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Advanced Outfitting Techniques for Shipyard Development: A 2000 GT Shipbuilding Case Study

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Abstract

The shipbuilding sector is currently facing issues due to long manufacturing schedules and delays in ship construction completion. These challenges come from national shipyards' conventional onboard outfitting process for equipment installation, which takes a lengthy time to complete. To address this issue, this study proposes implementing the advanced outfitting system (AOS) approach, which combines the zone outfitting system with the hull block construction method, in building a 2000 GT ship at PT. X in Surabaya, Indonesia. Technical analysis is performed to plan the shipbuilding process using the hull block construction method, and the efficiency of man-hours is calculated by implementing the AOS approach. The study also conducts an analysis of shipbuilding costs and the required shipyard development investment. The technical analysis shows that the AOS approach improves efficiency factors by enhancing material handling and testing activities. The AOS method has an efficiency factor of 50% for on-unit outfitting and 62% for on-block outfitting, compared to on-board outfitting. The construction of a 2000 GT ship employing the AOS approach represents a reduction of approximately 9.6% in working days and a cost-saving of approximately 4.3% when compared to the onboard outfitting method, resulting in savings of IDR 1,933,277,000 or about USD 124,175. To implement the AOS approach, an investment of IDR 3,040,776,000 or about USD 195,310 is required for construction facilities and human resources development. The return on investment is obtained after two 2000 GT ships are completed. As a result, the AOS approach can improve shipbuilding productivity by reducing construction time and costs. This study provides insights into the benefits of implementing modern shipbuilding techniques in the industry.

1. Introduction

The shipbuilding sector is characterized by intense competition, necessitating shipyards to consistently enhance their operational efficiency and productivity in order to maintain a competitive edge [1]. The efficiency of shipbuilding is influenced by various factors, including building technique, resource ability, and management level [2]. Therefore, it is important to develop an efficiency evaluation model based on these driving factors to analyze and improve shipyard performance. In Indonesia, the shipbuilding industry currently faces challenges related to long production times and delays in completing ship construction. The construction of one ship can take up to 24 months, with delays often occurring during the process. These issues stem from the traditional onboard outfitting method used by national shipyards for equipment installation, which takes longer to complete than alternative methods.

One of the key areas of shipyard development is the implementation of advanced outfitting methods. The outfitting process in shipbuilding, especially for complex vessels, is characterized by disorganization and rework due to a lack of coordination [3]. By applying advanced outfitting methods, such as lean production principles and process-centric simulation modeling, shipyards can optimize the outfitting process, reduce waste, and improve overall productivity [4], [5].

Furthermore, the integration of digital technologies, such as radio-frequency identification (RFID) [6], indoor positioning systems (IPS) [7], wearable device for welder recognition [8] and QR-Code technology [9], [10] can enhance the efficiency and visibility of shipyard operations [11]. These technologies enable real-time monitoring of various parameters, such as CO concentration and location tracking, which can help in identifying and addressing bottlenecks and improving overall operational performance.

To address this challenge, there is a need for a new shipbuilding method that can reduce production time and costs. The advanced outfitting system, proposed by Rajko Rubesa [12], is an innovative approach that can significantly reduce the time and cost of outfitting installation. The simulation model of this method provides a comprehensive analysis of the decrease in direct outfitting working hours when using various block delivery methods in an assembly shipyard [2]. With this technique, shipbuilding can be completed faster, cheaper, and more competitively without requiring the purchase of additional buildings, equipment, or tools [12].

Some research about shipyard technological level of development has been published. Rubesa developed criteria for evaluating technological level of ship pre-outfitting [13]. The technological level of ship pre-outfitting can be evaluated based on various criteria, including equipment capabilities, automation level, integration of information systems, availability of advanced tools and software, and employee expertise. These criteria help assess the shipyard's ability to efficiently and effectively carry out pre-outfitting activities, ensuring quality and timely completion. Furthermore, Zhou et al developed Lean Production of Ship-Pipe Parts Based on Lot-Sizing Optimization and PFB Control Strategy [14]. Lean production techniques, including lot-sizing optimization and PFB (Production Flow Balance) control strategy, can significantly improve the production process of ship-pipe parts. By optimizing lot sizes, shipyards can minimize waste, reduce inventory, and improve overall production efficiency.

In measuring shipyard performance, Semini analyses the relationship between build strategy and shipbuilding time [15]. Factors such as modular construction [16], concurrent engineering, prefabrication, and the use of advanced production techniques impact the overall efficiency and productivity of the shipbuilding process. By adopting lean principles and optimizing the build strategy, shipyards can reduce construction time, minimize costs, and enhance overall performance. In addition, Baihaqi combines value engineering and risk assessment methodologies to measure shipyard performance [17]. Value engineering focuses on optimizing costs, quality, and functionality, while risk assessment helps identify and mitigate potential risks and uncertainties. The integration of these approaches provides a comprehensive evaluation of shipyard performance, enabling effective decision-making and continuous improvement.

The main objective of this research is to provide a technical and economic analysis of the implementation of the advanced outfitting system in shipbuilding. The analysis includes an assessment of the necessary shipyard preparations to apply this method, as well as the expected reduction in construction time and costs. The novelty of this research lies in the comprehensive analysis of shipyard development using advanced outfitting methods for the 2000 GT shipbuilding process. While previous studies have focused on specific aspects of shipyard development, such as efficiency evaluation [1], location selection [18], or energy management [19], this research aims to provide a holistic analysis by considering technical, economical, and operational aspects.

By conducting this analysis, the research aims to provide valuable insights and recommendations for shipyards to enhance their development strategies and improve their competitiveness in the shipbuilding industry. The findings of this research can contribute to the body of knowledge in shipyard development and serve as a reference for future studies in this field.

2. Research Methodology

2.1 Identification of Problems

In the initial stage of this study, a thorough identification of problems is carried out. This involves conducting a literature review and field studies to understand the current state of the shipbuilding industry in Indonesia. The objective is to identify the key challenges and issues that are hindering the development of the industry, and to seek solutions that can improve its overall efficiency. In addition to identifying problems, this study also involves an assessment and evaluation of the technical and economic aspects required for the development of the shipyard. This includes an evaluation of the current shipbuilding processes, as well as an analysis of the costs associated with each process. By conducting a comprehensive analysis of these factors, we can develop a better understanding of the technical and economic feasibility of implementing new shipbuilding methods and technologies. Overall, the identification of problems and the assessment of technical and economic aspects are critical steps in developing a more efficient and competitive shipbuilding industry in Indonesia. Through this study, we aim to provide insights and recommendations that can help the industry to overcome its current challenges and achieve sustainable growth in the long term.

2.2 Comprehensive Review of existing method and proposed method

A thorough literature study was conducted in this research, aimed at understanding the concepts and appropriate methods to solve the problems identified in the previous stage. The study covered a wide range of references related to the research topic, including previous research, theories, and practices related to ship construction, outfitting installation, and shipyard development. By conducting a comprehensive literature study, this research aimed to gain a deeper understanding of the current state of the shipbuilding industry and to identify best practices and innovative approaches that could improve its overall efficiency. The study also helped to identify gaps in the existing literature and to suggest areas for future research.

2.2.1 Shipbuilding with HBCM

Shipbuilding requires a long and time-consuming process. One of the shipbuilding methods is HBCM (Hull Block Construction Method) as shown in Figure 1. This method allows construction to be faster because ship construction can be carried out simultaneously by blocks. The following diagram is a development processes using the Hull Block Construction Method [20].

