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Study on Implementation of Lean Six Sigma in Hospital Auxiliary Ship Block Construction Process

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Abstract

During the pandemic, transportation is needed to support the evacuation of patients through waterways; therefore, PT PAL Indonesia (Persero) has created a Hospital Auxiliary Ship project. In building a quality Hospital Auxiliary ship project, productivity is needed so the project can be completed properly. However, there are problems with the punctuality of completing the ship block construction with a total lead time of 19200 minutes and found the block quality is not up to standards like Surface Porosity, Former Stopper, Arc Strike, and Low Bead defects that require a rework process and cause long cycle times. This study aims to reduce the lead time value and minimize waste or activities that are not value-added using the lean six sigma method with stages (DMAIC). From the results of the study, it was found that the identification of the Process Activity Mapping (PAM) design, which resulted in the highest waste rating, namely 16.94% defect, with CTQ-4, lean six sigma value of 3.055 sigma and DPMO value of 59917 which was included in the excellent category for the industry average. The factors causing the problem were identified with Pareto diagrams and causal diagrams to determine the dominant type of defect and the causes of wastage of defects; there are four factors, namely material, human, machine, and environment. Recommendations for the improvement of waste are through material inspection, operator training, reworking defective blocks, and minimizing non-value-added activities. With the design of process activity mapping (PAM) and value stream mapping, the efficiency of ship block construction can increase from 67.81% to 74.06%.

1. Introduction

The tight competition in industrial activities in the current era triggers companies to show competitive advantages that are divided in terms of quality, cost, delivery time, and flexibility [1]. In addition to paying attention to product quality, the company can also be found in the environment. With the increasing number of products in the production process, there are indications of environmental impacts that occur in the production process [2]. Humans are the main factor in increasing productivity, but factors such as machines, work methods, location, and company buildings must be considered [3].

PT PAL Indonesia (Persero) is one of the companies in the maritime manufacturing sector that produces ships for both the state and the private sector. The project being built is an auxiliary hospital ship, as shown in Figure 1, when the ship block production process takes place, non-value-added waste occurs; as a result, the production cycle time is longer than the company's target. Based on initial observations, it was found that the lead time value was 19200 minutes; this was due to a large of non-value-added and necessary non-value-added activities, such as the process of storage and delay. In addition, it was found that the production of ship blocks had defects such as Surface Porosity, Stopper, Arc Strike, and Low Bead defects that required a rework process. Another source of waste is the lack of maintenance management of the products made, the lack of contractor knowledge, and designs that are not appropriate [4].

There are several previous studies in related Indonesia shipyards; W. Widiatmoko and Soejitno mention that productivity can be increased through productivity in hull construction by improving inventory and transport of materials to make it run effectively [5]. D. Madasari and Y. Praharsi mention that the production process wastes In the implementation of hull construction, where defects often occur, it is increased by rework [6]. Fitriadi and A. Faisal said that waste in the production process could occur because it is still using the traditional method and can be improved using continuous improvements can be made to the production line [7].

The lean six sigma method is applied for sustainable production in manufacturing and services [8]. The lean approach focuses on speeding up a process by reducing waste and the environment, while six sigma helps achieve higher product or service quality. As with ocean waste management, shipbuilding waste can be reduced by segregating non-value-added activities [9]. The principle of the existence of lean is that waste is reduced from a value stream, while six sigma aims at the target of the value stream [10]. The continuous improvement process through the DMAIC approach (define, measure, analyze, improve, and control) can reduce the process so that the output decreases and the number of products matches the quality [11]. The lean six sigma method is needed to reduce lead time and increase productivity, production output, and revenue. On the other hand, if the long waiting time harms the production process and affects various aspects, it will lose inventory in the warehouse and production line. Success in controlling lead time will result in higher revenue and profits.

The objective of this research is to reduce the waste that occurs in the auxiliary hospital ship block production process. The first step in reducing waste is to identify the cause of the problem and then take measurements using tools such as experimental design, life cycle interpretation, and value flow mapping (VSM). After knowing the cause of the problem, an analysis of the most influential causes of waste uses a fishbone diagram. The last stage focuses on solving the most critical problems that require corrective steps. Finally, the value of lean six sigma can increase, and the benefits can use to improve the company's quality standardization [12].

