



Study of Lavatory Installation Methods on Ship Landing Platforms

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Abstract

Increasing efficiency in the shipbuilding industry is one of the main focuses in line with market demands for faster production times and higher quality. Landing Platform Dock (LPD) ships as amphibious warships with complex accommodation systems, including lavatory installations, demand effective and efficient installation methods. This research was motivated by the need to compare two lavatory installation methods, namely the conventional method and the modular method, in an effort to increase productivity and reduce the number of reworks in LPD ship construction. The research method used is the direct observation method at national shipyards, by collecting data through records of installation time, number of person hours, material costs, and number of rework events. Data were analyzed using a quantitative descriptive approach by comparing these variables for each type of lavatory. In the conventional method, the lavatory installation is carried out after the main structure of the ship is complete, while in the modular method, the lavatory unit is assembled separately in the workshop and then integrated into the ship. In this study, 3 types of lavatories were used with different dimensions and shapes. The modular method, which takes 10-14 days to complete, has proven to be significantly more efficient in terms of implementation time than the conventional method with results of 19-25 days according to the lavatory type. Likewise, the number of person hours required reaches 384-480 JO for the conventional method and 264-456 JO for the modular method for the three types of work. The costs incurred for this production require IDR 67,880,890 - IDR 81,377,090 for the modular method and IDR 71,682,490 - IDR 87,713,090 for the conventional method. Thus, the modular method proves to be more effective in increasing productivity and lowering the cost of installing better lavatories on the ship's Landing Platform Dock.

Keywords: production efficiency, landing platform ships, conventional, lavatory, modularization, rework.

1. INTRODUCTION

As technology continues to develop, ship production at shipyards is also required to be faster and more precise in scheduling [1]. Of course, not only fast, but also "Planning the perfect schedule and the smallest possible costs to get maximum benefits in terms of completion and profits for the project organizer" [2]. A project can be declared successful if all aspects of the work are achieved, such as conformity between deadlines and implementation schedules, quality of work and costs according to plan [3].

As a class A shipbuilding company in Indonesia. This company has business advantages in Warship and Merchant Ship Construction and Design capabilities; Submarine Construction and Maintenance, Repair and Overhaul (MRO); Maintenance, Repair and Overhaul of Warships, Merchant Ships and maritime products; General Engineering of Energy and Electrification products; and Technological Development. Safety and comfort factors are also always strived for so that the crew gets adequate facilities. If the facilities are adequate, the crew will be better able to carry out their work while on the ship [4].

Various efforts to develop facilities have been made to create a safe and comfortable atmosphere for the crew, one of which is accommodation facilities where these facilities are directly related to the interaction process and the crew's rest time on the ship. There is a large need for space in the accommodation section as a facility provided for the ship's crew, one of which is the need for a wet room or what is usually called a WC in shipping terms. When installing a toilet, plate material is required for the platform, interior parts, sanitation parts, electrical parts. The process of installing WC materials was initially only carried out conventionally where the lavatory block had to be installed completely first.



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Conventional installations have several disadvantages such as long installation times, limited sophisticated facilities, and installation locations that are less conducive because the entire work stage after the ship is installed involves work other than installing the toilet. The development of technology in the shipping industry has encouraged a significant transformation of work methods. It is hoped that this research can make a real contribution, both academically and practically, in encouraging the application of innovation in the field of maritime construction.

2. METHOD

This research requires a series of activities to be carried out to complete the research objectives. Figure 1 shows the steps that will be taken to compile this research.