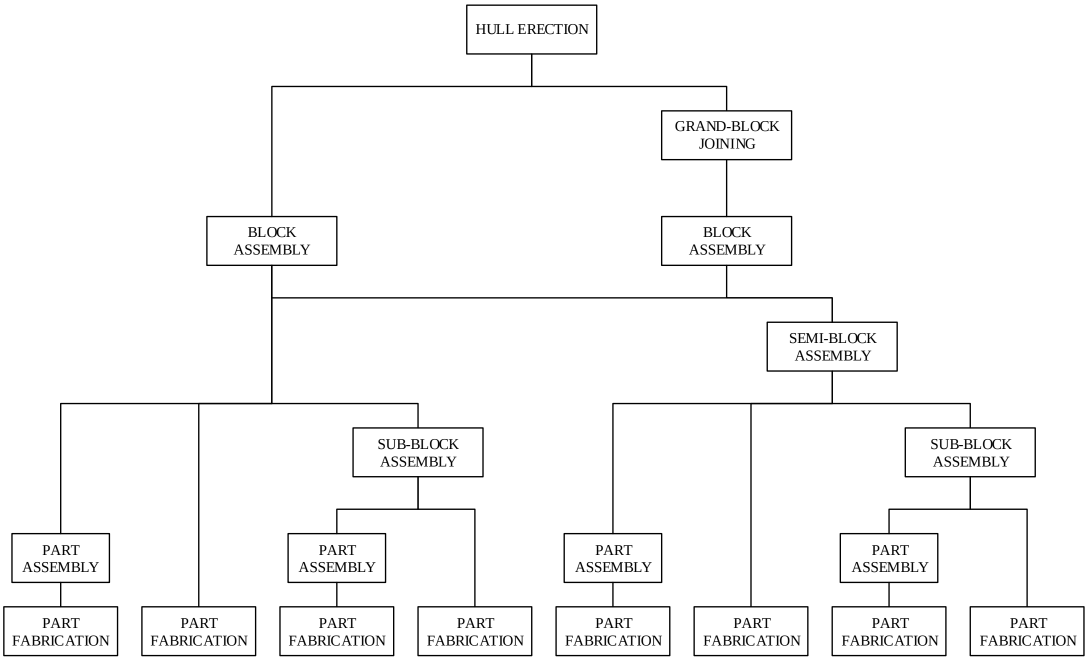


Figure 1. Workflow for HBCM in shipbuilding

2.2.2 Outfitting Installation Process

The outfitting installation method is divided into several categories based on the time of installation [3]. Another term for this installation process is the zone outfitting method. The following are several categories of ship outfitting installation [20], [21].

1. On-unit outfitting: the process of installing ship outfitting that was carried out in the equipment unit itself. Equipment and supplies are made into one outfit unit. The assembly process is carried out in the workshop.
2. On-block outfitting: the process of installing ship equipment that was carried out during the block assembly process. The form of ship equipment and supplies can be in the form of an outfitting unit or the smallest component of outfitting.
3. On-board outfitting: the process of installing ship equipment at the building berth when the erection process is carried out, or when the ship has just been launched. Ship equipment that is installed on-board is anything that cannot be installed on-unit and on-board.

2.2.3 Advanced Outfitting System

Advanced outfitting system (AOS) is a shipbuilding method by installing equipment as much as possible before the erection process is carried out [2]. AOS is a shipbuilding method that combines the hull block construction method and the zone outfitting method to build ships [12]. The outfitting installation process is prioritized in the following order: on unit outfitting, on block outfitting, and then on board outfitting [22]. The outfitting installation process in each Zone-Outfitting-Method (ZOFM) has its own efficiency factor. This efficiency factor is influenced by the ease of processing and faster material handling time as shown in

Figure 2. Some of the advantages of the AOS method are as follows:

- Fabrication and installation of outfitting at the beginning can reduce the workload of concentration work at the end of shipbuilding.
- Increase the safety factor of work because it is done in the workshop.
- The installation of outfitting is done in a position that makes it easier for workers.
- The equipment workshop environment allows for cleaner, higher-quality work.
- Increase the efficiency factor of outfitting installation as described in
- Figure 2.

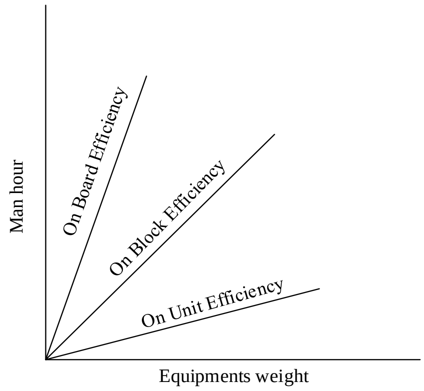


Figure 2. Efficiency improvement in advanced outfitting system

Overall, the literature study played a critical role in achieving the research objectives by providing valuable insights and knowledge related to shipbuilding processes, outfitting installation, and shipyard development. By building on the existing literature and previous research, this study aimed to contribute to the advancement of the shipbuilding industry in Indonesia and to help address the challenges facing the industry in the present day.

2.3 Data Collection and Management

After understanding the concept, the author collects data related to ship production planning using the advanced outfitting system method, namely:

- General arrangement, construction profile, and equipment for a 2000 GT cargo passenger ship
- Data on shipbuilding facilities for 2000 GT passenger ship builders
- Stages of building a 2000 GT cargo passenger ship
- Data on the quantity of materials needed to build a 2000 GT cargo passenger ship.

2.4 Technical and Economical Data Analysis

After completing the data collection and management process, this study conducts technical and economic analyses. The scope of technical and economic analysis in this research typically involves examining various aspects related to the system. The technical analysis involves planning for the construction of a 2000 GT cargo passenger ship at shipyard X using the advanced outfitting system method. This analysis aims to assess the efficiency of the shipbuilding process when using this method. The first step is analyzing the design and functionality of the advanced outfitting system, including its components, features, and capabilities. Second, assessing how the advanced outfitting system integrates with other shipbuilding processes and systems, such as hull construction, electrical systems, and propulsion. Then, evaluating the impact of the advanced outfitting system on shipbuilding efficiency and productivity, including factors such as reduced assembly time, improved accuracy, and increased automation.

On the other hand, the economic analysis focuses on calculating the investment needed to provide additional shipyard facilities and the cost of building a 2000 GT passenger ship using the advanced outfitting system method [23]. Finally, Cost-Benefit Analysis is conducted in assessing the economic viability of implementing the advanced outfitting system by comparing the costs associated with its implementation, operation, and maintenance against the potential benefits, such as increased productivity, reduced man-hours and labor costs [24]. The results of this analysis provide insights into the feasibility of implementing this method in shipyards and its potential economic benefits.

3. Existing Condition of the Shipyard

The shipyard being studied is a ship construction company located in the city of Surabaya. The company has previously constructed a 2000 GT ship for the Ministry of Transportation, which is currently operated by PT. PELNI. However, the ship equipment installation method used by the company still relies on the on-board outfitting method.

3.1 Shipyard Layout

PT. X has a comprehensive set of main facilities, including an 8000 DWT graving dock, a launching way, and a sizable working area located to the north and south of the pond dock. The shipyard's layout is illustrated in Figure 3 for reference.

