 26. Piping module (Eyres, 2012).

Piping modules can variety from a small pipe group supported by light framing of pipe hangers (Figure 26), to a large modular piping unit, which have even been test run previously to their installation on-block or on-board, and then are place together with several similar units, creating the majority of a complete engine room (Eyres, 2012).

Following are presented some example about machinery units (modules).

Figure 27. Machinery unit. Separator systems for fuel oil and lubricating oil combined in a single foundation. (source: http://www.alfalaval.com/products/separation/centrifugal-separators/separators/s-and-p-flex/)

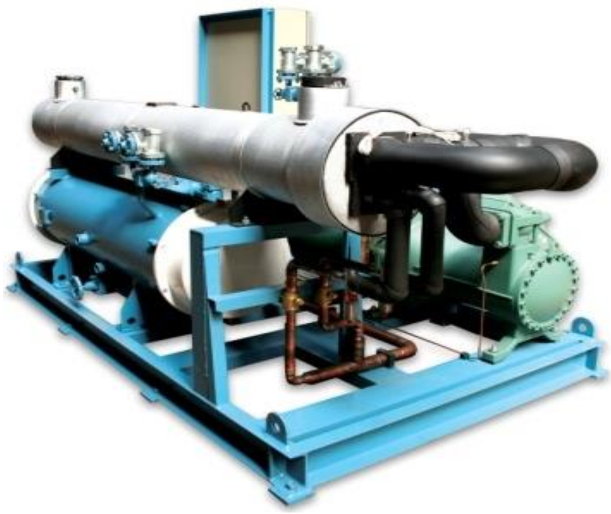

Figure 28. Machinery unit. Chilled water plant unit on a single foundation. (source: http://www.ship-technology.com/contractors/hvac)

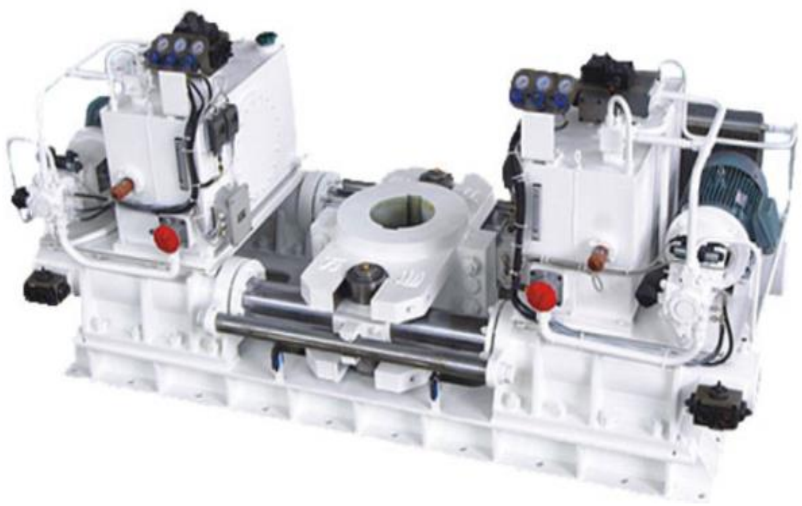

Figure 29. Machinery unit. Steering gear unit on a single foundation. (source: http://www.bmmgp.com)

Engine room and machinery space components are more feasible of unitizing to create units or machinery packages because these kinds of rooms generally are larger zones on-board and almost all the systems are connected each other, for example, fuel oil purifiers, fuel oil pumps for transferring and loading, fuel oil pre-filters sets, fuel oil pre-heaters, are components related to fuel oil system for engines; another example could be the pneumatic starter system for engines or well-known as compressed air engine starting system, these systems usually contains compressors, air accumulator bottles, pneumatic control bottles, air control valves, etc., all these equipment can be designed as a modules or machinery unit to be easy their installation and maintenance, instead of installing them separately.

In Figure 30, Wartsila, Finnish company specialized in marine mechanical equipment for ships, has designed auxiliary systems modules for diesel engines and generator sets, where components of fuel oil booster system, lubricating oil separating, cooling water preheating, starting air compressors, etc., can be delivered to the shipyard, in a common foundation, with the possibility to adjust them in size and capacity, according to the requirement of each ship.