Figure 1. Ship Production Process

2. Methods

2.1 The object of research

This study integrates lean and six sigma methods to analyze the waste during the construction process of the 121 ship blocks for Hospital Auxiliary ships. This ship consists of 3 types of ship blocks under construction, namely block erection in the dock, block ready to erection, and block on the assembly process, with a total ship size of 124 meters. The lean six sigma method can determine the cause of block defects, especially surface texture defects and dimensions requiring rework and additional cycle time to repair those blocks (see Figure 2), represents the types and number of ship blocks built.

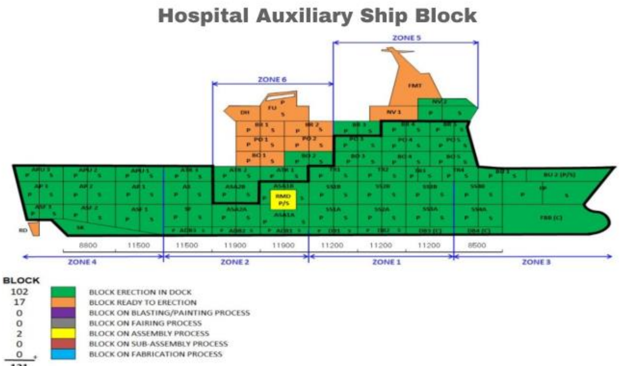

Figure 2. Ship Block Type

2.2 Treatment of research object

This study uses a comparison of cycle times for each activity in the shipbuilding process by measuring Value-Added Activities (VA), Non-Value-Added Activities (NVA), and Necessary but Not Value-Added activity (NNVA). After all, activities are measured, it can be seen that the lead time value in the ship block construction process causes long cycle times.

2.3 Method

The method used during this research was carried out non-experimentally with the data that had been provided. The data used are secondary data obtained from companies and primary data obtained through questionnaires. To solve this problem, a lean six sigma framework is used, namely DMAIC (Define, Measure, Analyze, Improve, Control). However, the control phase is not carried out and is only limited to a proposed improvement design to increase the productivity of the block development process. The analysis was carried out to answer the purpose of this research, namely to reduce the level of waste in terms of defects and shipbuilding cycle times. Furthermore, draw conclusions and suggestions for further research (see Figure 3), below shows the flow of problem-solving for research.

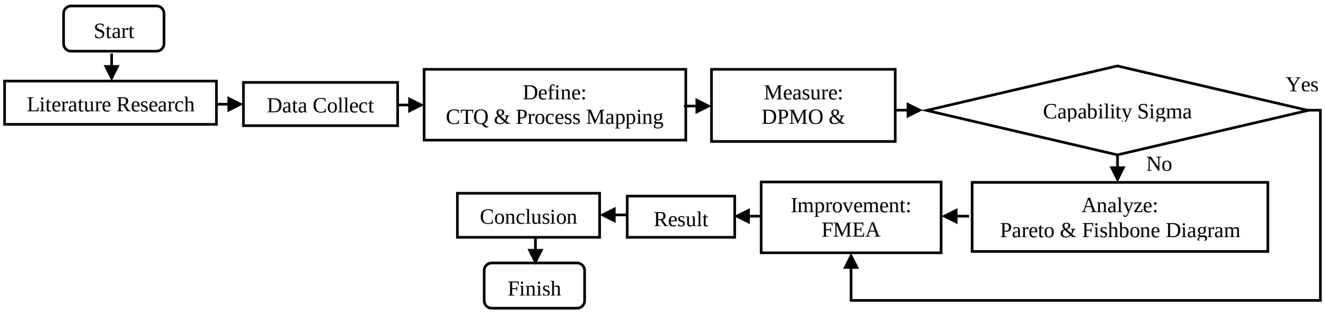

Figure 3. Research Flow Process

2.4 Tools and materials used in research

The tools used during the waste analysis process are Value Stream Analysis Tools (VALSAT), Big Picture Mapping (BPM), and Failure Mode Effect and Analysis (FMEA), which are described below.

1. Value Stream Analysis Tools (VALSAT)

In measuring the level of waste, data is collected on the entire activity of the production process to find out the waste that occurs in each activity. Then an analysis is carried out with Process Activity Mapping (PAM) to make details of each process on the required value-added, non-value added, and necessary non-value-added activities, as well as the creation of productivity of every step of the activity that occurs throughout the process[13]. Then, the highest correlation in waste was obtained, such as Over Production, Waiting, Excessive Transportation, Innarpropriate Process, Unnecessary Inventory, Unnecessary Motion, and Defect. The data was obtained by distributing questionnaires containing the various kinds of waste that existed later; the respondents measured the highest score ranking of the waste that occurred.

