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Article

Analysing the Quality of Traditional Shipbuilding Production Processes through Integration of Ergonomics and Lean Six Sigma in West Aceh, Indonesia

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Abstract: This study analyses the quality process using the integration of ergonomic and lean six sigma in the DMAIC cycle at CV. Wahana Karya shipyard. The ergonomic uses RULA tools while lean six sigma uses SIPOC diagram tools, current stream mapping, DPOM, Pareto diagrams, cause, and effect diagrams and FMEA. The improvement stage is recommendations for improvement through the highest RPN in the FMEA analysis and recommendations for improving ergonomics from work posture. The control stage is the supervision of the recommended improvements. The result indicates that there are 7 work postures that cause a decrease in quality where one of the risks of high work postures is in wood cutting activities with recommendations for improvement, namely designing ergonomic wood forming and cutting tools, on lean six sigma, recommendations for improving process quality are obtained based on analysis of FMEA tools for installing Advanced hull boards are tenuous hull boards with an RPN value of 384 with recommendations for improvement, namely replacing a new clamp press tool that is easy to install. Meanwhile, in the process of installing the ivory with an advanced level, which is not according to the size of the RPN 336 value, the recommendation for improvement is to make clear and written SOPs and work guidelines.

Keywords: quality; 3GT ships; ergonomic; lean six sigma.

1. Introduction

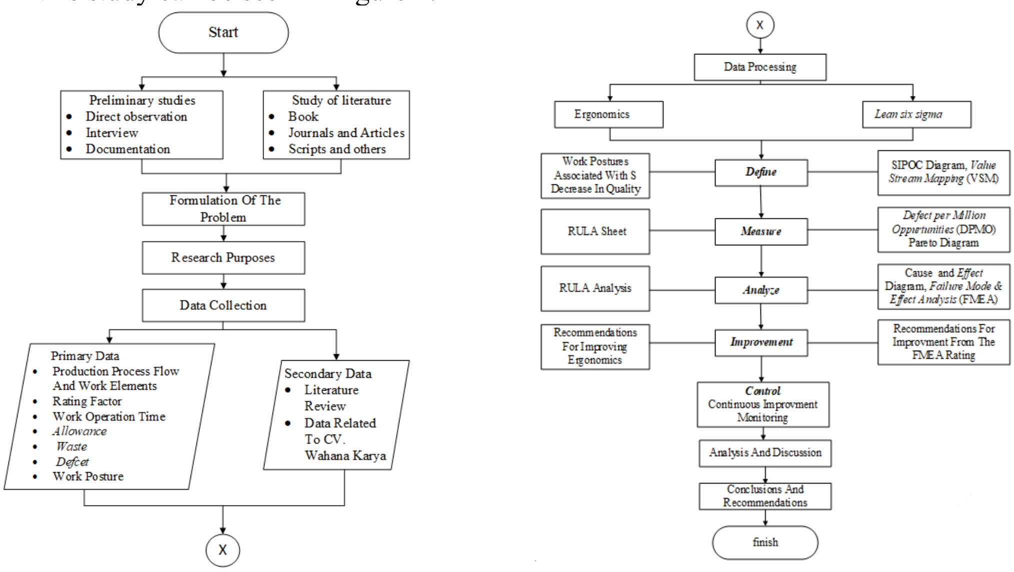
Current technological developments require companies to use a technique to develop and improve the quality of the products produced (Petrick & Echols, 2004). The company develops an evaluation or method change in improving its quality. Companies that do not pay attention to the quality of the products they produce will experience many obstacles in their marketing, so the products are not selling well and experience a decrease in sales (Redjeki & Affandi, 2021). Traditional wooden ships are wooden ships built traditionally based on the experience of the maker without any designs or drawings like conventional/modern ships in general (Malisan & Jinca, 2019). However, the quality of the ships made must be considered for the safety and security of the users (Branscomb, 2006). Product quality is the expertise of a product to carry out its functions, including reliability, durability, accuracy, ease of operation, and product improvement, as well as other valuable attributes (Weenas, 2013). The quality of the products produced can be seen from the production process, where the processing of the production process will run normally if the quality of the products produced by the production process is according to plan (Walujo et al., 2020).