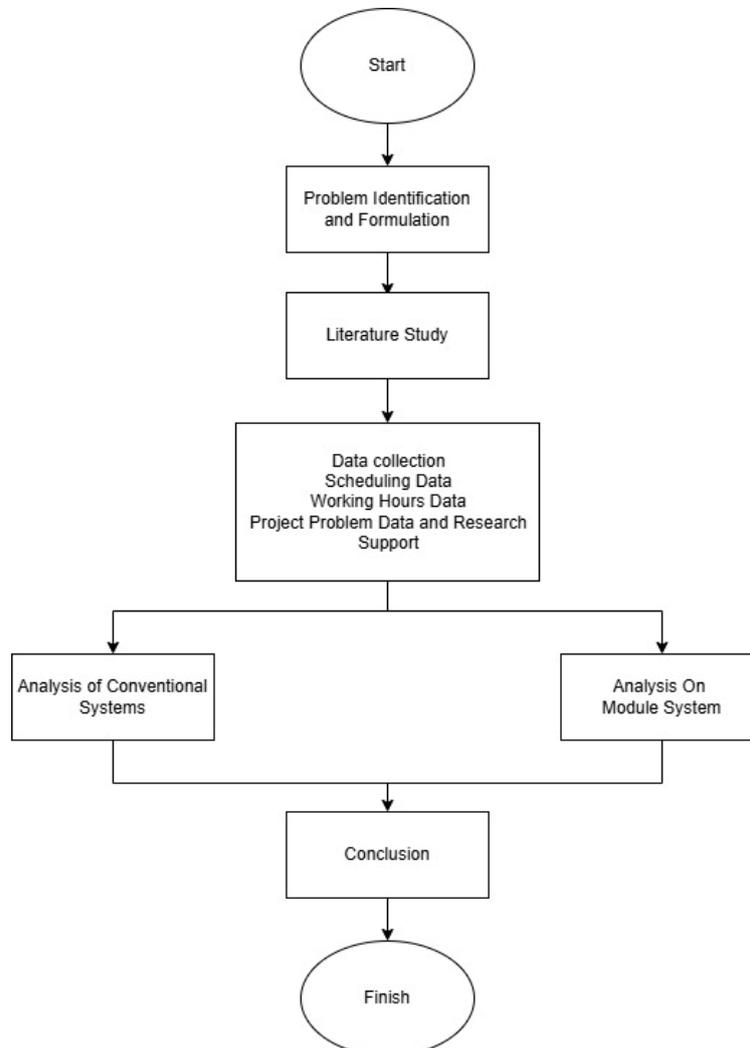


Figure 1. Research Flow Diagram

The following is an explanation of the image above:

- Identification and formulation of problems
This stage is carried out to identify problems that arise in the installation of lavatory modules related to key aspects such as production or installation costs, materials, methods, and installation duration.
- Literature study
This stage is conducted by observing the problems in the process of installing lavatory on the landing platform ship. Then continued by searching for references to theoretical foundations that support relevant problem solving through books, journals, or direct interviews with project actors.
- Data collection

This stage collects actual data from the implementation of the installation of lavatory in the field. The collected data is expected to be supporting data in the form of effective hour data, work duration, and cost estimates.

- Data processing and analysis

After the data collection stage, an analysis is carried out to obtain a comparison of values between using the conventional method and the modular method.

- Conclusion

The conclusion of this study is to determine the factors that influence the lavatory installation process, the effect of implementing a modular system on lavatory work, and a comparison of the estimated time and man-hour requirements for lavatory installation using conventional methods and modular methods on landing platform ships.

This research uses a comparative descriptive quantitative approach, namely comparing two methods of installing toilets on Landing Platform Dock (LPD) type ships, namely the conventional method and the modular method. The aim of this approach is to determine time efficiency, cost effectiveness, amount of rework and other technical aspects that can influence the selection of the best method to be applied in the shipbuilding industry.

2.1. Accommodation Package

According to KBBI[5], the word accommodation is defined as something provided to meet needs, such as a place to stay or a temporary residence for people who are traveling. A room or space is one example of the result of the package accommodation installation process. One of the results related to the bathroom or toilet facilities provided in the accommodation room, commonly called a lavatory. The lavatory unit requires 3 main aspects in its specifications to meet the production needs of ship construction and when operating later, namely a strong and watertight frame and platform structure, a good sanitation system and aesthetics in harmony with the surrounding interior.