2. Big Picture Mapping (BPM)

Waste data is determined and processed by describing the production system as a whole. Waste can do by visualizing the flow of information and physical flow into a BPM [14]. With the help of this BPM tool, all the main activities in each industry can be mapped to be more easily analyzed, such as interactions between activities, waiting times, and points of failure.

3. Failure Mode Effect and Analysis (FMEA)

After identifying the elements of work that do not add value to the production process, then analyzing the problem of the emergence of causes of waste, the problem must be clearly defined because the results of the waste factor will be the basis for making recommendations. The tool used to analyze the problem is FMEA which works to see failures by measuring and analyzing the RPN value of each cause so that the failure rate can be minimized.

3. Results and Discussion

The construction of the Auxiliary Hospital ship block has a relatively long stage; therefore, accuracy is needed in building the ship block. Below, an analysis will be carried out to determine the causes of waste and the factors that influence it. The lean six sigma method and other supporting data will be carried out in stages of analysis such as define, measure, analyze, and improve, described below.

3.1 Define Cause of Waste Ship Block

This stage identifies the causes of waste during the ship block construction process. Identification is made by describing the main process map as a whole, consisting of a map of the information flow and physical flow through value stream mapping. Many things can cause waste; for example, waiting time is long enough between processes, causing block queues. The existence of lead times in the block construction process can result in high costs for maintenance and supervision activities of the ship block. This is what causes the company to carry out the production process effectively and efficiently and improve lead times in the ship block construction process.

a. Information flow of block building activity
   1) Materials stored in warehouses are transferred to workshops to be processed into ship blocks
   2) After the material arrives, it is necessary to identify the quality by the QA/QC division and make a report for the warehouse supervisor.
   3) Sorting is done for the material to be used, separated between plates, and raw profiles are ready to be processed according to the design.
   4) The Steel Stock House (SSH) stage performs the blasting process to obtain materials that meet the standards.
   5) Furthermore, the materials that have been blasted are labeled to distinguish between materials.
   6) While waiting for the following process, the labeled material is stored temporarily.
   7) Materials are transferred to the fabrication stage by using a forklift.
   8) Before the material is processed, it is necessary to set up and control the material and machines used.
   9) At this stage of fabrication, the material is marked in the form of a line pattern according to the design size; the aim is to make it easier to cut at the next stage.
   10) After the material is marked, the material is cut according to the line pattern. At this stage, the cutting is done manually for small materials and by machine for large enough materials.

11) The material that has been cut is then smoothed on the edges to make it neat and ready for further processing.
12) After that, the material is waiting and labeled for the next stage.
13) Materials are transferred to the sub-assembly stage by using a forklift.
14) Before the material is processed, it is necessary to set up and control the material and machines used.
15) Materials that have been processed are re-sorted.
16) At the subassembly stage, the process carried out is welding the material to form a ship block.
17) The initial ship block that has been processed is then smoothed.
18) After that, the ship block is taken to the assembly workshop using a forklift.
19) Before the material is processed, it is necessary to set up and control the material and machines used to avoid failure.
20) Materials that have been processed are re-sorted.
21) The material to be processed is adjusted or fit-up.
22) The last stage is assembly by welding all the materials used as ship blocks.
23) Accuracy check stages are carried out in the form of checking dimensions according to the design to maintain the ship block's quality.
24) Quality control of the finished ship blocks is carried out by the QA/QC division to determine the standard of blocks that are ready for further processing. If the block is defective, it needs to be reworked.
25) The finished block is moved to the following process for erection.

b. Physical flow of block building activity
   1) Materials in the form of plates and profiles come from a storage warehouse
   2) Materials are inspected by the QA/QC division to identify their quality, which is inspected in the inspection of dimensions, types, and quantities of materials.
   3) During the block construction process, the QA/QC division continuously monitors the quality of the built blocks, especially during the welding process, which is prone to defects.

After identifying each material flow and physical activity of block construction, a table is made to distinguish value-added activities like operations. Necessary non-value-added activities are transportation and inspection activities. Meanwhile, non-value-added activities are waiting activities and delays that have to be minimized.