The production process to produce good quality products by each industry is also influenced by work posture where work posture is one of the determining points in analysis the effectiveness of a job (Appelbaum et al., 2000; Branscomb, 2006). The good quality of the ship can be seen from the type of wood used, the size of the ship, the colour of the wood, the joints of the wood on the sides of the ship and other things that affect the quality of the ship. The characteristics of wooden ships are based on the material used for the main construction, which can be classified in the same shape as straight, curved and the same construction as the shape of boards and beams. Ivory (frame), reinforcement (rib), keel, and deck beam are the main construction materials for wooden ships that can be made with lamination technology (Nugroho, 2017).

CV. Wahana Karya is an industry engaged in the production of traditional wooden ships of various sizes. Production process Shipyard CV. Wahana Karya still has many defects in each element of the process activities such as cracks, holes, black eyelets, uneven smoothing of wood, defects in ship beam galanges and ship joints that are not parallel, tenuous, inaccurate nailing and drilling which will make repetitive work which may be caused by the material or machine used and the worker's posture which is not ergonomic which may affect the quality of the resulting process. To solve these problems, a method is needed to improve the quality of a sustainable production process, namely by integrating ergonomics and lean six sigma. The aim of ergonomics is to design a system in which the location of the work location, work methods, equipment and machinery, and the work environment are in accordance with the physical limitations and characteristics of workers (Priyono et al., 2020). Lean Six Sigma is a very powerful continuous improvement methodology. Ergonomics integration during LSS implementation has the potential to gain substantial gains in productivity and simultaneously improve working conditions (Nunes & Simões-Marques, 2015). Ergonomics is seamlessly integrated with LSS, not only in terms of caring for the employees while LSS is concerned with the process, but also helps improve efficiency and quality (Quang et al., 2016).

2. Materials and Methods

This study was conducted at the shipyard CV. Wahana Karya on the process of making a 3GT size ship. The integration of Ergonomics and lean six sigma in the DMAIC cycle were used to solve problems. The stages in this study can be seen in Figure 1.



(a) **(b)**

Figure 1. Research Stages

3. Results and Discussion

Stage define is the identification stage, where this stage contains SIPOC diagrams, current state mapping and operator work posture which causes a decrease in the quality of the production process.

3.1. Diagram SIPOC

The SIPOC diagram is a process flow that starts from the flow of suppliers to customers in the shipyard to identify the production process depicted in the form of a SIPOC diagram (Supplier Input Process Output Customer), as seen in Figure 2.