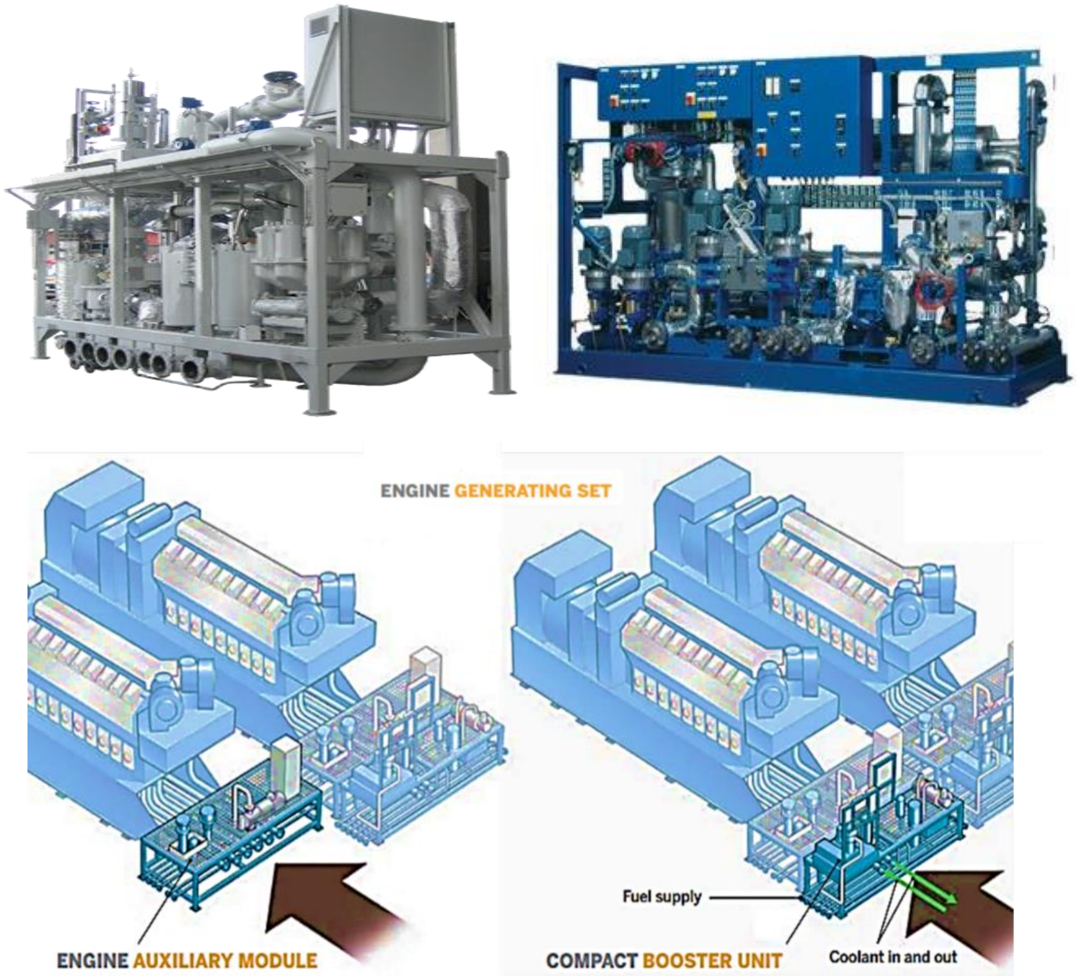

Figure 30. Engine Auxiliary Module (up-left). Compact Booster Unit (up-right). General illustration about modules in engine room (down). (Source: https://www.wartsila.com/products/marine-oil-gas/engines-generating-sets/wartsila-engines-auxiliary-systems)

The diesel engine or gen-set is connected to an Engine Auxiliary Module that supplies lubricant oil, compressed air, pre-heats the water before start-up and controls cooling water temperature when the engine is running. The Compact Booster Unit distributes fuel, pressure, flow rate, cleans the fuel and collects both clean and dirty leak fuel.

6.2.2. Pre-fabricated modules.

Another important aspect to implement advanced outfitting concept is the use of pre-fabricated equipment as a unit. This methodology has been used in many shipyards, and with more use in cruise shipbuilding projects where bathrooms, cabins and offices are installed as pre-fabricated units. For example, in CRIST shipyard (Gdynia, Poland), the use of modules as toilet units is frequently applied in shipbuilding projects because save time, increase the quality of accommodation areas, and simplify the construction process.

Figure 31. Pre-fabricated Wet unit-toilet. (source: http://www.norac.no)

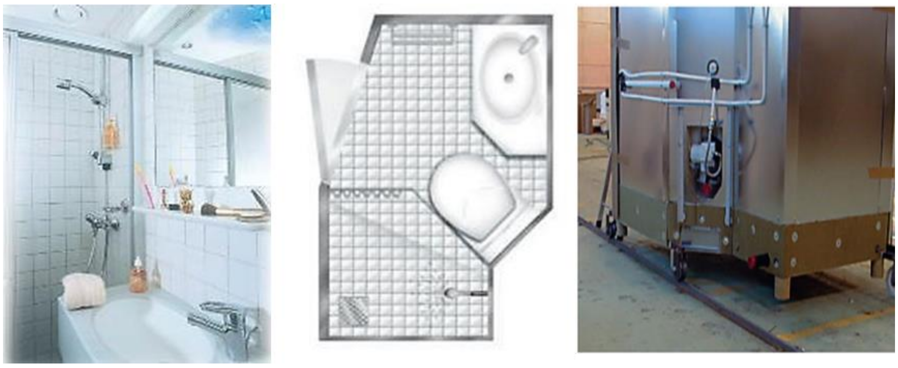

Figure 32. Figure 33. Pre-fabricated Wet unit-toilet. (source: http://www.norac.no)

Figure 33. Toilets units introduced in a block before hull assembly (Source: CRIST shipyard)

Typically, wet units are built to be easier their installation on-block and simplify the connection to water, drain and electrical system.