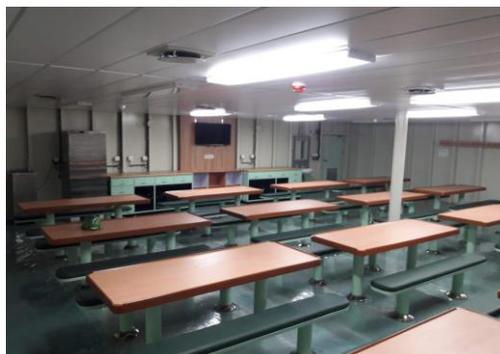


Figure 2. Result For Accommodation Installation

The room or space in Figure 2 is an example of the result of the accommodation package installation process which of course goes through several material work processes before becoming a complete room. Some elements of the accommodation package are:

- Deck Covering
- Ceiling Panel
- Wall Panel
- Lavatory
- Hollow Door

2.2. Conventional Method

Conventional installation is carried out directly on board the ship, usually after the main structure of the ship is completed. The stages in this method include and are explained in Figure 3 below:

- Transportation of materials to ships
- *Install steel coaming* for platform
- Installation of lavatory frame/structure
- Installation of sanitary parts



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- Electrical part inspection
- *Finishing* and cleaning
- *Function test*

Advantages are:

- More flexible to adapt to actual space shape
- Suitable for final modification

Disadvantages:

- High level of difficulty due to narrow space
- Installation time is relatively long

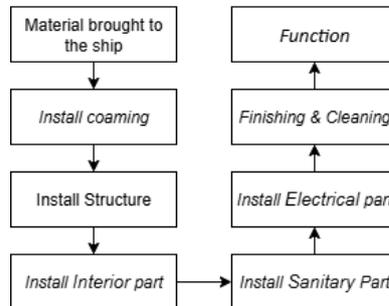


Figure 3. Conventional Installation Flow

2.3. Modular Method

In the modular method, the lavatory is first assembled outside the ship in the form of a complete module, then inserted and installed into the ship. The following are the modular installation stages and are depicted in Figure 4 below:

- *Cutting steel coaming* for the platform in the workshop
- *Assembly & welding steel coaming platforms*
- Structure installation
- Installation of interior parts
- Installation of sanitary parts
- Installation of electrical parts
- *Press Test* and check QC
- *Finishing* and cleaning
- *Loading* Module to ship
- Integration of plumbing and electrical systems
- *Function test*

Advantages are:

- The work was faster because it was done in parallel with the construction of the ship.
- Quality is more assured because it is carried out in a controlled environment.

Disadvantages:

- High precision is required in planning size and position.
- Risk of integration errors if ship design changes

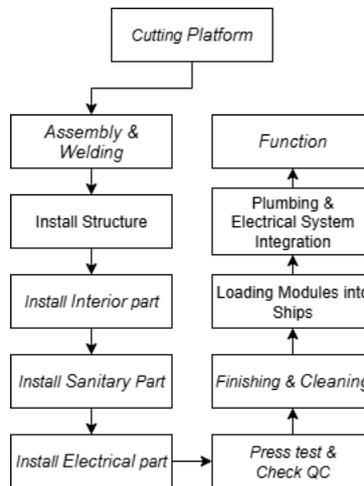


Figure 4. Modular Installation Flow

2.4 Modularization in the Maritime Industry

Modularization is a construction approach by dividing a system into modular units that can be assembled separately before final integration. In the maritime industry, this method is starting to be widely applied to increase shipyard productivity, especially in the construction of ship blocks and interior systems such as lavatories, crew rooms and galley areas. Advantages of modularization based on various research:

- Production time is shorter because work can be done in parallel.
- Quality is more stable because work is carried out in a controlled area (workshop).
- Ease of testing and quality control before integration with the ship's main systems.

There are several risks that can occur during the installation process using conventional systems, such as:

- Limited workspace causes a decrease in productivity
- Failure and repeat work rates are high
- Dependence on weather conditions (especially when the lavatory is not completely closed)
- Delays in work due to unsynchronization with ship progress

There are also risks from installing using the modular method, namely:

- Incompatibility of module dimensions with actual space on the ship
- Errors at the assembly stage have a big impact because they are difficult to modify
- Logistical challenges when transporting and lifting modules
- Limitations in technical improvisation during integration

3. RESULTS AND DISCUSSION

The implementation of conventional lavatory manufacturing and assembly becomes a problem for the completion of the overall work because the installation or installation waits for the formation of the room where the lavatory is placed (waiting for the block / construction to be completed). In general, the problems that are at risk of occurring with the conventional lavatory unit manufacturing pattern are:

- There is a lot of waiting time (waiting time for material arrival, waiting time for the assembly block, welding block, painting process)
- Work is carried out sequentially (series)
- Long processing time
- Limited work location

The installation of this lavatory is done by considering the aspects of time, number of man-hours, cost and quality. To accelerate and improve, the manufacture of the conventional lavatory unit method is changed to a modular method by doing its own fabrication according to the specifications and drawings obtained from the design team. The advantages of the modular system are:



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- Ensure the readiness of the lavatory unit to be installed according to the ship's production requirements schedule at the erection/joint block stage
- The work location is wide because it is carried out in a workshop
- Has a high level of accuracy
- Inspection can be carried out before the lavatory unit is integrated on the ship.

On the ship's landing platform dock (LPD) there are several types of toilets. However, in the research, the author adapted to the research object in the shipyard and only used 3 types of toilets with different dimensions and shapes. Figure 5 below are pictures of the three toilets.

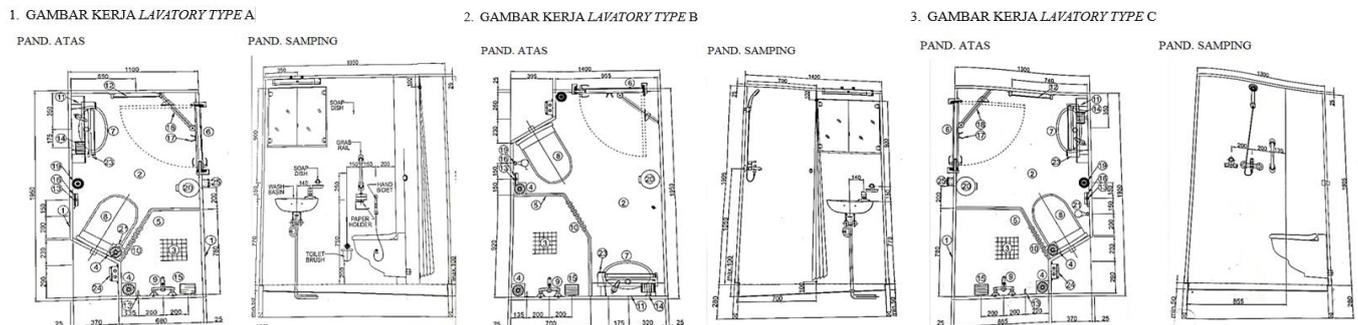


Figure 5. Working image of the Lavatory Module

3.1 Material Preparation

Material requirements to be used for the fabrication of lavatory modules (maximizing local materials & materials not imported) with consideration of increasing the TKDN value and accelerating the procurement of the required materials. According to Table 1 to Table 3 below:

Table 1. Material Requirements for Type A Lavatory

	Structure	Price
1	Plate 4mm for platform	Rp. 1,322,000
2	Plate 1.8 mm for side frame	Rp. 706,000
3	Profile Angle 40 x 40 mm for the upper frame	Rp. 244,000
4	Round bar 18 mm diameter for shower coaming	Rp. 60,000
5	Scupper bowl & drain pipe diameter 50 mm sch. 40	Rp. 124,000
6	Flat bar 1mm for cement anchor	Rp. 35,000
<i>Interior & Accessories:</i>		
7	Wall panels/lining	Rp. 17,836,000
8	Bottom Profile	Rp. 98,000
9	Ceiling Panel	Rp. 3,408,000
10	Hollow door	Rp. 5,046,000
11	Inspection door	Rp. 1,877,000
12	cement	Rp. 405,000
13	Floor ceramics	Rp. 908,810
14	Mirror box	Rp. 449,000
15	Curtain	Rp. 99,950
16	Soap dish	Rp. 89,970
17	Grab rail	Rp. 255,500
18	Towel bar	Rp. 279,000
19	Tissue paper holder	Rp. 199,000
<i>Sanitary Parts:</i>		
20	Wash basin/wash basin	Rp. 763,800
21	Closet vacuum type	Rp. 24,864,000
22	Jet shower/faucet	Rp. 207,000
23	Shower C/Whot & cold system	Rp. 2,399,000
<i>Electrical Parts:</i>		
24	Cables & lights	Rp. 406,000
25	Light switch	Rp. 14,000
26	Junction box	Rp. 96,000
27	Exhaust fan	Rp. 1,110,000
28	Copper pipe for hot water	Rp. 2,956,000