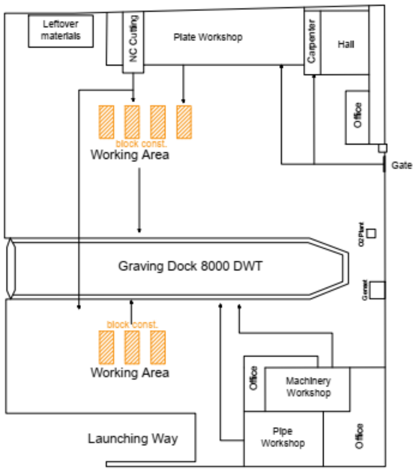


Figure 3. The existing layout of Shipyard PT. X

3.2 Shipyard Facilities

Shipyard PT. X. has shipbuilding facilities consisting of the main office, material storage warehouse, plate workshop, and other workshops related to the process of working on ship equipment. The main facility as a place for an erection is carried out in a graving dock with a capacity of 8000 DWT. In addition, supporting facilities for ship construction, such as crawler cranes, have a lifting capacity of 150 tons.

3.3 Shipbuilding Method

The shipbuilding method that the company currently uses is the HBCM (Hull-Block-Construction-Method) which involves building the ship's hull and outfitting it while it is still in the dry dock. This method is commonly used in shipyards due to its efficiency and ability to reduce the time required to build a ship. However, the company still uses the traditional on-board outfitting method for the outfitting installation process. This method requires the ship to be launched first before the outfitting process can be started, which adds significant time to the shipbuilding process. The traditional ship outfitting installation process and the advanced outfitting method differ in several ways:

a. Traditional Ship Outfitting Installation Process:

The traditional ship outfitting installation process involves installing outfit systems and components on a structural block or outfit unit after the ship's hull has been erected [12]. This means that the outfitting is done on-board the ship, typically in the later stages of construction. Some characteristics of the traditional outfitting process include:

1. Sequential Process: The outfitting is carried out in a sequential manner, where each outfit system or component is installed one after the other.
2. On-Board Installation: The outfitting is done on-board the ship, which requires access to the ship's interior spaces.
3. Longer Cycle Time: The traditional outfitting process often takes longer to complete due to the sequential nature of the installation.
4. Limited Flexibility: Any changes or modifications to the outfitting may be more challenging to implement once the ship's hull is erected.

b. Advanced Outfitting Method:

The advanced outfitting method, on the other hand, involves installing outfit systems and components on a structural block or outfit unit prior to shipboard erection [12]. This means that the outfitting is done off-board the ship, typically in a separate facility or building berth. Some characteristics of the advanced outfitting method include:

1. Parallel Process: The outfitting is carried out in parallel with the construction of the ship's hull, allowing for concurrent work streams and reducing the overall construction time.
2. Off-Board Installation: The outfitting is done off-board the ship, which provides better access to the outfitting areas and allows for more efficient installation.
3. Shorter Cycle Time: The advanced outfitting method can significantly reduce the cycle time required to build the ship, as outfitting can be completed concurrently with hull construction [25].
4. Increased Flexibility: The advanced outfitting method allows for easier modifications or changes to the outfitting, as it is done prior to shipboard erection.

In summary, the advanced outfitting method offers advantages such as shorter construction time, increased flexibility, and improved efficiency compared to the traditional ship outfitting installation process. It allows for parallel work streams and reduces the dependency on sequential installation, resulting in a more streamlined and efficient shipbuilding process.

4. Technical Analysis of Implementing Advanced Outfitting System

After analyzing the existing shipyard condition and based on the theory from previous research, the next step is implementing the AOS theory in design and production stage. The design of the new yard layout comes after the production process has been done. the advanced outfitting method can be applied and supported by certain shipyard facilities such as graving dock, multi pontoon floating dock [26], outfitting workshop, etc.

4.1 Hull Block Division

The hull is divided into 12 ship block sections. The division of the hull block is right above the main deck. While the division of super structure construction blocks and deck houses is done by dividing them just above the navigation deck. The division of ship blocks in Figure 4. is planned equally between the two methods. This was done because the block size of the ship is treated as a control variable so that further implications can be found in terms of construction time and costs.

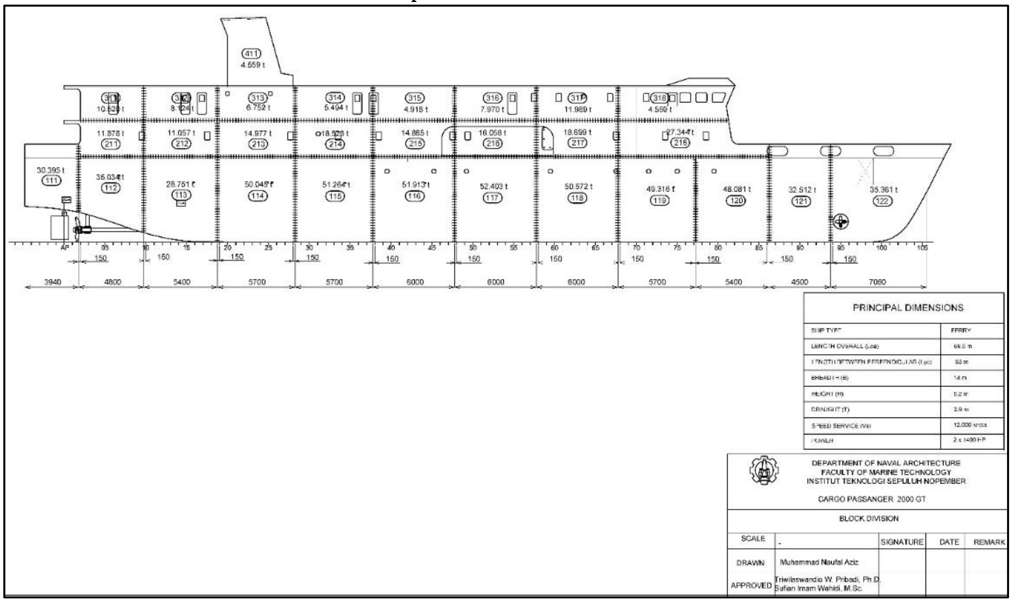
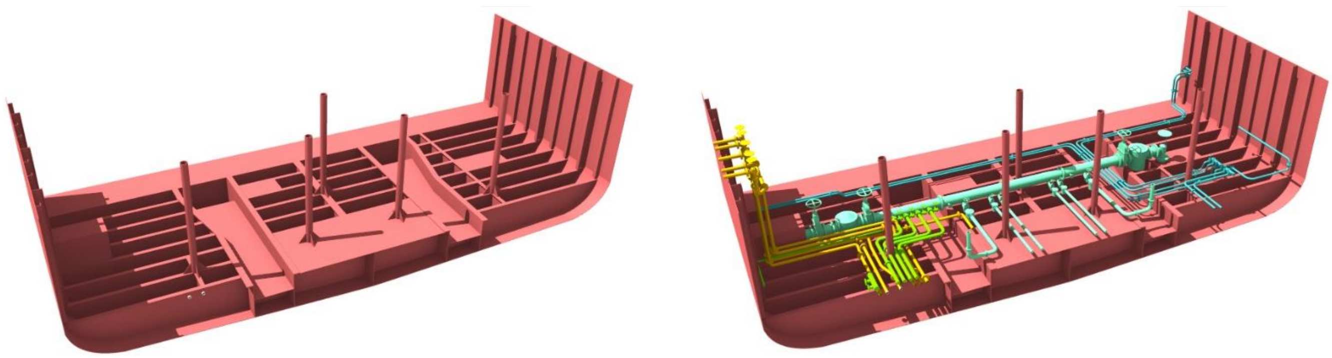


Figure 4. The hull block division plan

4.2 Block Plan in 3D Model

Making 3D ship blocks is used as a method to identify the smallest components in a ship block. The results of the 3D block are then included in the work breakdown structure diagram. To identify the process of making the complete ship, a work breakdown structure diagram is very important. The following is a 3D block comparison between the two shipbuilding methods.