Figure 34. Toilet unit installation configuration (source: http://www.hiseamarine.com)

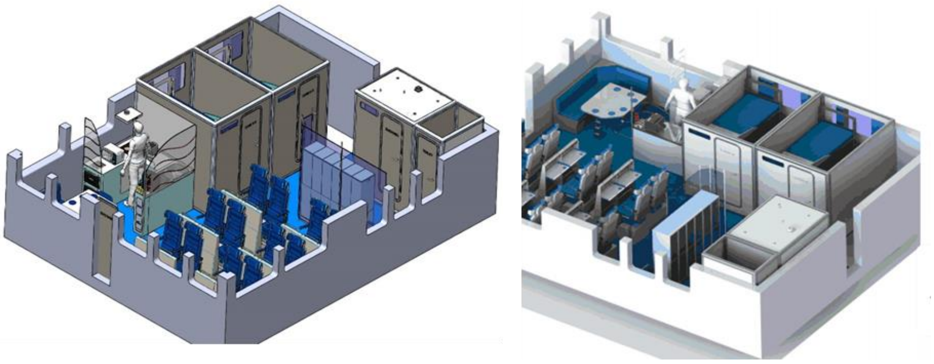

Figure 35. Render toilets units and cabin units installed on board a passenger ship. (source: http://kpm-marine.com)

Different advantages are linked with the use of pre-fabricated units. Fitters or people charge to install this equipment generate less rubbish material making cleaner this areas for delivery and inspection processes. Reduce time because it is avoiding the transportation of many materials and tools for building the same compartment (for example a bathroom) during on-boars stages. Also, these units are built to fulfill safety standards and military criteria, specifically related to fire protection, noise level, vibrations and comfort.

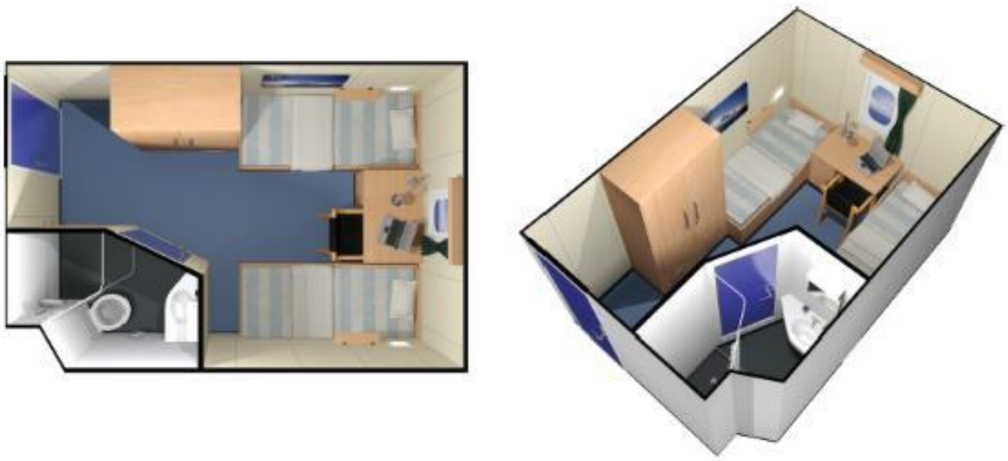

Figure 36. Pre-fabricated cabin unit for ships. (source: http://daejinsat.com)

Figure 37. Installation of pre-fabricated cabin unit. (Source: http://img.nauticexpo.com)

Another example about pre-fabricated units that could be implemented is modularized cabins. Nowadays, most of the shipyards involve in cruise ships building projects and even in military projects, are using these modules to save money and time. Some companies have developed products as pre-fabricated unit galleys, pre-fabricated provision store room and refrigerated food store rooms, being installed on board military ships (Figure 38).

Figure 38. Pre-fabricated galley unit for military ships. (source: http://www.tridentllc.com/military-testing.html)

6.3. Project management aspects.

Shipbuilding department and its project management group must to face the challenge to integrate hull construction and outfitting activities to implement advanced outfitting. The main goal will be to plan and organize all outfitting activities for different stages, mainly trying to maximize on-block and on-unit tasks, and likewise, following the outfitting zones and outfitting sequences established by design department.

The project team must plan a good shipbuilding master schedule for any project, following the basics of concurrent engineering. According with the "Cambridge dictionary", the definition of "concurrent engineering" is: *a method used in the development of a new product in which the different departments that are involved in the design, manufacturing, and selling of the product work together from the beginning of the project*.

Another definition comes from "Collins dictionary": *method of designing and marketing new products in which development stages are run in parallel rather than in series, to reduce lead times and costs.* It is with reference to this method that shipbuilding department, through project management team, should plan to develop advanced outfitting activities in parallel or simultaneously with the structural construction, it means that shipbuilding schedule should stablish the processes to manufacture parts and subassemblies to build blocks, at the same time with construction and installation of outfitting units and procurement of other equipment and components, getting a coordinated outfitting system.

A general approach about basic shipbuilding strategy focused on advanced outfitting concept that could be implemented in a mid-tier shipyard, is presented in Figure 39. The boxes in white color represent the basic physical areas in an average mid-tier shipyard., yellow boxes indicate the production processes, and finally, the production flow is divided in advanced outfitting (on-unit and on-block) and on-board outfitting. This diagram explains how structural and outfitting activities could be overlapped in a planning scenario to implement advanced outfitting.