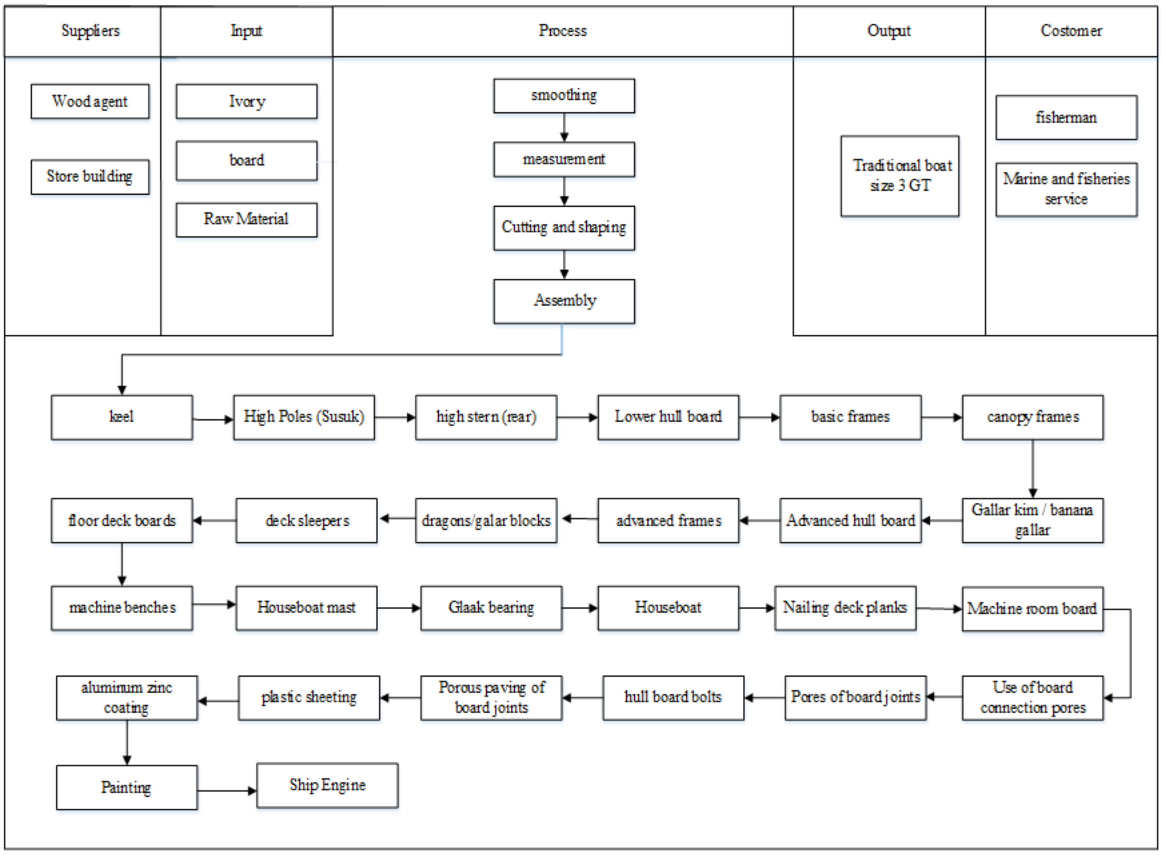


Figure 2. Research Diagram

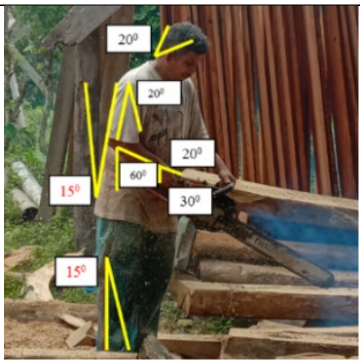
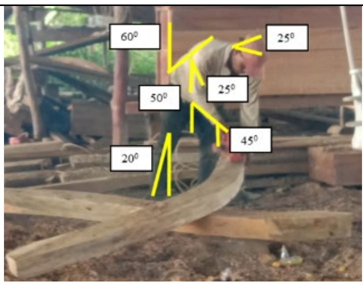
3.2.1. Work Posture

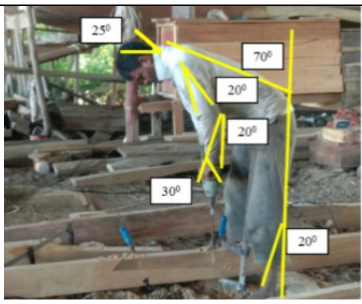
Working postures that often cause a decrease in the quality of the production process in the activities of operators of Wood Cutting, Timber Measurement, Wood Drilling, Ivory Installation, Board Cutting, Wood Smoothing, Hull Board Installation.

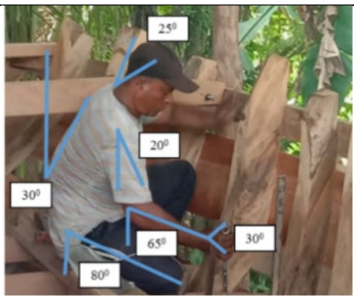
3.2.2. Measure

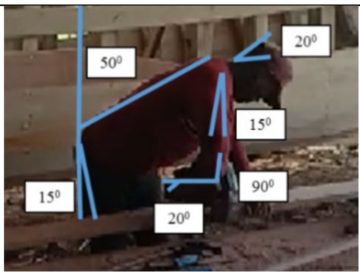
Measure is an ergonomics measurement step using RULA sheets and by measuring DPMO (Defects Per Million Opportunities) to calculate the six sigma for defects produced in processes that occur in traditional 3 GT shipbuilding and making Pareto diagrams to identify the percentage of problems that occur. The stages of work posture and worksheet RULA, as seen in Table 1:

Table 1. Research Stages through Work Posture and worksheet RULA

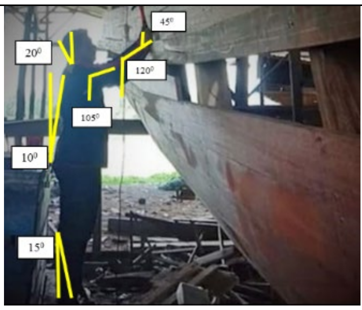
No	Work Posture	WP score using worksheet RULA
1.	 Wood Cutting Activity	Upper Arm (20 °) = 1 Neck (25°) = 3 Lower Arm (60°) = 1 Trunk (15°) = 2 Wrist 30°) = 3 Legs (15°) = 1 Wrist Twist = 1 Score Table B = 3 Score Table A = 2 Score Activity = 1 Score Activity = 1 Burden >5 Kg = 2 Burden >5 Kg = 2 Total Score B (3+2+1) = 6 Total Score A (2+1+2) = 5 Score Group C = 7
2.	 Timber Measurement Activity	Upper Arm (30 °) = 2 Neck (25°) = 3 Lower Arm (30°) = 1 Trunk (90°) = 5 Wrist (25°) = 3 Legs (25°) = 1 Wrist Twist = 1 Score Table B = 6 Score Table A = 3 Score Activity = 1 Score Activity = 1 Burden 0 Kg = 0 Burden 0 Kg = 0 Total Score B (6+1+0) = 7 Total Score A (3+1+0) = 4 Score Group C = 6
3.	 Wood smoothing activity	Upper Arm (25 °) = 2 Neck (25°) = 3 Lower Arm (50°) = 1 Trunk (60°) = 2 Wrist (45°) = 3 Legs (20°) = 1 Wrist Twist = 1 Score Table B = 5 Score Table A = 3 Score Activity = 1 Score Activity = 1 Burden 2,7 Kg = 2 Burden 2,7 Kg = 1 Total Score B (5+1+1) = 7 Total Score A (3+1+1) = 5 Score Group C = 7

<table>
<tr><td>4.</td><td>

Wood Drilling Activity</td><td>Upper Arm (20 º) = 1
Neck (25º) = 4
Lower Arm (20º) = 1
Trunk (70º) = 5
Wrist (45º) = 3
Legs (20º) = 1
Wrist Twist = 1
Score Table B = 7
Score Table A = 3
Score Activity = 1
Score Activity = 1
Burden >5 Kg = 2
Burden >5 Kg = 2
Total Score B (3+2+1) = 7
Total Score A (3+1+2) = 6
Score Group C = 7</td></tr>
<tr><td>5.</td><td>

Ship ivory installation activity</td><td>Upper Arm (20 º) = 1
Neck (25º) = 3
Lower Arm (20º) = 1
Trunk (30º) 5
Wrist (45º) = 3
Legs (20º) = 1
Wrist Twist = 1
Score Table B = 4
Score Table A = 2
Score Activity = 1
Score Activity = 1
Burden <2 Kg = 0
Burden <2 Kg = 0
Total Score B (4+1+0) = 5
Total Score A (2+1+0) = 3
Score Group C = 4</td></tr>
<tr><td>6.</td><td>

Board cutting activity</td><td>Upper Arm (15 º) = 1
Neck (20º) = 2
Lower Arm (90º) = 1
Trunk (50º) = 3
Wrist (20º) = 3
Legs (20º) = 1
Wrist Twist = 1
Score Table B = 4
Score Table A = 2
Score Activity = 1
Score Activity = 1
Burden >5 Kg = 0
Burden >5 Kg = 2
Total Score B (4+1+2) = 7
Total Score A (2+1+2) = 5
Score Group C = 7</td></tr>
</table>

7	 Gasboard Installation Activity	Upper Arm (15 °) = 1 Neck (20°) = 2 Lower Arm (90°) = 1 Trunk (50°) = 3 Wrist (20°) = 3 Legs (20°) = 1 Wrist Twist = 1 Score Table B = 4 Score Table A = 2 Score Activity = 1 Score Activity = 1 Burden >5 Kg = 0 Burden >5 Kg = 2 Total Score B (4+1+2) = 7 Total Score A (2+1+2) = 5 Score Group C = 7

3.2.3. Calculation DPMO (Defect Per Million Opportunities)

The following is a table of identification of defects that occur in the process of making a 3GT size ship on CV. Wahana Karya. The result of inspection defect in the ship production process for traditional ship size 3GT, as seen in Table 2.