Table 1. Value Added (VA), Non-Value Added (NVA) Activities

No	Process	VA (minutes)	NVA (minutes)
	Steel Stock House (SSH)		
1	Material Receipt		120
2	Control Material		120
3	Sortir		120
4	Blasting	480	
5	Labelling		60
6	Buffer		120
7	Transportation Transfer		60
	Fabrication		
8	Set Up & Control		60
9	Marking		60
10	Cutting	1440	
11	Grinding	1440	
12	Labelling		480
13	Trans to Sub Assembly		960
	Sub Assembly		
14	Set Up & Control		960
15	Sortir		480
16	Sub Assembly	2400	
17	Grinding	2400	
18	Trans to Assembly		240
	Assembly		
19	Set Up & Control		960
20	Sortir		480
21	Fitt Up	2400	480
22	Assembly	2400	
23	Check Accuracy		
24	Quality Control		240
25	Trans to Block Blasting		240
	Total	13020	6180
Lead time		**19200**	

Based on Table 1, then the Process Cycle Efficiency (PCE) value can be determined using the Eq. 1 [1]:

$$PCE = \frac{value\ added}{lead\ time} \times 100\% \quad (1)$$

Estimating the PCE in Equation. 1 is PCE = (13020/19200) × 100% = 67,81%. The total power required is 67,81%%. Therefore, the process of building block ships is still not running efficiently and effectively, so improvements are needed. Based on the Table 1 , current value stream mapping is made based on the information flow data and physical flow, as shown in Figure 4 Based on the data flow of information and physical flow, a value stream mapping is made to understand the overall system of the production process, and then it will be classified based on the accumulated time that occurs in each value-added and non-value-added activity in detail with VALSAT. Based on this state map, the total lead time is 19200 minutes, which determines the block-building time and needs to reduce by non-value-added activities such as storage and delay. In addition, a high lead time impacts low productivity in the production process and causes cycle times.

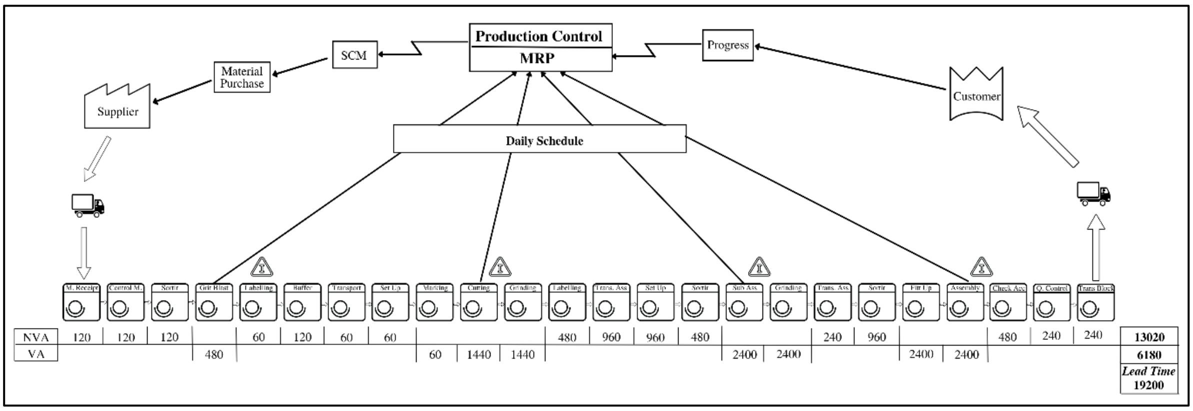

Figure 4. Current Value Stream Mapping

3.2 Measure Waste of Ship Block

The measuring stage performs calculations by measuring the company's current performance conditions so that the company's achievements can be known. The data needed in research on lean six sigma are:

a. Block building waste questionnaire
b. Ship block process time
c. Defect per ship block

Table 2. Lean Recapitulation Result

Waste	Weight	Ranking
Defect	2,0	1
Transportation	1,9	2
Waiting	1,8	3
Unnecessary Motion	1,7	4
Innarpropriate Process	1,6	5
Unnecessary Inventory	1,5	6
Overproduction	1,3	7

Based on Table 2, the most significant waste that occurs during the construction of the ship block is a defect because the ship block has many defects in its manufacture, especially during the welding process. Therefore, the operator must consider the accuracy factor to reduce the level of ship block defects. As for the most negligible waste in overproduction, there is no excessive block construction because the ship block construction is under the project needs.

