Lean six sigma methodology for waste reduction in ship production

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ABSTRACT

This study was conducted to reduce the amount of waste in ship production and assembly processes at PT ES. Several wastes during the ship production process result in the actual ship completion time being longer than the planning time set by the process planner. Therefore, accurate analysis is required to reduce waste. In this way, contributing factors can be identified, and more effective solutions can be obtained to reduce waste. This is done by implementing the Lean Six Sigma method (DMAIC processes) and several tools and methods, such as Pareto and fishbone diagrams and the FMEA method. The results show that the most critical potential root cause affecting production delays comes from the potential causes with the highest Risk Priority Number (RPN) value. The causes are welders who do not understand the WPS (RPN 432), unstable welding transformers (RPN 432), and unproductive loader movements (RPN 384). The recapitulation of welding defects produced in the production process at a sigma level of 2.48. Recommendations for the three potential critical wastes were made and planned for implementation. The estimated average RPN impairment for the three critical root causes was 32.3%. This condition will impact the total ship production time, which is 6% shorter (equivalent to 14 days) than the previous production time with a new sigma level of 2.55.

Keywords: Ship production; Lean Six Sigma; DMAIC; Sigma Level; RPN

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1. INTRODUCTION

The increasing demand for ships, primarily barges, has compelled the shipyard industry to compete to increase productivity in the production process and gain customer trust. Productivity is the key to the successful competitiveness of shipyard companies [1]. Inadequate work process management, excess scrap, and delays in ship delivery times from the planned time are often encountered in several shipyards in Indonesia [2]. Increased productivity can occur if the company systematically identifies waste earlier, streamlines operations, and improves the quality [3]. Therefore, the background of this research is the problem of productivity in the barge production process that occurs at PT ES. Historical data show a production delay of 48% of total ship production in the last three years (2019-2021). For example, the production time for the 330 ft barge in 2021 was delayed by eight weeks from the planning time set by management for 30 weeks. The shipbuilding process, which still has production problems, is caused by large amounts of waste. Therefore, special attention is required to improve performance. Another aspect that causes large production waste is rework owing to a large number of defects in the production process [4].

The Lean Six Sigma (LSS) method is a tool that can be used by manufacturing companies to eliminate or minimize waste to achieve Six Sigma using the DMAIC process (Define, Measure, Analyze, Improve, Control) [5]. The cycle of define, measure, analyze, improve, and control (DMAIC) in Six Sigma is widely used in Indonesia to solve quality challenges [6]. Lean practices improve operational and environmental performance by reducing waste, enhancing process efficiency, optimizing operational capabilities, and effectively utilizing resources [7]–[9]. In contrast, Six Sigma focuses on reducing variations and improving processes [10]. LSS, as a combined process improvement approach, has been employed over the last three decades to improve operational efficiency and reduce the causes of defects in business processes [11].

Implementing the Lean Six Sigma strategy provides better results in the manufacturing sector, but few articles have been published on LSS implementation in the manufacturing area [12]. In addition, LSS can enhance the implementation of automation strategies for process improvement and effective delivery [13].

LSS in the manufacturing industry can identify the factors that cause a company's failure to implement LSS [14]. This condition can still be improved so that project completion follows what the company sets.

2. METHODS

This study used a qualitative descriptive method by taking primary data from the production and QC departments and observing and recording waste activities during the fabrication, assembly, and erection processes. Secondary data from documentation and interviews with related parties (managers and operators).

1. **Define**. At this stage, Flow Process Mapping is performed to describe the actual condition of a ship production process following the General Arrangement so that it can provide information and identify the waste that occurs in each activity process. Flow Process Mapping can identify all the types of waste that occur in existing production systems.
2. **Measure**. At this stage, Pareto Diagrams of waste activities for each type of waste were constructed. The Pareto diagram aims to determine the waste-value activities with the greatest frequency (critical waste) compared to other non-value-added activities. At this stage, DPMO and Sigma Level measurements were also performed.
3. **Analyse**. At this stage, the factors that most affected the process were analyzed using the Fishbone Diagram. The critical waste obtained from each type of waste (waste) was used as input to create a Fishbone Diagram to determine the root cause of the problem in the shipyard. After obtaining the root of the problem, FMEA analysis was performed to determine and rank the Risk Priority Number (RPN) values of the overall root cause of the problem.
4. **Improve**. After obtaining the RPNs at this stage, we focus on the recommended improvements from the highest RPNs. If improvements are made based on recommendations, the latest RPN can be predicted so that the ship productivity time and sigma value can be estimated in the future.
5. **Control**. At this stage, the proposed improvements that have been obtained at the improve stage are maintained and controlled for future implementation so that waste that will arise can be overcome or minimized.