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29	<i>Plica tube</i>	Rp. 213,900
30	<i>Sleeve thread wall connection</i>	Rp. 323,000
31	<i>Flexible valve</i>	Rp. 495,800
32	<i>Elbow & flexible hose</i>	Rp. 147,160
TOTAL		Rp. 67,437,890

Table 2. Material Requirements for Type B Lavatory

	Structure	Price
1	<i>Plate 4mm for platform</i>	Rp. 1,322,000
2	<i>Plate 1.8 mm for side frame</i>	Rp. 706,000
3	<i>Profile Angle 40 x 40 mm for the upper frame</i>	Rp. 244,000
4	<i>Round bar 18 mm diameter for shower coaming</i>	Rp. 60,000
5	<i>Scupper bowl & drain pipe diameter 50 mm sch. 40</i>	Rp. 124,000
6	<i>Flatbar 1mm for cement anchor</i>	Rp. 35,000
<i>Interior & Accessories:</i>		
7	<i>Wall panels/lining</i>	Rp. 4,800,000
8	<i>Bottom Profile</i>	Rp. 153,600
9	<i>Ceiling Panel</i>	Rp. 480,000
10	<i>Hollow door</i>	Rp. 3,440,000
11	<i>Inspection door</i>	Rp. 826,400
12	<i>cement</i>	Rp. 405,000
13	<i>Floor ceramics</i>	Rp. 908,810
14	<i>Mirror box</i>	Rp. 449,000
15	<i>Curtain</i>	Rp. 99,950
16	<i>Soap dish</i>	Rp. 89,970
17	<i>Grab rail</i>	Rp. 255,500
18	<i>Towel bar</i>	Rp. 279,000
19	<i>Tissue paper holder</i>	Rp. 199,000
<i>Sanitary Parts:</i>		
20	<i>Wash basin/wash basin</i>	Rp. 763,800
21	<i>Closet vacuum type</i>	Rp. 24,864,000
22	<i>Jet shower/faucet</i>	Rp. 207,000
23	<i>Shower C/Hot & cold system</i>	Rp. 2,399,000
<i>Electrical Parts:</i>		
24	<i>Cables & lights</i>	Rp. 406,000
25	<i>Light switch</i>	Rp. 14,000
26	<i>Junction box</i>	Rp. 96,000
27	<i>Exhaust fan</i>	Rp. 1,110,000
28	<i>Copper pipe for hot water</i>	Rp. 2,956,000
29	<i>Plica tube</i>	Rp. 213,900
30	<i>Sleeve thread wall connection</i>	Rp. 323,000
31	<i>Flexible valve</i>	Rp. 495,800
32	<i>Elbow & flexible hose</i>	Rp. 147,160
TOTAL		Rp. 48,872,890

Table 3. Material Requirements for Type C Lavatory

	Structure	Price
1	<i>Plate 4mm for platform</i>	Rp. 1,322,000
2	<i>Plate 1.8 mm for side frame</i>	Rp. 706,000
3	<i>Profile Angle 40 x 40 mm for the upper frame</i>	Rp. 244,000
4	<i>Round bar 18 mm diameter for shower coaming</i>	Rp. 60,000
5	<i>Scupper bowl & drain pipe diameter 50 mm sch. 40</i>	Rp. 124,000
6	<i>Flatbar 1mm for cement anchor</i>	Rp. 35,000
<i>Interior & Accessories:</i>		
7	<i>Wall panels/lining</i>	Rp. 4,800,000
8	<i>Bottom Profile</i>	Rp. 153,600



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9	<i>Ceiling Panel</i>	Rp. 480,000
10	<i>Hollow door</i>	Rp. 3,440,000
11	<i>Inspection door</i>	Rp. 826,400
12	<i>cement</i>	Rp. 405,000
13	<i>Floor ceramics</i>	Rp. 908,810
14	<i>Mirror box</i>	Rp. 449,000
15	<i>Curtain</i>	Rp. 99,950
16	<i>Soap dish</i>	Rp. 89,970
17	<i>Grab rail</i>	Rp. 255,500
18	<i>Towel bar</i>	Rp. 279,000
19	<i>Tissue paper holder</i>	Rp. 199,000