Table 3. VALSAT Result

Waste	Weigh t	VALSAT						
		PAM	SCRM	PVF	QFM	DAM	DPA	PS
Over Production	1,3	1,3	3,9	0	1,3	3,9	3,9	0
Waiting	1,8	16,2	16,2	1,8	0	5,4	5,4	0
Excessive Transportation	1,9	17,1	0	0	0	0	0	1,9
Innarpropriate Process	1,6	14,4	0	4,8	1,6	0	1,6	0
Unnecessary Inventory	1,5	4,5	13,5	4,5	0	13,5	4,5	1,5
Unnecessary Motion	1,7	15,3	1,7	0	0	0	0	0
Defect	2,0	2,0	0	0	18,0	0	0	0
Total Weight		70,8	35,3	11,1	20,9	22,8	15,4	3,4

The calculation results above are obtained by multiplying the results of the wastage weight with the VALSAT scale. Based on Table 3, above, the percentage results of the assessment process are obtained. It can be seen that PAM has the highest value, amounting to 70.8, so the tools used in this research waste analysis use PAM. Next, identify the type and number of defects that occur during the construction of the ship block. The observations were used for the preparation of the CTQ, and it was found that the ship blocks have four types of CTQ which are described in Figure 5, 6, 7 and 8

Figure 5. Surface Porosity Defect

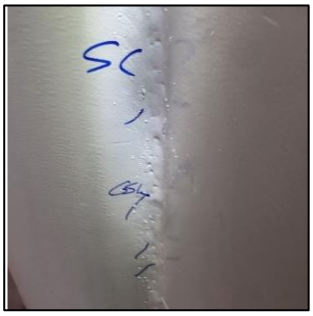

Figure 6. Former Stopper Defect

Figure 7. Low Bead Defect

Figure 8. Arc Strike

Table 4. Block Defect Data

Defect	Total	Percentage
Surface Porosity	7	5,78%
Former Stopper	11	9,09%
Arc Strike	9	7,43%
Low Bead	2	0,82%

The calculation results show that the sigma value is 3.055, which shows that it can compete in the Indonesian industry. Because a manufacturing company in the maritime sector, ship block construction standards must be tightened to have quality results. Then the Defect per opportunites (DPO) and Defect per Million Opportunities (DPMO) value can be determined using the Equation 2[15] and Equation 3[16]:

$$DPO = \frac{total\ block\ defect}{total\ building\ block \times CTQ} \tag{2}$$

$$DPMO = DPO \times 1000000 \tag{3}$$

The calculation to determine the value of DPO in Eq. 2 is DPO = 29/(121×4) = 0,059917. While DPMO in Eq 3 is. DPMO = 0,059917×1000000 = 59917.To measure the sigma value, tools are used in the form of a sigma conversion table or Microsoft Excel. This study used the help of Microsoft Excel with the formula Equation 4 [17] following.

$$Six\ Sigma = normsiv\left(\frac{1000000 - DPMO}{1000000}\right) + 1,5 \tag{4}$$

From the results of Equation 4 of calculations using the help of Microsoft Excel, it can be seen that the sigma value is 3.055, which shows that it can compete in the Indonesian industry. Because PT PAL Indonesia is a manufacturing company in the maritime sector, ship block construction standards must be tightened to have quality results.

3.3 Analyze Waste of Ship Block

The analysis stage aims to analyze the root cause of the problem. Based on Table 3, the waste identified during the ship block construction process is as follows.

a) Defect: occurs because the construction of the block does not comply with quality specifications according to company standards. Usually, defects come from the welding process, fitting design improvements, and processes not following work standards.
b) Excessive Transportation: The layout in the workshop between workstations is far enough so that the movement of people, information, and materials can be delayed. For example, the next step is carried out in finishing material or blocks, but the process is still busy, so it is delayed and returned to the previous workshop and mixed with other processes.
c) Waiting: occurs due to incomplete materials or blocks and results in waiting for the following work. In addition, conditions where humans, materials, and information are inactive for an extended period while waiting for the process.
d) Unnecessary Motion: occurs because the operator moves too much in picking up the material, causing fatigue. As well as workplace conditions with non-ergonomic equipment, the operator makes unnecessary movements when carrying out activities.
e) Inappropriate Processing: The flow of information in the design drawings does not match the material sent to the production workshop, causing an increase in lead time because the material process has not been fully processed.
f) Unnecessary Inventory: there are buffers or leftover raw materials throughout the block production process, such as between the fabrication process and the sub-assembly and between the sub-assembly and the assembly, so the blocks should be completed at the same time.