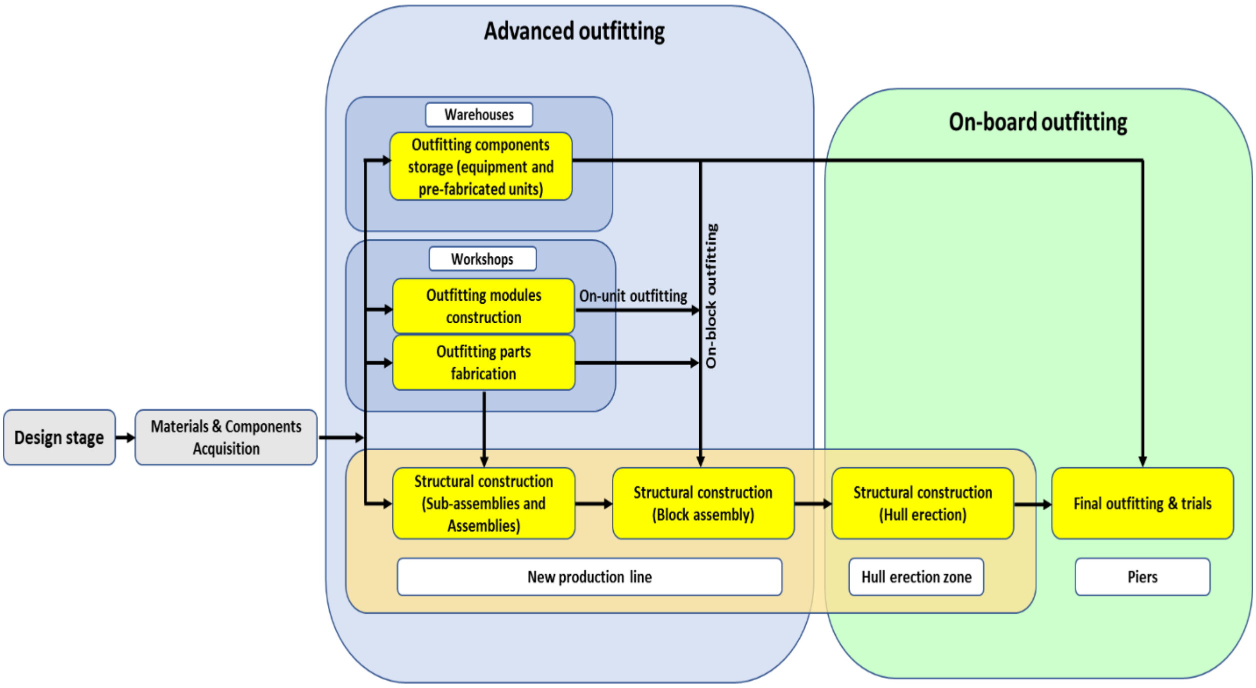

Figure 39. Proposed shipbuilding strategy for a mid-tier shipyard, focused on advanced outfitting.

In terms of time and schedule, the outfitting plan can be grouped according to outfitting groups that were discussed in chapter 6. A basic example of advanced outfitting planning and consequent schedule is proposed in Figure 40 and Figure 41. Note that many activities related to outfitting including delivery of drawing, prefabrication and installation, are overlapped between then, as well as with structural construction activities. Two hull structural blocks are exposed as an example on outfitting schedule, both correspond to the same outfitting zone in a hypothetic shipbuilding project, because the main idea is to follow the methodology of Zone Outfitting Method (ZOFM) described in Chapter 3.3. Typically, it is possible to derivate an outfitting detailed schedule from Project Master Schedule, in the same way as for hull structure schedule, dividing it in three sections: on-unit, on-block and on-board outfitting, including milestones, workload and assigned resources for each task.

Particularly, when advanced outfitting activities are carried out in typical congested areas as engine rooms, auxiliary machinery rooms, confined spaces, etc., where match many different systems, this integration of production activities must be more accurate in terms of planning and organization. It must be avoided any kind of interference between equipment installation and structure building tasks during on-block stages, or when outfitting units and pre-fabricated modules are going to be introduced and installed on any block. Also, interferences between shipyard and subcontractors (outsourcing companies) could generate problems, for example, many re-works, work accidents, damages in equipment or components, etc.

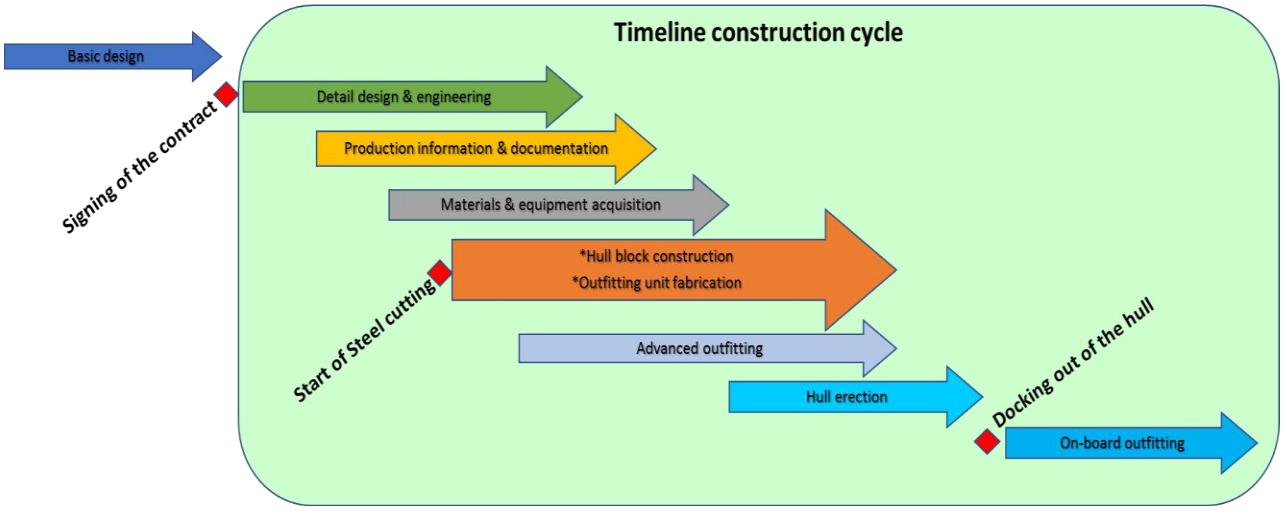

Figure 40. Proposed advanced outfitting planning.