Sanitary Parts:

20	<i>Wash basin/wash basin</i>	Rp. 763,800
21	<i>Closet vacuum type</i>	Rp. 24,864,000
22	<i>Jet shower/faucet</i>	Rp. 207,000
23	<i>Shower C/Whot & cold system</i>	Rp. 2,399,000

Electrical Parts:

24	<i>Cables & lights</i>	Rp. 406,000
25	<i>Light switch</i>	Rp. 14,000
26	<i>Junction box</i>	Rp. 96,000
27	<i>Exhaust fan</i>	Rp. 1,110,000
28	<i>Copper pipe for hot water</i>	Rp. 2,956,000
29	<i>Plica tube</i>	Rp. 213,900
30	<i>Sleeve thread wall connection</i>	Rp. 323,000
31	<i>Flexible valve</i>	Rp. 495,800
32	<i>Elbow & flexible hose</i>	Rp. 147,160
TOTAL		Rp.48,872,890

From the data on material requirements for making a lavatory according to the Table 3 above, type A lavatory requires material costs of Rp. 67,437,890, type B lavatory Rp. 48,872,890, and type C lavatory Rp. 48,872,890.

3. 2 Data retrieval

Based on field studies and data from previous experiences, a schedule for the manufacture and installation of lavatories using conventional and modular methods was obtained. The Microsoft Project schedule shows in Figure 6 below that the construction of Type A, B and C modular lavatory systems can be completed before the construction schedule is completed so that the lavatory is ready to be loaded according to needs. The duration for making a modular lavatory system is the same as the manual schedule, namely for type A lavatory 10 days, type B 12 days and type C 14 days.



Figure 6. Modular Method Actual Schedule Gantt Chart

Based on the manual schedule and Microsoft project for making a modular lavatory system above, the need and cost of person hours can be calculated as follows:

Table 5. Modular Method Man-Hour Cost Calculation

Item	Duration (days)	Number of People	Working hours / day	JO	Cost (Rate: Rp. 52,800,-)
<i>Lavatory Type A</i>					
Cutting & Fabrication Platform	2	2	6	24	Rp. 1,267,200,-
Assembly & Welding Platform	2	2	6	24	Rp. 1,267,200,-
Fabrication & Install structure	2	2	6	24	Rp. 1,267,200,-
Install Interior parts	2	2	6	24	Rp. 1,267,200,-
Install sanitary parts	2	2	6	24	Rp. 1,267,200,-
Install electrical parts	2	2	6	24	Rp. 1,267,200,-
Press Test & QC Check	3	2	6	36	Rp. 1,900,800,-
Cleaning & Finishing	2	2	6	24	Rp. 1,267,200,-
Loading Modules onto the ship	2	2	6	24	Rp. 1,267,200,-
Integration of plumbing and electrical systems	1	2	6	12	Rp. 633600,-
Function test	2	2	6	24	Rp. 1,267,200,-
TOTAL					Rp. 13,939,200,-
<i>Lavatory Type B</i>					
Cutting & Fabrication Platform	4	2	6	48	Rp. 2,534,400,-
Assembly & Welding Platform	4	2	6	48	Rp. 2,534,400,-
Fabrication & Install structure	4	2	6	48	Rp. 2,534,400,-
Install Interior parts	4	2	6	48	Rp. 2,534,400,-
Install sanitary parts	2	2	6	24	Rp. 1,267,200,-
Install electrical parts	2	2	6	24	Rp. 1,267,200,-
Press Test & QC Check	3	2	6	36	Rp. 1,900,800,-
Cleaning & Finishing	2	2	6	24	Rp. 1,267,200,-
Loading Modules onto the ship	2	2	6	24	Rp. 1,267,200,-
Integration of plumbing and electrical systems	1	2	6	12	Rp. 633600,-
Function test	2	2	6	24	Rp. 1,267,200,-
TOTAL					Rp. 19,008,000,-
<i>Lavatory Type C</i>					
Cutting & Fabrication Platform	6	2	6	72	Rp. 3,801,600,-