From the activity mapping process, the overall time of the ship block construction process was 19200 minutes, with a total of 25 activities in the process, as shown in Table 5 & 6.

Table 5. Current Time of Each Activity

Activities	Total	Time (minutes)	Percentage (%)
Operation	8	13020	67,82%
Transportation	5	1620	8,44%
Inspection	6	2820	14,68%
Storage	1	120	0,62%
Delay	5	1620	8,44%%

Table 6. VA, NVA, and NNVA

Category	Total	Time (minutes)	Percentage (%)
Value added (VA)	8	13020	67,82%
Necessary Non Value Added (NNVA)	12	4560	23,75%
Non Value Added (NVA)	5	1620	8,43%

Based on Table 4, the causes of the highest defects can be analyzed using a Pareto diagram as in Figure 9 then, analyze the causes of the most dominant defects as follows.

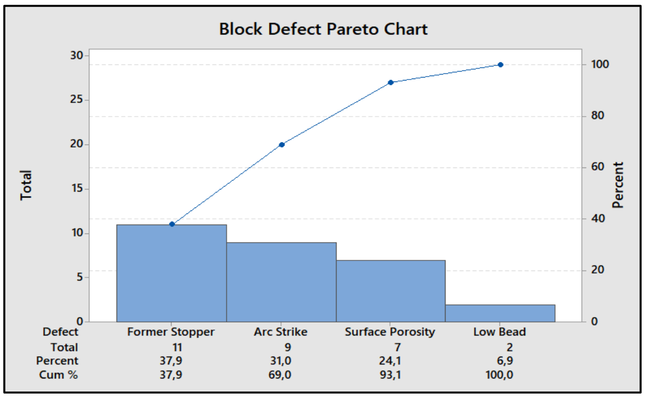

Figure 9. Block Defect Pareto Chart

It can be seen frrom Figure 9 that the types of defects that occur in the ship block construction process show that the types of defects that are used for stoppers are the most dominant defects, with a cumulative percentage of 37,9%. So it is assumed that 37,9% can represent all types of defects in the block construction process.

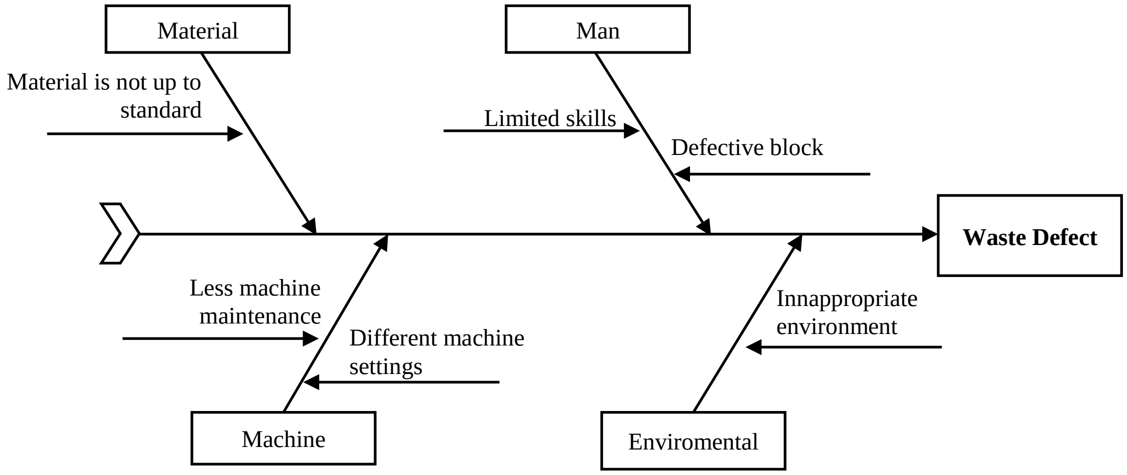

Figure 10. Fishbone Diagram of Defect

The cause-and-effect diagram of the causes of wastage of defects is in Figure 10, shows four factors that cause wastage of defects: human, material, machine, and environmental. The root cause of wastage of defects in terms of material, namely materials, especially plates and profiles that do not meet company standards, can be in the form of differences in dimensions and material quality. The cause from a human perspective is the operator's lack of skill and expertise when building blocks; besides, there are defective blocks that need to be reworked to be repaired. The cause in terms of the machine is that the machine or production support equipment is quite old and needs to be treated; besides that, different types of machines have different settings. In comparison, the causes that are viewed from the environment are high air temperatures that can affect the production process and the operator in operating the machine.