3. RESULTS AND DISCUSSION

3.1 Define

Flow Process Mapping (FPM) was performed at this stage to describe the actual conditions of ship production processes (Figure 1). This FPM shows all ship production activities in the fabrication, assembly, and erection stages, thus providing information for identifying the waste that occurs.

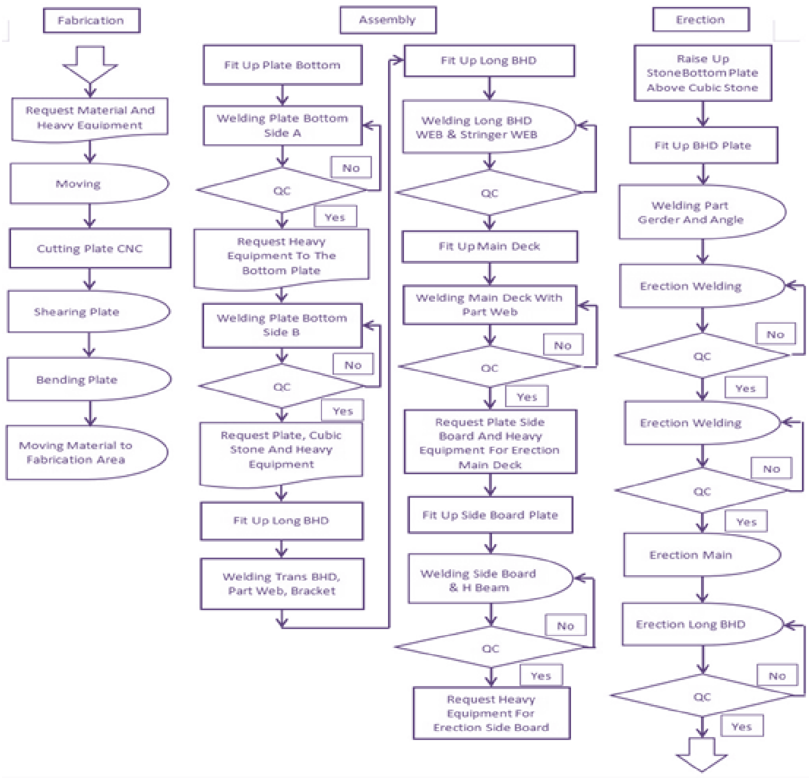

Figure 1: Flow Process Mapping for ship production (barge 330 ft)

Ship production waste was defined according to the following seven waste criteria:

1. Over production, which almost does not occur because the production process is based on orders,
2. Defects, that originate from the welding process and improper fit-up,
3. Unnecessary inventory arises due to the accumulation of material during the production process,
4. Inappropriate process occurs when the operators repeat the process in the production workshop,
5. Unnecessary transportation, which is caused by material blocking Loaders and Cranes from traveling longer distances
6. Waiting, which is caused by heavy equipment (loaders or cranes) and material requests
7. Unnecessary motion, there is a movement of the auxiliary equipment, which makes the travel time longer, which does not have added value

The results were obtained at the defined stage by identifying the types of waste activities based on the Flow Process Mapping. There were 23 types of dominant waste activities observed in the six categories.

3.2 Measure

At the measurement stage, the results obtained were the critical waste from each waste through Pareto diagrams (as shown in Figures 3, 4, and 5). Critical waste was determined using the 80/20 rule, meaning that 20% of defects can cause 80% of process failures. All measurement data for the seven wastes in ship production are listed in Table 1.