(a) (b)

Figure 5. (a) The existing block model, (b) the block model for advanced outfitting system

The 3D Block results in Figure 5 has differences. In Figure (a) the ship block is not equipped with any ship equipment. Meanwhile, in Figure (b) the ship block is equipped with a piping system installed on block outfitting. The added value of the advanced outfitting system in shipbuilding lies in its ability to streamline the construction process, reduce cycle time, increase flexibility, and improve efficiency. By installing outfit systems and components on a structural block or outfit unit prior to shipboard erection, the advanced outfitting method allows for parallel work streams and concurrent construction of the ship's hull and outfitting. This results in a shorter overall construction time and improved productivity.

The advanced outfitting system also offers increased flexibility, as modifications or changes to the outfitting can be more easily implemented before the ship's hull is erected [12]. This flexibility allows for adjustments to be made based on evolving requirements or design changes, leading to a more adaptable and responsive shipbuilding process. In terms of its contribution to modern strategies, the advanced outfitting system aligns with the goals of modern shipbuilding practices. It enables shipyards to adopt more efficient and technologically advanced methods, such as assembly line approaches and modular construction techniques. These modern strategies aim to enhance productivity, reduce costs, and improve the overall competitiveness of shipbuilding industries. By embracing advanced outfitting methods, shipyards can stay at the forefront of technological advancements in shipbuilding and contribute to the modernization and advancement of the industry as a whole.

4.3 Efficiency Factor of Advanced Outfitting System

The efficiency factor of the advanced outfitting system is influenced by the ease of work at it. There are three factors that determine the efficiency value of the advanced outfitting system, such as material handling time, ease of place of work, and ease of testing process. To identify the efficiency factor, first, identification of the jobs that contribute to the process of installing equipment in each outfitting zone is carried out [21]. Activity breakdown and comparison table are used to find the efficiency value. Table 1 is the result of the efficiency factor of the obtained value of advanced outfitting system. Efficiency factors are derived from several factors as follows [12], [13]:

1. Material Handling Time: The transfer of ship equipment materials from the workshop to the building berth takes longer compared to the transfer of materials carried out per unit outfit module.
2. Workspace for installation: The installation of ship equipment contributes to the labor requirements. Tasks performed during ship construction are more challenging than those in machine workshops and ship blocks. Workshops are equipped with machinery and other supporting equipment, making additional work more manageable.
3. Testing Convenience: The installation process in a completed ship construction requires subsequent testing. Workers must conduct thorough testing on an entire system already installed within the ship. In contrast, testing in units and blocks can be carried out more easily because testing can be performed for each pipe lane/unit outfitting created.

Table 1. Efficiency factor of advanced outfitting system

Efficiency of AOS using activity breakdown			**On Board**					**Efficiency rate**
			Fabrication	**Material handling**		**Installation**	**Testing**	
			As production drawing	**Workshop to graving dock**	**Graving dock to ship**	**Piece part installation**	**Testing after complete**	
On unit	Fabrication	As production drawing	1					0.5
	Material handling	Workshop to workshop		0.1				
		Outfitting workshop			0.3			
	Installation	Piece part installation				1		
	Testing	Unit testing					0.1	
On Block	Fabrication	As production drawing	1					0.62
	Material handling	Workshop to working area		0.5				
		Working area to block			0.3			
	Installation	Piece part installation				1		
	Testing	Testing per system on block					0.3	

These three factors yield efficiency factors for each zone′s outfitting. The efficiency factor for each zone is calculated using an activity breakdown analysis of the advanced outfitting method compared to the on-board outfitting method. Activity comparisons are made using a table that outlines the activities in each zone outfitting. Then, the efficiency factors found in on-unit and on-block outfitting are determined using an average formula.

Table 1 illustrates the efficiency values of the advanced outfitting system for each unit outfitting. The determination of efficiency values in each activity breakdown is derived from the description of the activities performed. For example, the material handling from one workshop to another workshop has an efficiency factor of 0.1 because the distance covered is 90% shorter than that from the workshop to the graving dock. Similarly, the testing process for unit outfitting and the piping system within the block follow the same logic. The overall efficiency of the zone outfitting is calculated as the average value of all the efficiency breakdown activities obtained.

4.4 Man-Hour Calculation

The number of man hours in ship production is calculated in two main activities, first is construction of the ship's hull block and second is the installation of ship outfitting [21]. In calculating the man-hours required for ship hull block construction, the total man-hour requirement is determined by multiplying productivity by the workload at each stage of ship construction, namely fabrication, assembly, and erection. The results show that there is no difference in man-hour requirements between the two methods for the entire ship construction process, as illustrated in Figure 6. This is due to the fact that both methods utilize the same workload and productivity factors. The workload remains constant because the planning for ship block division remains unchanged. Likewise, productivity remains consistent as the ship construction process is carried out in the same shipyard. Subsequently, this man-hour data is used in the calculation of the ship construction timeline.