3.4 Improvement Waste of Ship Block

The improvement stage is carried out to reduce waste in the ship block construction process; the method is to determine an improvement plan during the block construction process and identify the priority of the repair plan.

Table 7. FMEA of Defect

Potential Failure Mode	Potential Effect of Failure	S	Potential Cause	O	Curent Control	D	RPN
Proses pembangunan blok	Waste Defect	9	Material is not up to standard	8	Material inspection	8	576
			Limited skills	7	Training the operator	8	504
			Defective block	8	Rework block defect	6	432
			Less machine maintenance	6	Schedule machine maintenance	7	378
			Different machine setting	7	Recalibrate the machine	5	315
			Innappropriate environment	5	Anticipating the environment	5	225

Based on FMEA Table 7, on the waste of defects, it is known that the highest RPN value is 576. The proposed improvement that needs to be done is to inspect the dimensions and quality of the material, especially plates and profiles that will be used as blocks to maintain company standards.

Table 8. Time of Each Proposed Activities

Activity	Total	Time (minutes)	Percentage (%)
Operation	8	13020	74,07%
Transportation	5	1620	9,21%
Inspection	4	2220	12,63%
Storage	1	120	0,68%
Delay	2	600	3,41%

Based on Table 8, it can be seen that there are 25 activities during the ship block construction process. After improvements have been made to the ship block construction process, the proposed activities are changed to 20 activities that come from merging stations and reducing non-value-added activities because they are inefficient and have no effect on the process. The proposed value-added changed to 12600 minutes, while the proposed non-value-added changed to 4980 minutes, so the lead time based on future state mapping was reduced by 1620 minutes. The future state VSM diagram depiction is shown in Figure 11.

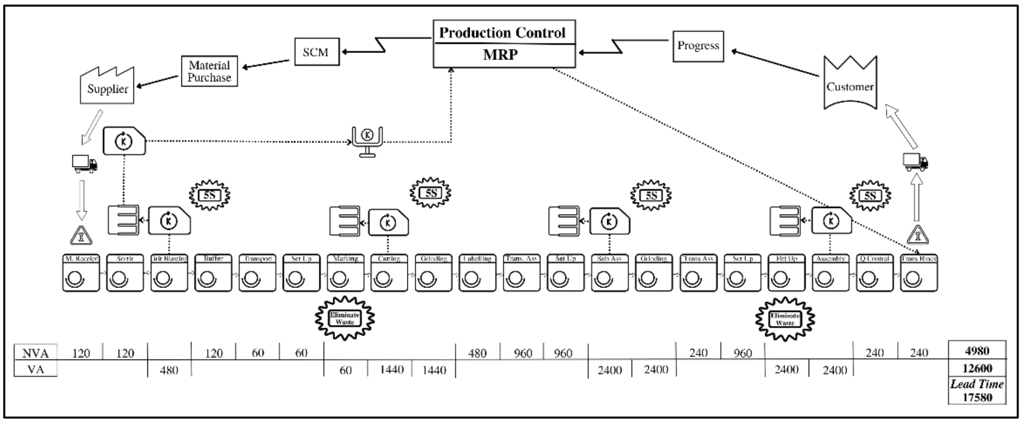

Figure 11. Future State Mapping

4. Conclusion

From the results of the examination of waste using the lean six sigma method, it can be seen that the most significant waste is 20%. Therefore, it is efficient to obtain a lean six sigma value of 3.055 sigma with a DPMO of 59917. After the improvement process that comes from reducing value added and has no effect on the process, the lead time value of 19200 minutes is reduced by 17580 minutes. It is expected that this can increase the productivity and efficiency of ship block construction from 67.81% to 74.06%. The most significant cause of waste is that materials do not meet company standards and will face obstacles. Recommendations for repairs made to examine plate and profile materials prior to inspection.

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