Table 2. Inspection Data Defect in the ship production process for Traditional ship Size 3GT.

No.	Element activity	Score
1	Making of keel	0
2	Making High Poles (Susuk)	7
3	Making high stern (rear)	5
4	Lower hull board installation	12
5	Installation of basic frames	17
6	Installation of canopy frames	19
7	Installation of kim / banana gallar	11
8	Advanced hull board installation	27
9	Installation of advanced frames	24
10	Making dragons/galar blocks	22
11	Installation of deck sleepers	16
12	Installation of floor deck boards	5
13	Manufacturing of machine benches	7
14	Building a ship's mast	6
15	Glaak bearing manufacture	4
16	Houseboat installation	9
17	Nailing deck planks	14
18	Machine room board installation	8
19	Use of board connection pores	6
20	Pores of board joints	2
21	Installation of hull board bolts	5
22	Porous paving of board joints	0
23	Installation of plastic sheeting	0
24	Installation of aluminium zinc coating	3

25	Painting	0
26	Ship Engine Installation	0

Calculation DPMO and sigma levels are as follows:

$$DPO \quad = \frac{Total\ production\ defects}{Total\ production}$$

$$DPMO = \frac{Total\ production\ defects}{Total\ production}\ X\ 1000000$$

Conversion of six sigma values (Ms. Excel) =NORMSINV (1000000-DPMO)/1000000) + 1,5.

Table 3. Calculation Recapitulation DPMO

No.	Observation	Result
1	Observed Process	All Manufacturing Process ship 3GT
2	Many Process Elements Are Observed	26
3	Many Elements of Possibility Defect	21
4	Many Processes Elements Defect	229
5	DPO	0,4194
6	DPMO	41.941.3,9
7	Sigma levels	1,7034

Table 3 displays the calculation of the sigma level gets a value of 1.7034 which indicates the sigma level is at the 6th sigma level so that it can be stated that the operator is not good at doing the job and it is better to make improvements and adjustments to the work environment in the shipyard. Pareto Diagram

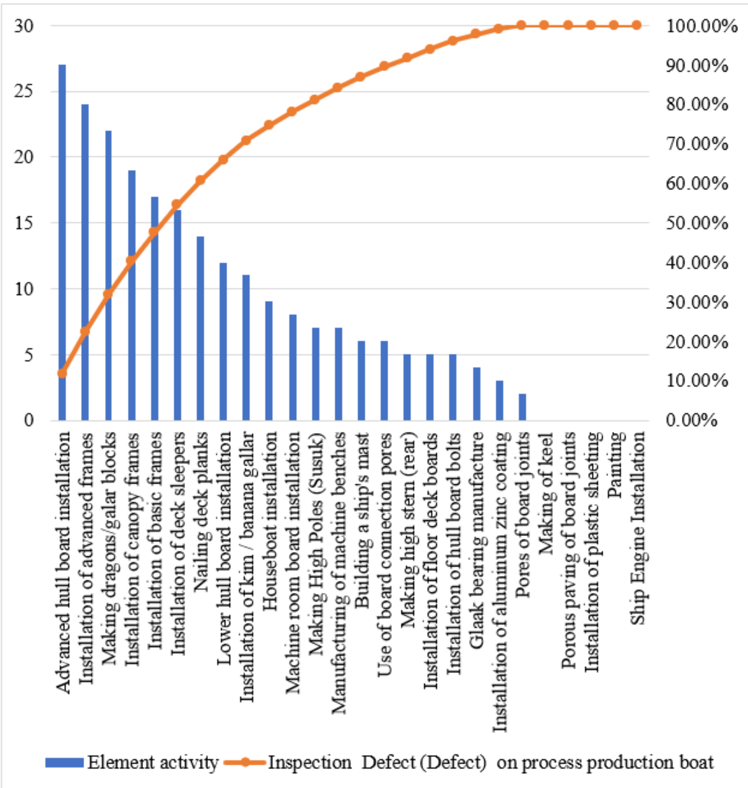


Figure 3. Pareto Diagram

Figure 3 explained that defects in the most dominant process occurred in 20% of the causes or problems of 80% of incidents were the process of installing and manufacturing advanced hull boards, manufacture, and installation of canopy frames where the cumulative percentage occurred at 21.83%.