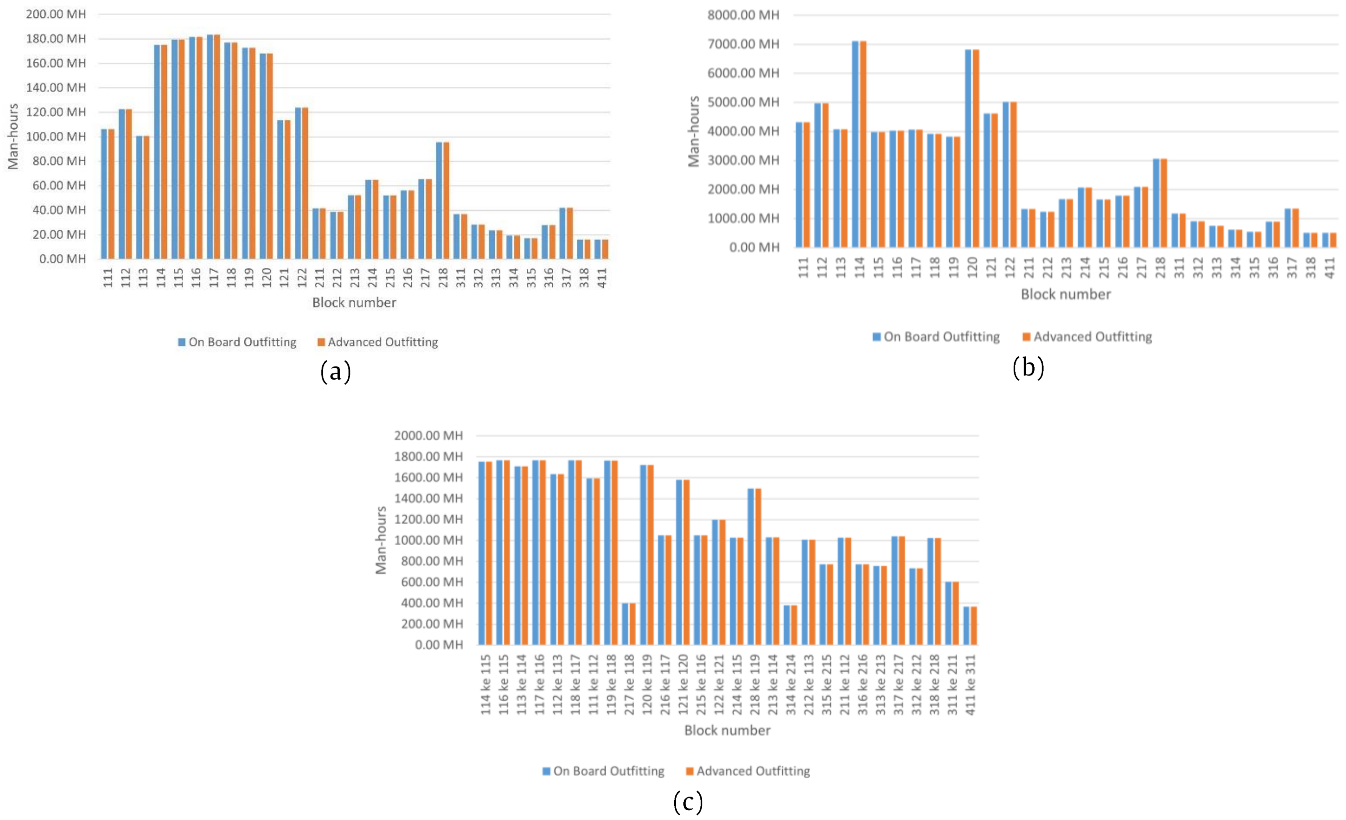


Figure 6. The number of man hour needed in construction: (a) fabrication (b) assembly (c) erection.

After completing the calculation of man-hours required for ship hull block construction, the process proceeds to the outfitting phase. The calculation of man-hours for outfitting work is analyzed for each outfitting zone. The data utilized for this analysis includes the results of the outfitting zone identification and the shipyard's productivity calculations. Additionally, a crucial factor to consider when determining man-hour requirements is the efficiency factor of the work processes in the on-unit and on-block methods as compared to the on-board outfitting method, as obtained in Table 1. Furthermore, the calculation of man hours required for ship equipment installation activities has different results. The advanced outfitting system method has an efficiency factor so that the number of hours needed is getting smaller. Figure 7 explain the details information.

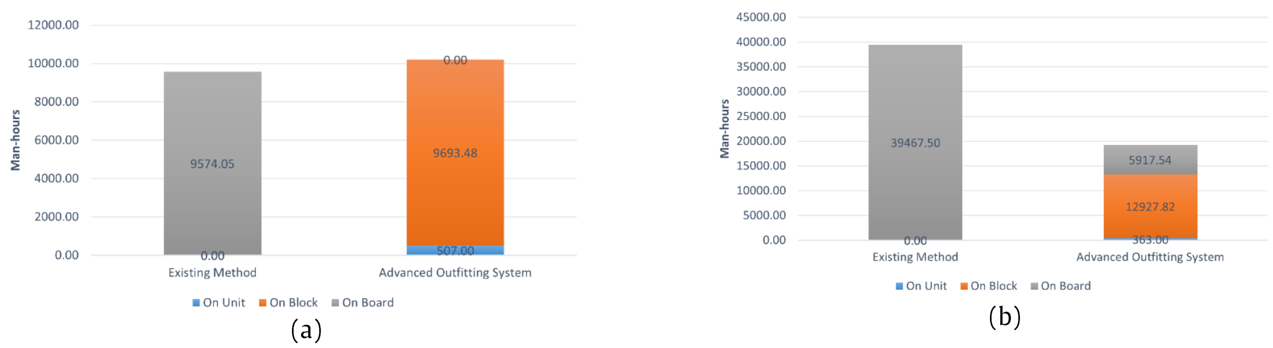


Figure 7. The number of man-hours needed in fabrication and installation of ship outfitting: (a) fabrication (b) installation.

Figure 7a illustrates the man-hour requirements during the ship outfitting fabrication stage for both construction methods. The blue bars represent man-hours for on-unit outfitting fabrication, the orange bars represent man-hours for on-block outfitting fabrication, and the gray bars represent man-hours for on-board outfitting fabrication. In the conventional method, there are no on-unit and on-board outfitting fabrication activities, thus requiring no man-hours. Therefore, the total man-hour requirements for the conventional method are lower than those for the advanced outfitting method.

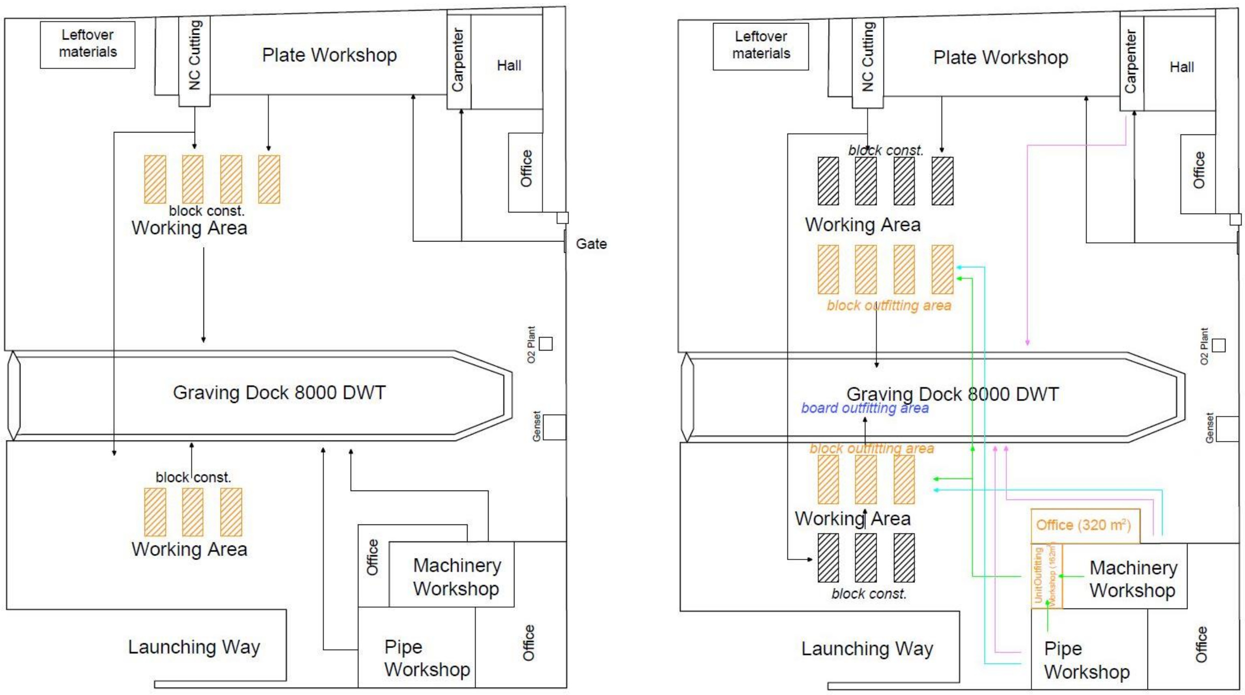
On the other hand, Figure 7b shows a significant difference in man-hour requirements during the installation stage for both construction methods. The blue bars represent man-hours for on-unit outfitting installation, the orange bars represent man-hours for on-block outfitting installation, and the gray bars represent man-hours for on-board outfitting installation. In the conventional (existing) method, outfitting installation focuses on on-board activities, with no on-unit and on-block installation tasks. In comparison, the advanced outfitting method requires man-hours for each outfitting zone. However, the total man-hour requirements for the installation process are lower in the advanced outfitting method than in the conventional method. The phenomenon occurs because outfitting work is optimized during the equipment assembly process in the workshop [27]. As a result, man-hours required during the installation process on the ship can be minimized.