Some of the main factors that project management department must consider at the time to implement advanced outfitting concept are:

- To plan and sequence outfitting activities with the information, orientation and support of design department who will deliver the production information.
- To integrate and control outfitting tasks and working sequences of outsourcing companies (subcontractors). This point is important because delays come from external entities as subcontractors, can affect other outfitting activities, even other production activities (structural & painting tasks). Project managers must to be aware subcontractors about following the project plan and how they should act in case of presenting special situations that can change the general schedule.
- To balance and reschedule outfitting activities according to ship structure construction progress, available labor force and construction equipment. Occasionally, it is possible to advance some activities because structural production activities have been developed earlier, or on the contrary, reschedule other ones because structural delays are presented.
- To check and verify all acquisition orders from financial and administrative department, considering delivery dates of equipment and materials, and specifications and technical characteristics according to requirements from design department. As the previous item, rescheduling activities it is necessary when delays in delivery have presented.

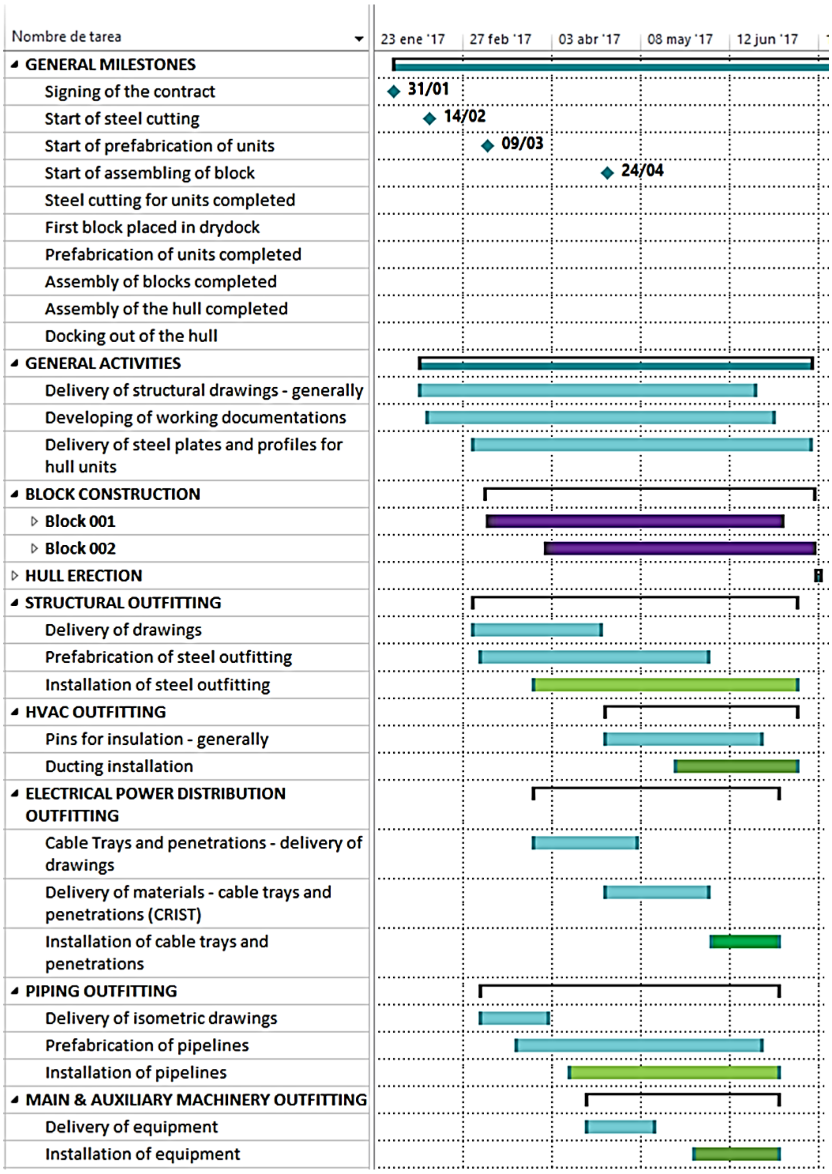

Figure 41. Sample of basic advanced outfitting schedule.

- To check delivery time and dates, and manage internal process for outfitting, including inspection and quality control tests, storage and logistics aspects.
- If it is possible, to plan tests of function and condition for equipment after they have been installed in advance.
- Cooperate to strength the relationship between design department and production areas.
- To integrate painting activities with installation activities. For example, for foundations, painting activities must be considered because these must be painted before corresponding equipment be installed on it. For compartments also, it is possible to perform anticipated painting activities, when most of hot outfitting tasks have been completed and remains

pending some cold outfitting as the installation of equipment, pre-fabricated units or machinery units.