Table 1 : Waste during the production process (fabrication, assembly, and erection)

Type of waste	Activities	Qty	%	Critical (*)
Waiting [minute]	Loaders must rotate when carrying plates, causing a queue.	24’	5.66	
	The shearing machine stops working because there is no plate on the table Gantry Crane is used to raise the WEB plate to the Bending machine table.	20’	4.72	
	The loader must clean the area first before trans bulkhead fabrication.	160’	37.74	*
	Fitter is waiting for the crane to lift the web plate when joining the web plate with the longitudinal bulkhead.	15’	3.54	
	Fitter waiting for the crane to lift web plate when joining web plate with transverse bulkhead	10’	2.36	
	The loader removes the material blocking the Angle Bar	35’	8.25	
	Crawler crane waiting for loader cleaning Area for Crane placement (Erection)	15’	3.54	
	Waiting for the erection area to disconnect power and for cleaning the loader	145’	34.20	*
Inventory [assy]	The finished cut plates are stacked, waiting for the bending machine	35	16.3	
	The bent web plates are piled up, waiting for the forklift to move them at the fabrication area	180	83.7	*
Defect [assy]	Welding defects (assy), each assy has an average of 20 defects.	30	69.8	*
	Fit-up inaccuracy (assy)	8	18.6	*
	Scantling inaccuracy (assy)	5	11.6	
Motion [minute]	The Crawler crane operator turns toward the hull area	105’	84	*
	Subcontractors going back and forth looking for tools (loader/forklift)	20’	16	
Transportation [m]	Repetitive motions of the wheel loader as it removes material blocking the plate [m]	10	1.9	
	The crane ramp rotates due to the short hook [m]	20	3.8	
	Loaders go back and forth looking for stone cubes [m]	425	80.2	*
	Loaders travelled around the hull tidying up the area from a transformer and stacked plates [m]	15	2.8	
	Loaders rotate because the road is blocked by the Tugboat block that is being moved [m]	35	6.6	

Type of waste	Activities	Qty	%	Critical (*)
	The road trailer spun around because a broken crane was blocking the road [m]	25	4.7	
Inappropriate Processing [times]	Operators lifted the shearing machine blade too quickly (times)	10	83.3	*
	Repeated use of the blade on the bending machine (times)	2	16.7	

3.2.1 Waiting

There are three dominant waiting activities shown by the Pareto diagram in Figure 2 the loader must clean the area before trans bulkhead fabrication, wait for the electricity-disconnect erection area and loader cleaning, and remove materials that block the angle bar. The three critical wastes cumulatively resulted in 80.19% waiting activities in the fabrication area.

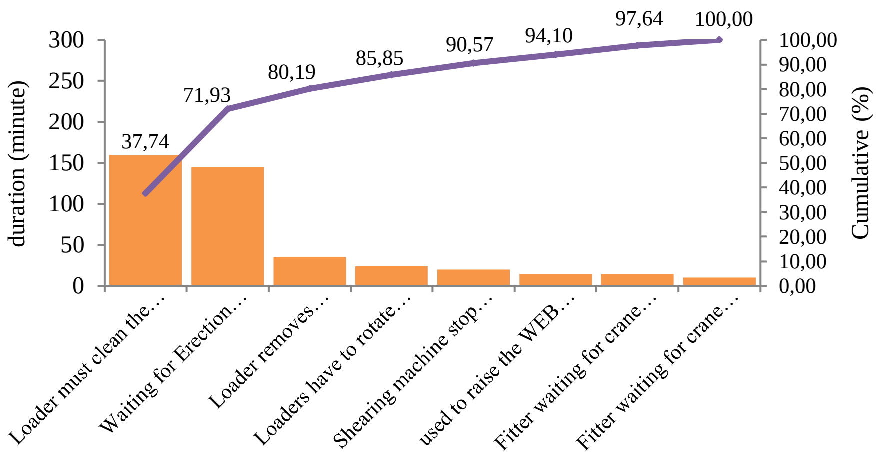

Figure 2 : Pareto diagram for waiting

3.2.2 Inventory

This waste was identified when several materials in progress were stacked in the production area. The dominant waste of inventory came from stacked bend web plates and waiting for forklifts to be transferred to the fabrication area (83.7%).

3.2.3 Defect

The dominant causes of defects were welding defects and fit-up inaccuracy, with a cumulative frequency of 88.4% of the waste defects (see Figure 3). These defects cause rework, which increases production time. The level of defects that occur according to Lean Six Sigma on the production of new ships (330 ft barge) is expressed in the Defects Per Million Opportunity (DPMO) and Sigma value. From the data obtained from the QC, 30 panels and blocks (assy) experienced welding defects in 92 inspected panels and blocks withdifferent numbers of welding defect points for each panel or block.