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Function & QC Test	2	2	6	24	Rp. 1,267,200,-
Total					Rp. 20,275,200,-
<i>Lavatory Type B</i>					
Cutting & Fabrication	5	2	6	60	Rp. 3,168,000,-
Transportation of materials to ships	4	2	6	48	Rp. 2,534,400,-
Install Coaming Platform	5	2	6	60	Rp. 3,168,000,-
Installation of Lavatory structure	6	2	6	72	Rp. 3,801,600,-
Install Interior Parts	6	2	6	72	Rp. 3,801,600,-
Install Sanitary Part	3	2	6	36	Rp. 1,900,800,-
Install Electrical Parts	2	2	6	24	Rp. 1,267,200,-
Finishing & Cleaning	3	2	6	36	Rp. 1,900,800,-
Function & QC Test	2	2	6	24	Rp. 1,267,200,-
Total					Rp. 22,809,600,-
<i>Lavatory Type C</i>					
Cutting & Fabrication	5	2	6	60	Rp. 3,168,000,-
Transportation of materials to ships	4	2	6	48	Rp. 2,534,400,-
Install Coaming Platform	7	2	6	84	Rp. 4,435,200,-
Installation of Lavatory structure	8	2	6	96	Rp. 5,068,800,-
Install Interior Parts	6	2	6	72	Rp. 3,801,600,-
Install Sanitary Part	3	2	6	36	Rp. 1,900,800,-
Install Electrical Parts	2	2	6	24	Rp. 1,267,200,-
Finishing & Cleaning	3	2	6	36	Rp. 1,900,800,-
Function & QC Test	2	2	6	24	Rp. 1,267,200,-
Total					Rp. 25,344,000,-

From the calculation results in the table above, it is obtained that the manufacture of modular lavatory type A requires 384 JO and a man-hour cost of Rp 20,275,200, type B requires 432 JO and a man-hour cost of Rp 22,809,600, and type C requires 480 JO and a man-hour cost of Rp 25,344,000. Based on the results of the comparative analysis of the manufacture to installation of the lavatory with conventional and modular methods, it can be summarized for man-hours, duration and total costs in Table 7.

Table 7. Total Cost Calculation

<i>Toilet</i>	Method	JO	Duration	Cost		
				JO	Material	Total
<i>TypeA</i>	Conv.	384	19	Rp. 20,275,200	Rp. 67,437,890	Rp. 87,713,090
	Modular	264	10	Rp. 13,939,200	Rp. 67,437,890	Rp. 81,377,090
<i>TypeB</i>	Conv.	432	22	Rp. 22,809,600	Rp. 48,872,890	Rp. 71,682,490
	Modular	360	12	Rp. 19,008,000	Rp. 48,872,890	Rp. 67,880,890
<i>TypeC</i>	Conv.	480	25	Rp. 25,344,000	Rp. 48,872,890	Rp. 74,216,890
	Modular	456	14	Rp. 24,076,800	Rp. 48,872,890	Rp. 72,949,690

The amount of rework in conventional methods is much higher than in modular methods. This can be explained by the following factors:

- In conventional methods, all work is carried out on a ship that is already standing (post-erection), so that space for movement is limited, visibility of work is low, and coordination between systems (structure, pipes, electricity) is more difficult.
- In addition, conventional methods rely more on manual accuracy in the field, which is prone to human error.
- In the modular method, the manufacture of lavatory units is carried out in a workshop that is more controlled in terms of dimensions, equipment access, and quality control (inline QC). Before the module is installed on the ship, a thorough inspection has been carried out on all installations including wall panel alignment, plumbing pressure test, and electrical continuity test.

The following is comparative data on errors that occur during the manufacture of lavatories using each method in Table 8 and a comparison of costs, duration and man-hours for each type, which is summarized from the table above.