In advanced outfitting planning, one of the most important milestones for outfitting are the delivery dates. Even are more important when it is about imported equipment and high technology systems that require special attention and checking processes, for example, engines, gen-sets, weapons and surveillance systems, reverse osmosis systems, fuel and lube oil purifiers, and other components that typically are not designed and build by the shipyard., and sometimes, they are designed and build under special owner's requirements. Likewise, delivery dates of materials and components to build machinery units in workshops, are tasks that must also be controlled. Bottlenecks that come from delays in delivery of materials, equipment and even production of machinery units, decrease production rate and increase production costs.

Another important point in terms of management is the labor force administration. The project management group should control the man-hours required for all process, even if advanced outfitting concept is going to be implement in any new project. The quantity of workers to develop outfitting activities must be into account during all the construction cycle time. For example, welders, mechanics, metal workers, insulation and piping installers, electricians and fitters, are the common jobs that will be increased during on-unit and on-block stages. The main goal is to calculate or estimate the man-hours required for any outfitting activity, as well as the quantity of workers according to their specialties.

A consideration obtained during this research is that regularly shipyards let start advanced outfitting activities when the structural block has been accomplished around 70 or 80 percent, allowing the rest of structural task be carried out simultaneously with outfitting activities. Obviously, this point is established according to experience, learned lessons of previous projects, and different assessments made by design department, shipbuilding departments, and project management group.

6.4. Ship production aspects.

Advanced outfitting requires the maximization of working activities during earlier stage of construction (on-unit and on-block), this approach will increase the efficiency of building cycle allow to carry out the assembly of outfitting on-block or on-assembly unit with better labor conditions for workers, supervisor, inspectors and engineers. Outfitting units or modules will be fabricated in workshops where the environment (lighting, space, air, noise, etc.), access to tools, machinery, CAD systems, etc., permit a better developing of activities.

From the production point of view, during this research there have been identified some aspects that a mid-tier shipyard would have to control to have a successful implementation of advanced outfitting concept.

- Outfitting on structural sub-assembly parts or units, usually includes foundations and structural outfitting.

- Outfitting on structural assembly parts, as it was explained in Figure 24, when it is upside down, it is possible to install pipes, cable trays, ducting for HVAC system and lighting system. When the assembly is turned to right-side, it is possible additionally to install some lightweight equipment (small auxiliary equipment as electric motors, pumps, manifolds, etc.), overall on flat panels. Typical sequences related to position and turnover to right-side are: on-ceiling fitting, on-ceiling welding, on-floor fitting and on-floor welding (Richard Lee Storch, 1995).

  Upside down position allows welders and fitters to perform installation activities more comfortable and faster. Likewise, the quality and accuracy increase because the working space, mobility and access to structural elements are better compare with on-board outfitting. For example, overhead welding tasks are substituted by down-hand welding tasks, because the down-hand implies a better welding speed and quality. In general, the productivity growths when is possible to install component in upside down position.

Figure 42. Outfitting on structural assembly unit (upside-down). Includes pipelines, ducts for HVAC system, cable trays. (source: http://dot.alaska.gov/amhs/alaska_class/)

- On-block outfitting includes the installation of pipes, ducting, cable trays, electrical equipment, auxiliary and main machinery, structural outfitting, insulation, etc. This stage covers all different components of outfitting groups.

Figure 43. Outfitting on-block assembly (right-side). Includes pipelines, main machinery protected with wooden boxes (gen-sets) and auxiliary machinery. (source: http://dot.alaska.gov/amhs/alaska_class/)

Figure 44. Outfitting on-block assembly (right-side block). Includes pipelines, cable trays, ducting for HVAC system. (source: http://www.worldmarine.com)

Figure 45. On-block outfitting. Insertion and installation of auxiliary machinery, in this case a dynamic pull system. (source: fieldwork during internship at CRIST shipyard)

- Outfitting units (modules or pre-fabricated units) are installed on-block or on-board. However, the advantages in term of labor force, quality and time, come when they are usually installed on-block stage.

- Protection of equipment or components installed in advanced, to prevent damages during and after installation activities. Some activities as welding and cutting that are performed on-block or on-board stages, can affect the physical and functional condition of any equipment without the required protection. The typical products used to protect equipment are canvas and galvanized, sheets that are adjusted to the external geometry of each equipment. Likewise, these products protect against dust, welding fumes, sparks come from grating and cutting activities, scratches from people working with tools or doing other mechanical activities, etc. (Figure 46 & Figure 47). Some shipyards use the same wooden boxes which manufacturing companies deliver the equipment, partially re-assembly them once the equipment is installed on-block (Figure 48).

Figure 46. Gen-sets installed on-block stage. (source: fieldwork during internship at CRIST shipyard).

Figure 47. Gen-sets installed on-block stage, and protected with canvas and galvanized sheets, during welding activities carried out at the same space. (source: fieldwork during internship at CRIST shipyard).

Figure 48. Main machinery protected with wooden boxes, during the installation of another structural assembly above (source: http://dot.alaska.gov/amhs/alaska_class/).

- Scaffoldings system for on-block outfitting activities must be check and improved to provide a safe and comfortable access to all block spaces, internal as well external, to workers and equipment lifting tasks. It must be into account the block geometry and dimensions, outfitting sequences, size of outfitting and quantity of fitting groups or persons working at the same time.

Figure 49. Fitters are introducing a dynamic pull component on-block. A good quality scaffolding system allows them to perform lifting maneuvers with safety and comfort. (source: fieldwork during internship at CRIST shipyard).