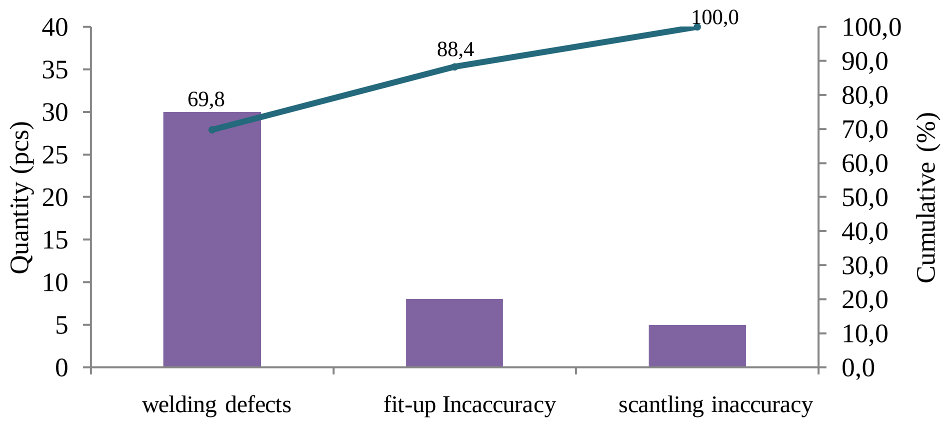

Figure 3 : Pareto diagram for defects

The following is the calculation of the company's DPMO value and sigma performance value:

$$DPMO = DPO\ x\ 1.000.000$$

$$= \frac{\text{The number of defective unit}}{\text{Number units inspected} \times \text{Dominant defect opportunities}}\ x\ 1.000.000$$

$$= \frac{30}{92 \times 2}\ x\ 1.000.000$$

$$= 0.163043\ x\ 1.000.000$$

$$= 163.043$$

$$DPMO = (1 - DPO)\ x\ 100$$

$$= (1 - 0.163043) x\ 100$$

$$= 83.7\%$$

DPMO of 163,043 can be converted into a sigma value of 2.48 according to the Motorola Concept, which is widely used in the Indonesian industry [15]. The Six Sigma recapitalization of defective waste results is shown in Table 2.

Tabel 2 : The Six Sigma results for defective waste

No.	Follow-up	Equation
1	What process do you want to know	Welding Defects
2	Number units inspected	92
3	The number of units is defective	30
4	Dominant defect opportunities / critical waste	2
5	DPO	0.163043
6	DPMO	163,043
7	Convert DPMO value into sigma value	2.48
8	Yield (%)	83.7

3.2.4 Motion

The wasted motion in ship production is the motion of the crawler crane turning towards the hull area (84%) and the movement of subcontractors back and forth looking for tools (loaders/forklifts).

3.2.5 Transportation

According to the measurement data shown in Table 1, six activities caused transportation waste. Waste in transportation can be identified by defining transportation activities that do not add value to the distance traveled by heavy equipment. Based on the Pareto Diagram (Figure 4), the dominant cause of 80% of the waste in transportation is the loader going back and forth looking for stone cubes.

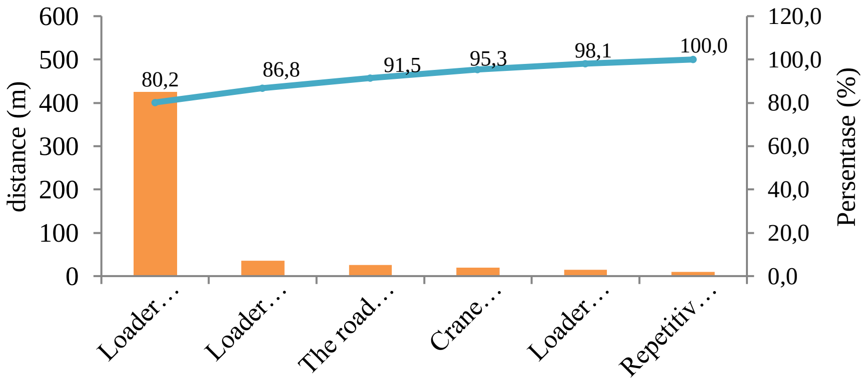

Figure 4 : Pareto diagram for waste in transportation

3.2.6 Waste in processing

Inappropriate processes occur when the operators repeat the process during the production workshop. The waste in processing that can be identified in ship production is the repetition of the process because the operators lifted the shearing machine blade too quickly and repeated the use of the blade on the bending machine by the operator.