4.5 Implication to the Shipbuilding Time

The scheduling process using Microsoft Project was based on the calculation of man-hours in the construction process up to the outfitting installation, which served as the main data. The advanced outfitting system method resulted in a shorter construction time of 357 days compared to the existing method, which took 403 days. The reduction in time was mainly attributed to the implementation of block construction and outfitting installation simultaneously, thus increasing the overall efficiency factor. As a result, the advanced outfitting system reduced the man-hours required and the time needed for shipbuilding without having to increase the number of workers. This outcome is significant since it can potentially increase the productivity and profitability of shipyards, as well as improve their competitiveness in the global shipbuilding market.

4.6 Shipyard Development Plan

The development is intended to increase the capacity and capability of PT. X in order to be able to apply the advanced outfitting system method. Capacity building is carried out on human resources and other resources, in the form of main facilities and supporting facilities owned by the company. Facility development plan is carried out by considering the results of the shipbuilding plan using the advanced outfitting system method [27]. The shipbuilding plan using the AOS method requires a place to install outfitting in each outfitting zone. This place includes facilities for installing equipment on unit, on block, and on board. Figure 8 is the result of planning for the development of the main shipyard facilities of PT. X.



(a) (b)

Figure 8. Shipyard layout: (a) existing (b) development plan

Figure 8(a) is the layout of the current condition of the shipyard. While Figure 8(b) is a shipyard layout that has added a place to make outfitting units. This place must be facilitated with equipment to support the unit assembly process. The assembly unit of the outfit is also designed to be closed to protect machinery and electronic equipment from weather changes at the work site. It is planned to build an outfitting unit workshop located in the western part of the machine shop. This workshop is also planned to be close to the piping workshop. The location of the adjacent outfitting unit workshop is intended to facilitate the material handling process for the components that make up the outfitting unit before assembly is carried out in the workshop [27]. The equipment and supporting facilities required also need to be identified.

The unit outfitting workshop depicted in Figure 8b is planned to include storage space for plates and profiles. This space serves as a storage area for the components that constitute the unit outfit structure. Furthermore, the unit outfitting workshop is equipped with various machinery for fabrication and assembly processes, such as cutting machines and welding machines. To facilitate the work process, the workshop is also equipped with a 2-ton overhead crane, matching the weight of the outfitting components being processed. Details of the equipment inside the workshop are listed in the Table 2.

Table 2. Equipment required in outfitting unit workshop.

Equipment	Number	Unit
Gas cutting machine with rail	1	lot
Cutting torch	1	unit
MIG Welding	1	unit
Stick Welding	1	unit
Overhead crane 2 ton	1	lot
Gas cylinders	6	unit

Table 2 is a list of equipment required as operational support facilities for the unit outfitting workshop. In the planning of acquiring support facilities, there is no need for fabrication machinery for unit outfit components as the machinery available in the pipe and machinery workshop can be utilized. The proximity of these workshops supports this scenario. As shown in Figure 8b, the material flow from the machine workshop and plate workshop directly leads to the unit outfitting assembly area. Subsequently, the unit outfit components are transported to the buffer area, where they await installation on the ship's hull. Figure 8b also illustrates the planned location for ship equipment installation using the on-block outfitting method. The provision of a dedicated area for on-block equipment installation within the working area reduces the capacity for block assembly workstations. To ensure that the assembly space remains sufficient, it is necessary to arrange the number of groups simultaneously performing assembly work.

The production planning for ships using the advanced outfitting system is conducted through scheduling simulations. With this data, the maximum number of blocks that can be accommodated in the working area during production planning is determined to be 8 blocks. However, the maximum capacity of the working area is 20 ship blocks. Therefore, this indicates that planning for the block outfitting area is feasible. In Figure 8b, there is also a designated area for on-board outfitting installation. The installation plan for equipment on board is carried out within the graving dock, as is the current practice. This installation process is aided by a gantry crane with a capacity of 35 tons. The application of these new methods requires a good understanding of how an advanced outfitting system works. This understanding must be obtained by all permanent employees by conducting training and simulation. Including construction employees, piping, machine, safety, and additional employees who work in shipyard.

5. Economical Analysis of Implementing Advanced Outfitting System

The economic analysis is intended to determine the implications of the outfitting installation method on reduction of shipbuilding costs [28]. Components of ship building costs that are calculated include the cost of purchasing ship components, the cost of permanent workers, and the costs of sub-contractor workers [23].

5.1 Ship Components Cost

Ship components are divided into two main parts, ship construction and ship equipment. Identification of the type and number of components is carried out using general plan drawings, construction drawings, and shell expansion of the 2000GT passenger cargo ship. Calculation of ship construction includes the number of plates required for the ship's hull and superstructure. In addition, the calculation of the number of ship profiles is also carried out for the reinforcement and cross section of the ship. The market value used is IDR. 14,000/kg for ship plates, and IDR 10,000/kg for ship profiles.

By the same method, the ship's machinery, safety equipment, deck equipment, and painting costs are calculated per unit price of the equipment required [29]. For the price of painting the ship, the standard tariff from IPERINDO is used, IDR 8,100/m^2. There is no difference in the cost of purchasing materials between the advanced outfitting system method and the on-board outfitting system. Table 3 shows the costs required to purchase ship components. From the calculation results, we get the costs for the advanced outfitting system and existing methods. There is no cost difference in this cost component.

Table 3. Calculation results on ship components procurement

No	Components	Cost (x1000) (IDR)	
		Advanced outfitting	Existing method
A	Construction		
1	Plate	4,818,886	4,818,886
2	Profile	3,349,637	3,349,637
	Sum	8,168,523	8,168,523
B	Equipment		
1	Machinery & Pipes	6,201,888	6,201,888
2	Deck machinery and outfitting	2,861,660	2,861,660
3	Safety equipment	6,034,700	6,034,700
4	Corrosion protection	3,157,202	3,157,202
	Sum	18,255,450	18,255,450

5.2 Fixed Cost from Workers

The author uses the assumption that the salary of workers is the same as the Surabaya regional minimum wage, which is IDR 3.900.000 per month. This monthly salary is calculated per day and then multiplied by the calculation of the man hours of shipbuilding process. Table 4 shows the cost of permanent workers required in the shipbuilding process [30].

This monthly salary is calculated per day and then multiplied by the ship construction period, in accordance with the calculated shipbuilding schedule. In the shipbuilding schedule, it is determined that the number of days required for ship construction using the conventional method is 403 days, while the advanced outfitting system method takes 357 days. Thus, the company's costs for paying its permanent employees in each division can be compared with the number of workers collected from the data collection.

Table 4. Calculation results on fixed cost from workers

Division	Number of workers	Cost (x1000) (IDR)	
		Advanced outfitting	Existing method
Safety	6	278,460	314,340
General	1	46,410	52,390
Equipment facility	13	603,330	681,070
Electrical facility	8	371,280	419,120
Dock master	61	2,831,010	3,195,790
Construction	51	2,366,910	2,671,890
Piping	17	788,970	890,630
Vent	20	928,200	1,047,800
Accommodation	61	2,831,010	3,195,790
Engine Mechanic	15	696,150	785,850
Propulsion Mechanic	17	788,970	890,630
Workshop Mechanic	1	46,410	52,390
Total	271	12,577,110	14,197,690

5.3 Cost from Sub-Contractors

The construction ship also uses sub-contractor workers. Calculation of the cost of subcontractor workers is divided into two main activities, hull construction work and ship equipment installation. Construction work and ship equipment are calculated by calculating the required man-hours approach. The number of man hours earned is multiplied by the cost of wages paid per person hour. The author plans the sub-contractor's salary to be adjusted to the market price, which is IDR 130,000 per person per day, or IDR 18,570 per hour person.