Table 8. Comparison of Error Levels in Lavatory Manufacturing

Model	TypeA	TypeB	TypeC
Amount	19	9	3
Conv. (Error)	4	2	1
Modular (Error)	1	1	0

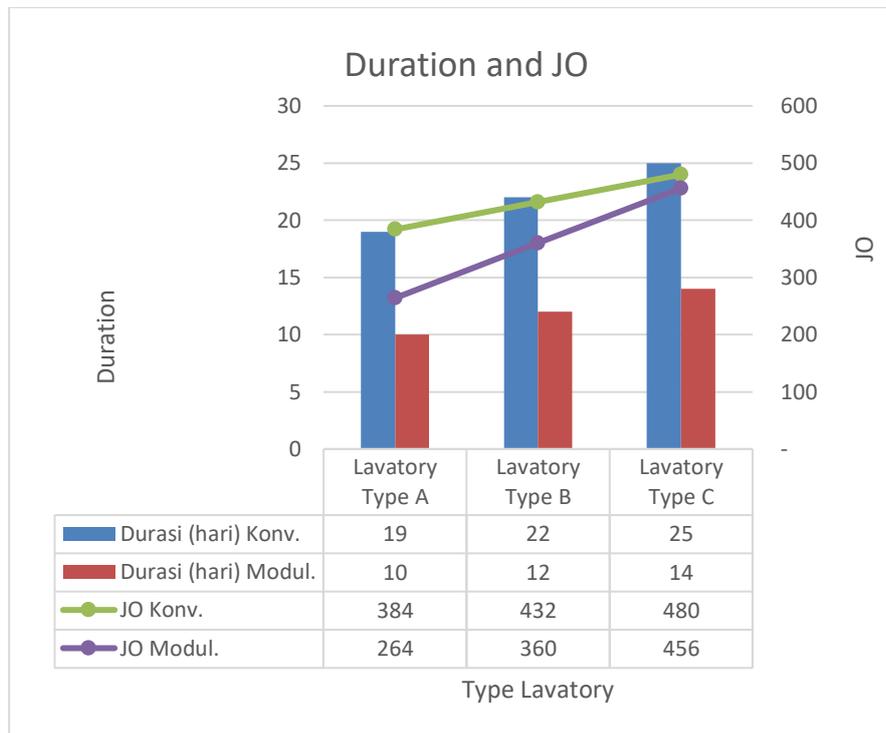


Figure 7. Comparison Graph of Duration Against Person Hours



Figure 10. Comparison Chart of Total Cost of Making a Lavatory

Productivity per worker increases with the modular method, because work is done with more complete tools and facilities. The modular method shows a sharp reduction in the number of installation errors. This is due to better quality control before installation into the lavatory.

4. CONCLUSION

Based on the results of research that has been conducted regarding the comparison of ship lavatory installation methods between conventional methods and modular methods on Landing Platform Dock (LPD) type ship platforms, several things can be concluded as follows:

- 1) Time Requirements for Job Implementation
The modular method has proven to be significantly more efficient in terms of implementation time compared to the conventional method. Installation of lavatory with the Conventional approach averages 19 days for Type A while with the modular approach for Type A 10 days. The conventional approach for Type B takes 22 days and the modular approach takes 12 days as well as Type C takes 25 days for the conventional approach and 14 days for the modular approach. This shows the time efficiency in installing Lavatory using the modular method. This time saving is obtained from the absence of waiting time from the previous process and alternating work locations as in the conventional installation process.
- 2) Man Hour Needs
Installation with modular method shows the number of Man Hours requirement is less compared to conventional method with details of Type A Man Hour requirement as many as 264 JO for modular, and 384 JO for conventional. Man Hour requirement of Type B as many as 360 JO for modular and 432 JO for conventional. Furthermore, Man Hour requirement of Type C as many as 456 JO for modular and 480 JO for conventional
- 3) Job Cost Requirements
From the calculation and simulation results, the modular method provides production cost savings consisting of the number of man-hour costs plus material costs where the production of Type A lavatory costs Rp81,377,090 with the modular method, and Rp87,713,090 with the conventional method. And the production cost of Type B lavatory is Rp67,880,890 in the modular method, and the conventional method costs Rp71,682,490. While for Type C, the production cost is Rp72,949,690 in the modular method and Rp74,216,890 in production with the conventional method.
- 4) Number of Rework/Error Occurrences
Installation with modular method shows better quality results, higher level of precision, and lower need for rework. This is due to quality control that is carried out simultaneously during the work process and before the module is shipped on board. In contrast, conventional methods often face challenges in non-ideal field conditions and a greater risk of human error due to many overlapping jobs in the process.

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