3.3 Analyze

At this analysis stage, the critical waste activities (highlighted in Table 1) are listed in Table 3. Fishbone diagram analysis (Cause-and-Effect Diagrams) was used to determine the potential causes of critical waste activities (as examples shown in Figure 5 and Figure 6). Failure Mode and Effect Analysis (FMEA) evaluates each potential cause based on risk assessment. This assessment was conducted in three stages:1) severity (assessment of the level of impact of the waste), 2) occurrence (how often the potential causes occur or opportunity), and 3) detection (assessment of the Company's ability to detect the causes of problems). The risk priority number (RPN) is defined as the product of severity (Sev.), occurrence (Occ.), and detection (Det.).

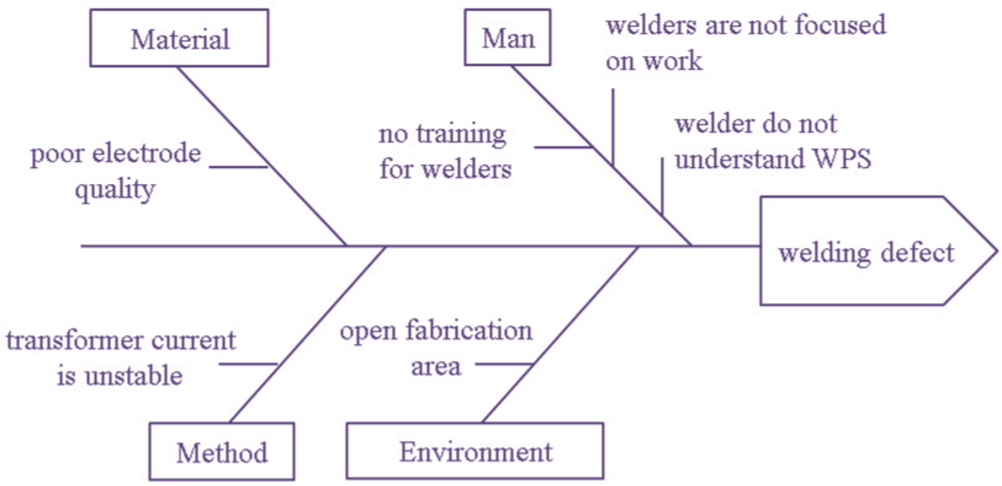

Figure 5 : Fishbone diagram to determine the potential causes of welding defects

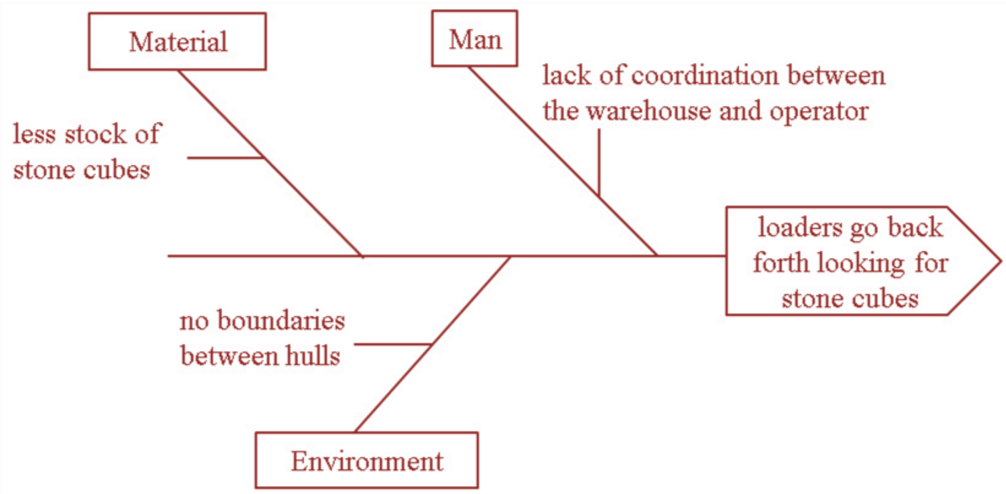

Figure 6: Fishbone Diagram to determine the potential causes of transportation wastes

The RPN value indicates the level of seriousness and requires immediate improvement. For instance, a severity value of 9 indicates that the severity criterion is very high and has an impact above 20% on the project schedule. An occurrence value of 9 means it may occur in almost any condition, and a detection value of 9 means work plans or procedures are nearly impossible to detect risks.