It is known that the calculation of ship construction costs by sub-contractor workers has no difference between the two methods. Because the man-hours needed to complete the work have the same value. Meanwhile, in case of installation of ship equipment, the two methods have different needs for man hours. Therefore, the costs required for sub-contractor salaries are also different. Table 5 shows the result of cost required from sub-contractor workers.

Table 5. Calculation results on cost from sub-contractors

Zone Outfitting	Cost (x1000) (IDR)			
	Advanced Outfitting		Existing Method	
	Fabrication	Installation	Fabrication	Installation
On Unit	9,416	6,741	0	0
On Block	180,022	240,088	0	0
On Board	0	109,897	177,804	732,968
Sum	189,437	356,727	177,804	732,968

5.4 Shipbuilding Cost Saving Calculation

From the results of the cost calculation above, it can be compared the total cost of building a ship for each shipbuilding method. Shipbuilding costs are the total amount of ship construction costs, permanent labor costs, and sub-contractor labor costs for construction work and ship equipment installation. Table 6 is a comparison of the shipbuilding costs obtained.

Table 6. Comparation on shipbuilding cost from two methods

No	Components	Cost (x1000)	
		Advanced Outfitting (IDR)	Existing Method (IDR)
1	Ship Components	25,309,732	25,309,732
2	Organic workers	12,577,110	14,197,690
3	Third party	2,080,000	2,080,000
4	Sub-cont workers on construction	2,121,559	2,121,559
5	Sub-cont workers on outfitting	546,164	910,772
	- On unit	16,157	-
	- On block	420,110	-
	- On board	109,897	910,772
Total		42,843,677	44,776,954

The difference in the shipbuilding cost structure between the advanced outfitting system method and the existing method is in the salary costs of permanent employees and the costs of ship equipment installation from sub contractors. Total cost savings is IDR 1,933,277,000. Salaries of permanent employees have differences because the length of shipbuilding time in each method is different. This causes the biggest difference, which is IDR 1,620,580,000 or contribute 84% of the total difference in shipbuilding cost. While the difference in the cost of sub-contractor ship construction is only IDR 312,697,000 or contribute 16% of the total difference in shipbuilding costs.

5.5 Shipbuilding Development Investment

Shipyard development required a substantial investment for implementation, and a meticulous calculation of these investment costs is needed [28]. In the shipyard development plan, there are two primary components that constitute the overall development costs [23]. These components encompass the enhancement of shipyard facilities and the development of human resource capabilities, both of which are calculated individually [30]. Firstly, the expenses associated with facility development are meticulously assessed based on the inventory of additional or upgraded shipyard facilities. Table 7 provides a breakdown of the investment requirements for facilities at PT. X.

Table 7. Investment required on the development of PT. X Shipyard

No.	Type	Name	Number	Unit	Total Price (x1000) IDR
1	Main facility	Unit Outfitting Workshop	162	m^2	486,000
		Office	320	m^2	960,000
2	Support facility	Gas cutting machine with rail	1	unit	28,055
		Cutting torch	1	unit	1,365
		MIG Welding	1	unit	18,358
		Stick Welding	1	unit	71,490
		Overhead crane 2 ton	1	unit	746,508
		Gas tube	6	unit	9,000
		Total			**2,320,776**

Second, the development of PT. X. also requires the development of its human resources (HR). HR development includes permanent employees of PT. X., which is directly related to the shipbuilding process. Technical development is carried out by training and simulation. The estimated cost required for training the employees is Rp.720.000.000. From the two calculations above, it is found that the investment cost for the procurement of the necessary facilities is IDR 2,320,776,000. Meanwhile, the investment cost for HR development is IDR 720.000.000. So, the total investment required for the development of the shipyard is IDR 3,040,776,000. The nominal investment costs can be overcome by saving on shipbuilding costs with advanced outfitting methods. If one ship can save construction costs of IDR 1,933,277,000, then two shipbuilding are needed to cover the investment costs of ship development.

6. Conclusion

After conducting a thorough analysis and calculation, several conclusions can be drawn from this research. Firstly, it was found that PT. X., the shipyard under study, is still using the hull block construction method for building the hull construction and the on-board outfitting method for outfitting installation. These traditional methods are still commonly used in the shipbuilding industry, but they are not as efficient as the advanced outfitting system method. Secondly, the advanced outfitting system method requires planning from the ship design stage. The ship block division influences the number of outfitting that can be installed on-block, and the identification of ship equipment installed on the unit is done by reviewing machinery and equipment that are close to each other. On the other hand, the identification of ship equipment installed on-block is carried out by reviewing the combined block division drawings, piping systems, and general arrangements to produce composite drawings for each block. The ship equipment that is installed on-board is the rest of the equipment that cannot be installed on-unit or on-block. By implementing the advanced outfitting system method, shipyards can achieve better efficiency and reduce the overall construction time. Thirdly, the research found that the on-board outfitting method takes 403 days of work, and the cost of shipbuilding is IDR 44,776,954,000. Meanwhile, the advanced outfitting system method takes 357 days of work, and the cost of shipbuilding is IDR 42,843,677,000. Therefore, the advanced outfitting system method is able to shorten the construction time and reduce the shipbuilding costs, making it a more efficient and cost-effective method for shipyards to use.

To sum up, by implementing the advanced outfitting system method, shipyards like PT. X can reduce the construction time and costs, while still maintaining high-quality standards in shipbuilding. It is recommended for shipyards to consider implementing this method in their shipbuilding process to improve efficiency and reduce costs.

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References

[1] L. Xue, G. Shi, D. Dai, and Y. Xu, "Two-Stage Efficiency Structure Analysis Model of Shipbuilding Based on Driving Factors: The Case of Chinese Shipyard," *Open J. Soc. Sci.*, vol. 08, no. 02, pp. 182–200, 2020, doi:

10.4236/jss.2020.82015.
[2] L. M. Kujala, M. Nallilkari, H. A. Tokola, and H. Remes, "Influence of block building method on outfitting efficiency at an assembly shipyard," *RINA, R. Inst. Nav. Archit. - Int. Conf. Comput. Appl. Shipbuild. 2015, ICCAS 2015 - Pap.*, vol. 1, pp. 109–116, 2015, doi: 10.3940/rina.iccas.2015.43.
[3] C. Rose, J. Coenen, and H. Hopman, "Definition of Ship Outfitting Scheduling as a Resource Availability Cost Problem and Development of a Heuristic Solution Technique," *J. Sh. Prod. Des.*, vol. 32, no. 03, pp. 154–165, Aug. 2016, doi: 10.5957/jspd.2016.32.3.154.
[4] D. Kolich, S. Sladic, and R. L. Storch, "Lean IHOP Transformation of Shipyard Erection Block Construction," *J. Sh. Prod. Des.*, vol. 35, no. 03, pp. 273–280, Aug. 2019, doi: 10.5957/JSPD.04180010.
[5] Y.-K. Jeong, P. Lee, and J. H. Woo, "Shipyard Block Logistics Simulation Using Process-centric Discrete Event Simulation Method," *J. Sh. Prod. Des.*, vol. 34, no. 02, pp. 168–179, May 2018, doi: 10.5957/JSPD.170006.
[6] I. Salo, T. W. Pribadi, and S. I. Wahidi, "Analysis of Access and Monitoring Systems Implementation on Human Resources to Improve the Shipbuilding Industry Performance," no. Senta 2018, pp. 79–86, 2020, doi: 10.5220/0008542600790086.
[7] I. CIL, F. ARISOY, A. Y. CIL, and H. Kilinc, "a Comparative Analysis of Indoor Positioning Technologies in Shipyard Digitalization Context," *J. Mar. Technol. Environ.*, vol. 2022, no. 1, pp. 15–25, 2022, doi: 10.53464/jmte.01.2022.03.
[8] T. W. Pribadi and T. Shinoda, "Hand Motion Analysis for Recognition of Qualified and Unqualified Welders using 9-DOF IMU Sensors and Support Vector Machine (SVM) Approach," *Int. J. Technol.*, vol. 13, no. 1, pp. 38–47, 2022, doi: 10.14716/ijtech.v13i1.4813.
[9] M. S. Arif, H. Supomo, W. U. Alifia, and S. I. Wahidi, "Ship production process monitoring application using QR-code technology," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 972, no. 1, p. 012016, 2022, doi: 10.1088/1755-1315/972/1/012016.
[10] S. I. Wahidi, T. W. Pribadi, and H. M. Rahman, "Study of QR Code Technology Application for Monitoring Activity of Ship Planned Maintenance System," *Kapal J. Ilmu Pengetah. dan Teknol. Kelaut.*, vol. 19, no. 2, Jun. 2022, doi: 10.14710/KAPAL.V19I2.45507.
[11] P. Fraga-Lamas, D. Noceda-Davila, T. M. Fernández-Caramés, M. A. Díaz-Bouza, and M. Vilar-Montesinos, "Smart Pipe System for a Shipyard 4.0," *Sensors*, vol. 16, no. 12, 2016, doi: 10.3390/s16122186.
[12] R. Rubeša, N. Fafandjel, and D. Kolić, "Procedure for Estimating the Effectiveness of Ship Modular Outfitting," *Eng. Rev.*, vol. 1, no. 1, pp. 55–62, 2011.
[13] R. Rubeša, M. Hadjina, and T. Matulja, "Criteria for Evaluation the Technological Level of Ship Pre-Outfitting in Shipyard," *J. Marit. Transp. Sci.*, vol. Special ed, no. 4, pp. 201–210, 2022, doi: 10.18048/2022.04.14.
[14] F. Zhou, P. Ma, Y. He, S. Pratap, P. Yu, and B. Yang, "Lean production of ship-pipe parts based on lot-sizing optimization and PFB control strategy," *Kybernetes*, vol. 50, no. 5, pp. 1483–1505, 2020, doi: 10.1108/K-06-2019-0389.
[15] M. Semini, C. Patek, P. O. Brett, J. J. G. Agis, J. O. Strandhagen, and J. Vatn, "Some relationships between build strategy and shipbuilding time in European shipbuilding," *Proc. Inst. Mech. Eng. Part M J. Eng. Marit. Environ.*, vol. 237, no. 3, pp. 658–676, 2023, doi: 10.1177/14750902221141749.
[16] T. W. Pribadi, M. S. Arif, S. I. Wahidi, and I. W. Maditiara, "Modular system construction for laminated wooden fishing vessel industry," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 649, no. 1, 2021, doi: 10.1088/1755-1315/649/1/012009.
[17] I. Baihaqi, I. Lazakis, and R. E. Kurt, "Development of a novel integrated value engineering and risk assessment (VENRA) framework for shipyard performance measurement: a case study for an Indonesian shipyard," *Ships Offshore Struct.*, 2023, doi: 10.1080/17445302.2023.2228115.
[18] Sukisno and M. L. Singgih, "Location Selection Analysis for New Shipyard Using Integration of DEMATEL and ANP: A Case Study (PT IKI)," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 598, no. 1, pp. 0–6, 2019, doi: 10.1088/1757-899X/598/1/012109.
[19] S. Vakili, A. Schönborn, and A. I. Ölçer, "Application of the transdisciplinary shipyard energy management framework by employing a fuzzy multiple attribute group decision making technique toward a sustainable shipyard: case study for a Bangladeshi shipyard," *J. Shipp. Trade*, vol. 7, no. 1, p. 22, 2022, doi: 10.1186/s41072-022-00123-8.
[20] R. L. Storch, *Ship Production*. Cornell Maritime Press, 1995. [Online]. Available: https://books.google.co.uk/books?id=T1N8QgAACAAJ
[21] T. Lamb and A. Arbor, *ENGINEERING F0R SHIP PRODUCTION by Prepared for The National Shipbuiiding Research Program bY The Society of Naval Architects and Marine Engineers Ship Production Committee The University of Michigan N / A*, no. January. 1986.
[22] R. D. Okayama, Y. Ando, K. Tomisawa, M. Honda, K. Chirillo, L. D. Chirillo, *Integrated hull construction, outfitting and painting*. Washington, D.C.: U.S. Department of Transportation, 1983. doi: LK - https://worldcat.org/title/11146824.
[23] S. I. Wahidi, V. M. Virmansyah, and T. W. Pribadi, "Study on Implementation of Activity-Based Costing (ABC) System on Determination of Indirect Costs in Ship Production," *KapalJurnal Ilmu Pengetah. dan Teknol. Kelautan.*, vol. 18, no. 1, pp. 1–7, 2021, doi: https://doi.org/10.14710/kapal.v18i1.33000.
[24] N. Chu, X. Nie, J. Xu, and K. Li, "A systematic approach of lean supply chain management in shipbuilding," *SN Appl. Sci.*, vol. 3, no. 5, pp. 1–11, 2021, doi: 10.1007/s42452-021-04562-z.
[25] S. Chakraborty, "What Is Advanced Outfitting in Shipbuilding?," *Marine Insight*, 2019. https://www.marineinsight.com/naval-architecture/advanced-outfitting-in-shipbuilding/ (accessed Oct. 04, 2023).
[26] S. I. Wahidi, T. W. Pribadi, M. I. Firdausi, and B. Santosa, "Technical and Economic Analysis of a Conversion on a Single Pontoon to a Multi Pontoon Floating Dock," *Nase More*, vol. 69, no. 2, pp. 114–122, 2022, doi: 10.17818/NM/2022/2.5.
[27] T. W. Pribadi, R. N. Adam, and S. I. Wahidi, "Technical and Economical Analysis of Shipyard Re-Layout for Product-Oriented Work Breakdown Structure Implementation," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1052, no. 1, p. 012046,

2021, doi: 10.1088/1757-899x/1052/1/012046.

[28] T. J. Eccles and H. S. Marcus, "Integrating design and production: A case study of the naval submarine program," *Int. J. Prod. Econ.*, vol. 28, no. 1, pp. 107–126, 1992, doi: 10.1016/0925-5273(92)90116-O.

[29] S. I. Wahidi, T. W. Pribadi, S. R. W. Pribadi, and S. Megawati, "Implementation Study of Activity Based Costing System to Define Indirect Costs on Ship Repair Industries," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1052, no. 1, p. 012049, 2021, doi: 10.1088/1757-899x/1052/1/012049.

[30] S. I. Wahidi, S. R. W. Pribadi, T. W. Pribadi, N. L. A. Wardhana, and M. S. Arif, "Fixed Manpower Reduction Analysis to Reduce Indirect Cost of Ship Production," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1052, no. 1, p. 012048, 2021, doi: 10.1088/1757-899x/1052/1/012048.