Figure 50. High quality and design scaffoldings allow carried outfitting activities safer and faster. (source: fieldwork during internship at CRIST shipyard)

- Improve training of fitting teams because advanced outfitting requires high level of skill in terms of outfitting installation on-block, even much more when many parallels activities are carried out in the same space (welding, cutting, insolation, piping, cable trays, ducting, etc.). Fitters should increase their ability to create or visualize a three-dimensional idea or concept taking as reference isometric drawings, and to avoid mistakes during installation processes that could generate additional work and possible delays in outfitting schedule. Likewise, if future shipbuilding projects will include pre-fabricated units as wet units or cabins, fitters, electricians, mechanics, engineers, designers and all people related to outfitting processes, must understand and become familiar with this equipment, its installation method, connections, operating and maintenance.

- Dimensional control (3D metrology) process must be improved to assure the correct position and alignment of equipment and its connections, following the defined designs produced by Design and Engineering Department. A correct checking and analysis of measurements and dimensional aspects in any compartment (CAD models and drawings versus actual measurements inside the compartment), not only allow to know the actual parameters and tolerances for joining hull block sections, if not to check the accuracy of reference and mounting processes for some outfitting during their installation on-block or on-board. Likewise, it is a helpful system to verify the fabrication and assembly of machinery and piping units in workshops. In general, a high level of dimensional control reduces the risk of re-building parts or components, doing re-works as repositioning of equipment or modification of foundations, and implementing changes in design drawings and shipbuilding schedule due delays, instead of that, this allows to increase the quality and engineering level as outfitting units are built in workshops, help the checking process of equipment fabricated for outsourcing companies, and assure a correct outfitting installation. Some of current dimensional control systems are: laser trackers (Figure 51), TST (total station theodolite), digital photogrammetry, etc.

Figure 51. Leica Geosystems High-Definition Surveying (HDS) laser system tracking ship engine room in construction.

- Testing of components and installed equipment keeping the methodology component-module-system. The great advantages of advanced outfitting are that machinery units and pre-fabricated units can be tested and checked in workshops, simplifying the process and taking more and better opportunities to correct and make changes before their installation on-block or on-board. Sometimes, equipment or systems that expose problems during tests on -board, require more time to be evaluated, find the failure, correct it and solve it.

- Tools that fitters usually use for outfitting installation activities has to be checked and improved, including portable welding and cutting machines, small metal-mechanical sets, handling and lifting equipment (block chains, slings, hooks, chain slings, shackles, beam and plate clamps, elephant hoists, lever hoists, lifting jacks), pneumatic and hydraulic tools, etc.

In general, all production aspects in advanced outfitting imply cost and time, that makes them very important in terms of scheduling, planning, and their integration with the complete building cycle.

6.5. Logistics and acquisition aspects.

Materials, components, equipment and everything related to outfitting in a shipbuilding project, must be available just on time, following the master schedule established by project management group, and previously agreed between all departments in any mid-tier shipyard, including the financial and administrative department which is charged of all acquisition processes. Thus, once the commercial contract has been accepted and signed between the client, and shipyard's design and engineering department has started the detailed design for a specific project, the acquisition processes must have carried out as soon the purchase lists (EBoM or engineering bill of materials) have been delivered.

Advanced outfitting concept requires a high level of purchase and acquisition system, which must be integrated to design, production and planning systems. The main goal is guarantee the correct development of master schedule and therefore of outfitting schedule. However, typically, problems that affect advanced outfitting activities are related to delivery of material and outfitting, and those must be estimated and controlled in the best way. Most of times, difficulties in acquisition processes come from lack of information in specifications displayed on material lists, no updated technical information, delays in contractual processes, delays due contractor's internal processes, national and foreign custom processing, and deficiency of supervision and control on purchase orders.

On the other hand, problems that can cause logistic problems most of times are related to incorrect checking processes after materials or equipment have been delivered. Sometimes, people charged to inspect equipment and materials according to specifications that come from design and engineering department, could skip some steps in this process, and finally is the fitter or installation group who will realize about the error. The final situation is that the component, material or equipment will have to be returned, and therefore, the acquisition process will take more time.

Generally, in terms of time, shipbuilding procurement processes and purchase orders should consider (Koenig, 1995):

- design and fabrication outfitting plan from supplier: including information about final design of equipment, module or component, technical data approval process, and other aspects related to the procurement progression.
- material and delivery time from subcontractors: including material and parts procurement, particularly for components or equipment that are part of the determined critical path.
- in factory: testing, quality control, customer visits, and preparation for shipment.
- shipping time.
- customs and nationalization processes.
- transporting time from port, company or warehouse, to shipyard.
- shipyard reception, inspection, and preparation processes.

The impact of acquisition processes directly affects the project schedule and the correct progress of shipbuilding cycle, for this reason a high-level of cooperation between financial and administrative department, design and shipbuilding departments should be improved, to solve and establish alternatives or action courses to allow the shipbuilding project progresses in the proper way.

For military projects, a critical point is specifications and standards that must be well interpreted and documented according the established requirements. Critical equipment as propulsion system, weapons & surveillance systems, need a high level of purchasing management, outsourcing management and special quality control system, to avoid delays or interferences that can affect the development of the project.