Table 3 : shows the critical waste activities, potential causes, and the risk priority number (RPN)

No.	Critical waste activities [from Table 1]	Potential Cause(s) (obtained from Fishbone Diagrams analysis)	FMEA			
			Sev.	*Occ.*	*Det.*	RPN
1	The loader must clean the area before trans bulkhead fabrication.	Irregularly placed work tools and equipment	3	7	6	126
		Remaining plates scattered	3	6	6	108
		Lack of coordination between the operators and the electricians	3	5	6	90
2	Waiting for the power disconnection in the erection area and cleaning loader	Equipment not set up properly	4	6	7	168
		Lack of coordination between the electricians and the production	4	5	7	140
		Electric cables scattered	4	6	7	168
		Incorrect fabrication area settings	4	7	7	196
		There is no barrier between the hull	4	4	7	112
3	The web plates are piled up, waiting for the forklift to move them to the fabrication area	Work operators are not serious	4	5	6	120
		Improper web plates storage	4	6	6	144
		Lack of coordination between the subcontractor and the operator	4	5	6	120
		Shared fabrication area without clear boundaries.	4	4	6	96
4	Welding defects	Welders are not focused on work	8	7	6	336
		Welders do not understand welding procedure specification (WPS)	8	9	6	432
		poor electrode quality	8	7	6	336
		The transformer current used is unstable	8	9	6	432
		Open fabrication area	8	7	6	336
		No training for welders or inspectors	8	7	6	336
5	Fit-up inaccuracy	Unskilled fitters	7	8	6	336
		Poor fitter technical drawing skill	7	8	6	336
		Lack of clarity of the numbers on the working drawings	7	8	6	336
6	Crawler crane operators turned toward the hull area	Unorganized equipment	4	6	5	120
		Other cranes blocked the way	4	5	5	100
		Cables prevent the motions of the crane	4	5	5	100
7	Loaders go back and forth looking for stone cubes	Less stock of stone cubes	8	8	6	384
		Lack of coordination between the warehouse and the operator	8	7	6	336
		no boundaries between hulls	8	5	6	210
8	Operators lifted the shearing machine blade too quickly	The subcontractors do not understand the correct procedures	4	8	4	128
		The automatic control of the machine does not work properly.	4	7	4	112
		Operators do not understand SOP properly.	4	7	4	112

The potential effect for numbers 1, 2, 3, 6, 7, and 8 is additional production times.
The potential effects for numbers 4 and 5 were rework and increased production times.

Table 3 shows that the highest RPN values are welders who do not understand the welding procedure specification (WPS) with an RPN value of 432, the transformer current used is unstable (RPN-432), and the loader is back and forth looking for stone cubes because of the lower stock of stone cubes (384). The magnitude of the RPN indicates a problem in the potential failure mode, whereas a greater RPN indicates a higher level of seriousness that requires immediate correction.

3.4 Improve

In the improvement stage, the potential causes with the three highest RPN values were prioritized for improvement. They focus on the causes of this high risk, where a series of recommendations are expected to reduce waste and speed up production time.

a. In the maintenance process, cooperation between the subcontractor and maintenance team is also required to maintain the welding transformer under optimal conditions, such as inspections by the maintenance team in the field, replacement of spare parts, repairs, and determining the proper transformer mass.

Inspections can be applied every week from the previous week only once during the project. Periodic maintenance of the transformer minimizes weld defects, such as slag inclusion, porosity, underfill, undercut, overlap, and scatter [16].

b. Increased understanding of WPS by welders and tighter WPS supervision by supervisors. The design is to conduct a WPS briefing once a week by the QC project staff. The WPS is made in a pdf file or printed and then approved by the shipyard company. A WPS that is customized according to shipbuilding processes is used as a reference for shipyards in shipbuilding [17]. Supervisors are expected to provide tighter supervision when the welder works so that the welding results follow project-specified standards.

c. Procurement of the stone cubes. The loader must find cubes as far as 425 m which takes 480 minutes. Therefore, it is important to add cubes and maintain the availability of stone stocks to avoid going back and forth looking for stones. Loaders can only carry a maximum of two stones to the hull area and cannot use trailers, as they would also interfere with access to other hull fabrications.

Table 4 : Predicted RPN after Recommendations

No	Potential Cause(s) of Waste	Current RPN	Recommendations	Prediction				RPN reduction
				Sev	*Occ*	*Det*	RPN	
1	The transformer current is unstable	8 x 9 x 6 = 432	Periodic maintenanceon the transformer	7	6	6	252	41.7 %
2	Welders do not understand WPS	8 x 9 x 6 = 432	Increase understanding of WPS and tighter WPS supervision	7	7	6	294	31.9 %
3	Limited availability of stone cubes	8 x 8 x 6 = 384	Procurement of more stonecubes immediately	7	7	6	294	23.3 %

Based on these three recommendations, the RPN value for each potential waste source will be lower. The predicted RPN values obtained after the recommendations are shown in Table 4. Then, the reduction in production time after the recommendation can be estimated by multiplying the number of total RPNs after the recommendation by the current ship production time (236 days) against the total RPNs before improvement.

$$\text{Estimation of production time} = \frac{\text{Total RPNs after recommendation } \times \text{existing ship production time}}{\text{total RPNs before improvement}}$$

$$= \frac{6.644\ x\ 236}{7.052}$$

$$= 222\ days\ (it\ means\ 14\ days\ shorter)$$

A decrease in the RPN value (prediction) also significantly affects the sigma value. This was because the amount of DPMO was directly proportional to the number of defects. Thus, the RPN values of the welding defects before and after the recommendations can be determined (see Table 3, number 4). Furthermore, the number of predicted defects can be calculated as follow,

$$\text{Number of predictied defects} = \frac{\text{PNs of the welding defect after } \times \text{number of welding defects before}}{\text{RPNs of the welding defect before}}$$

$$= \frac{2{,}898 \times 30}{3{,}216}$$

$$= 27 \text{ defetcs}$$

The predicted DPMO can be determined by the number of predicted defects.

$$\text{Predicted DPMO} = \text{DPO x } 1.000.000$$

$$= \frac{\text{The number of defective unit}}{\text{number of units inspected} \times \text{dominant defect opportunities}} \text{ x } 1.000.000$$

$$= \frac{27}{91 \text{ x } 2} \text{ x } 1.000.000$$

$$= 0.1467391 \text{ x } 1.000.000$$

$$= 146.739$$

Then, a Sigma Value of 2.55 can be obtained by converting this DPMO value using the Sigma Conversion Table. A comparison of the Six Sigma results before and after the recommendations is presented in Table 5.

Table 5 : Comparison of Six Sigma results before and after the recommendation

No.	Comparison	Before recommendation	After recommendation
1	RPNs of welding defect	3,216	2,898
2	Number of units inspected	92	92
3	Dominant defect probability	2	2
4	Number of defective units	30	27
5	DPO	0.1630434	0.1467391
6	DPMO	163,043	146,739
7	Sigma Value	2.48	2.55

3.5 Control

At this stage, recommendations are maintained and controlled to overcome or minimize future waste. Control over the recommendations given to the welder requires the welder and QC to read the WPS together during a briefing before welding [18]. For transformer welding maintenance, the subcontractor must coordinate with the facility division to maintain the welding transformer on a weekly basis. Under the condition of sufficient cubes (after procurement of an additional number of cubes), the subcontractor with the loader operator must cooperate in a disciplined manner to return the cubes to the warehouse.

4. CONCLUSION

The implementation of the Lean Six Sigma (LSS) method to produce a 330 ft barge has resulted in several recommendations to reduce waste. Consequently, these impacts reduce delays in barge production completion. This method has several potential causes or root causes for waste activity. Based on a series of potential causes, three causes were obtained, which are the most serious and require a high priority for improvement (highest Risk Priority Number). This study also recommended periodic maintenance of the welding transformer, a better understanding of WPS, a stricter WPS supervision procedure, and the immediate procurement of more stone cubes. By focusing on improving the three highest Risk Priority Numbers, a shorter production time of 6% or 14 days can be estimated, and the sigma value increases to 2.55. The DMAIC process in LSS can only be used effectively up to the Analyze stage. The other two stages, namely Improve and Control, cannot be implemented in real terms because it takes a long time to measure the conditions after the recommendations are implemented. In addition, the LSS method maps the production flow of barges and identifies critical processes that become potential defects.

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DECLARATIONS

Author contribution

E. Priyanda: Writing - Original Draft, Writing, Conceptualization, Formal analysis, Investigation, Resources, Visualization. A. Sutanto: Writing - Review & Editing, Formal analysis, Supervision and Verification.

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Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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