7. CONCLUSIONS

The results of the research illustrated in this document, present a general point of view about the implementation of advanced outfitting concept in any mid-tier shipyard. Also, main aspects related to advanced outfitting concept were established and described, and the following are the main conclusions:

- The optimization of design and production processes for inclusion of outfitting units (pre-fabricated or outfitting modules) will improve the productivity and will be the main support for a good implementation process in the achievement of a good level of advanced outfitting concept.

- Advanced outfitting will allow to perform outfitting tasks in production facilities (workshops and land level docks) where equipment and components of different systems can be positioned and installed better and easier, avoiding the difficulties for outfitting on-board where for military ships is usually more complicated to move, insert and install equipment in confined or space restricted spaces.

- The implementation of advanced outfitting concept will reduce the construction costs, in terms of labor force, and therefore in time, especially in some outfitting groups as main and auxiliary machinery, HVAC, electrical distribution, and accommodation and habitability.

- In case of on-unit outfitting, working conditions will improved because of better ventilation, lighting, access for tools and design information, and protection against severe climate conditions. Machinery or piping units will be built with a better quality and with better quality control processes.

- In case of on-block outfitting, working conditions will improved because fitters can do a better use of lifting equipment and scaffoldings, likewise, the access to confined spaces or some complicated areas as tanks or bottom compartments, will be easier and safer. The work environment will be better because welding and cutting complementary activities for outfitting will performed on-block where ventilation and lighting services are better.

Likewise, workers (fitters) will increase their productivity, reducing the working time spent on these tasks.

- Equipment and components installed on-unit or on-block, are less susceptible to damages during transportation, mobilization and installation processes than equipment installed on-board stages. Also, after being commissioned and operated, the maintenance, repairing and updating process for this equipment will be easier and more economic.

- A fourth-generation shipyard could be achieved: where the modularization of outfitting and the implementation of advanced outfitting methods are used along all ship. Also, blocks will become larger and the construction cycle times reduced.

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9. REFERENCES

(NSRP), N. S. (1980). *Japanese Technology that could Improve U.S. Shipbuilding Productivity.* Maryland, USA.: Administration, U.S. Department of Commerce.

Aalto, U. (2017, August 30). *Shipyard Engineering Lecture - Shipyard productivity.* Retrieved from https://mycourses.aalto.fi/mod/folder/view.php?id=44360

Chakraborty, S. (2017, May 21). *www.marineinsight.com*. Retrieved from http://www.marineinsight.com/naval-architecture/advanced-outfitting-in-shipbuilding/.

CRIST. (2017, June 11). *http://www.crist.com.pl*. Retrieved from http://www.crist.com.pl/about-us,2,en.html

Eyres, D. J. (2012). *Ship Construction.* Oxford, UK.: Elsevier.

FMI. (2007). *First Marine Internaitonal findings for the global shipbuiliding insdustry base becnhmarking study - part 2: Mid-tier shipyards.* London, United Kingdom: First Marine Internaitonsl Co.

FMI, F. M. (2016). *2014 US Naval Shipbuilding and Repair - Industry Benchmarking.* London, United Kingdom: First Marine Internaitonal Co.

G.N., R. (1972). *Group Technology: A foundation for Better Total Company Operation.* London, UK.: 1972.

John F. Schank, H. P. (2005). *Outsourcing and Outfitting Practices.* Santa Monica, California, U.S.A.: RAND Corporation.

Koenig, W. L. (1995). Standard Outfit Package Units in the LPD 17 Ship Design: A Production Impact Study . *Journal of Ship Production*, Vol. 11, No. 4, Nov. 1995, pp. 252-263 .

Lamb, T. (1986). *Engineering for Ship Production.* Michigan (USA): SNAME (Society of Naval and Marine Engineers).

Lamb, Thomas. (2004). *The Advanced Outfitting Dilemma.* University of Michigan.

NSRP, National Shipbuilding Research program U.S. (1979, December). Outfit Planning.

Rajko Rubeša, N. F. (2011). *Procedure for Estimating the Effectiveness of Ship Modular Outfitting.* Rijeka, Croatia.: University of Rijeka.

Richard Lee Storch, C. P. (1995). *Ship Production.* Centreville, Maryland, USA.: Cornell Maritime Press.

Schank, J. F. (2005). *Outsourcing and Outfitting Practices.* Santa Monica, California, U.S.A.: RAND Corporation.

TMS, T. M. (2014). *Addressing the Challenges of Modern Warship Design - Blohm+Voss MEKO FLEX.* Germany.

Wei, Y. (2012). *Automatic Generation of Assembly Sequence for the Planning of Outfitting Processes in Shipbuilding.* Delft, Netherlands.: VSSD-Delft University.

APPENDIX 1. Advanced outfitting photo gallery - CRIST shipyard projects.

Installation of Air Handling Units (AHU) on-block

(source: fieldwork during internship at CRIST shipyard)

Installation of dynamic pull components on-block

(source: fieldwork during internship at CRIST shipyard)

Installation of gen-sets on-block

(source: fieldwork during internship at CRIST shipyard)

Installation of cable trays, insulation pins, foundations, structural outfitting and painting activities on-block

(source: fieldwork during internship at CRIST shipyard)

Installation of pipelines and valves on-block

(source: fieldwork during internship at CRIST shipyard)

Installation of auxiliary machinery on-block

(source: fieldwork during internship at CRIST shipyard)

Installation of auxiliary machinery on-block

(source: fieldwork during internship at CRIST shipyard)