3.3. Analysis

Stage analysis which aims to Analysis the production process from an ergonomic perspective using the RULA method and lean six sigma using the tools cause and effect diagrams and FMEA. The results of the assessment using RULA to see the risk of work postures which result in operator fatigue by looking at the score from the measure can be seen in Table 4 below.

Table 4. analysis RULA

No.	Activity	Score RULA	Risk Category	Description
1	Wood cutting	7	Tall	Investigate and implement changes
2	Measurement Wood	6	Currently	Investigate further changes soon
3	Wood smoothing	7	Tall	Investigate and implement changes
4	Wood drilling	7	Tall	Investigate and implement changes
5	Ivory installation	4	Small	further investigation, changes may be required
6	Board cutting	7	Tall	Investigate and implement changes
7	Board installation	6	Currently	Investigate further changes soon

3.3.1. Analysis Cause Effect Diagram

The following is an analysis of the causes of defects that occur most dominantly in elements of the advanced hull board installation process.

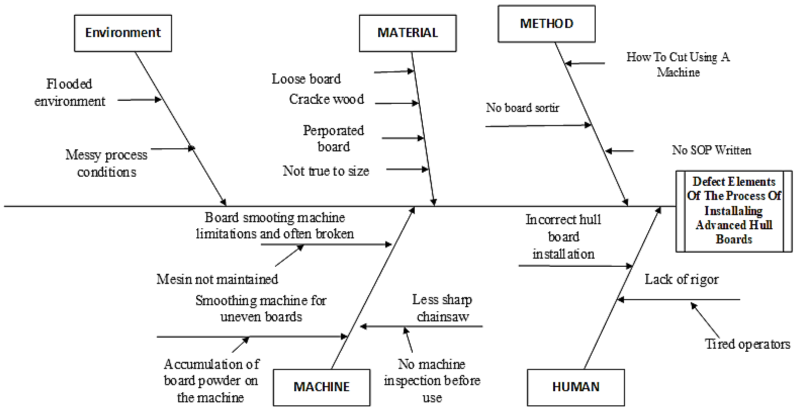


Figure 4. *Cause Effect Diagram* Elements of the Process of Laying Boards

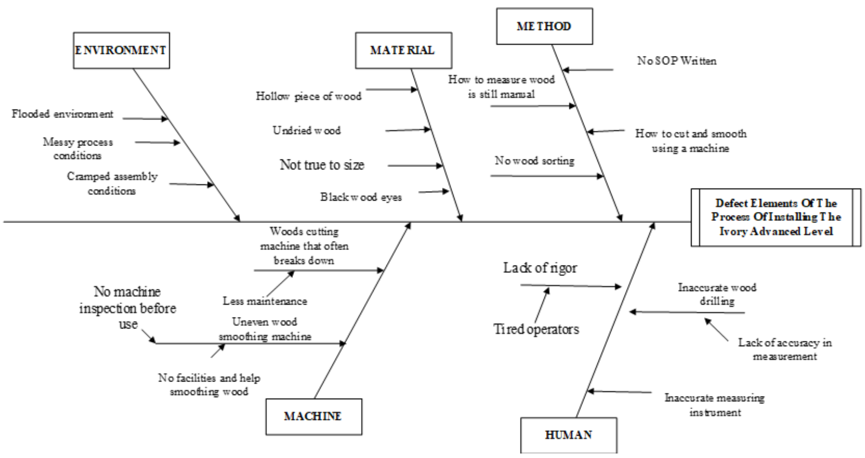


Figure 5. *Cause Effect Diagram* Elements of the Process of Installing the Ivory Processes Advanced.

3.3.2. Analysis FMEA (Failure Mode Effect Analysis)

Table 5. Analysis FMEA (*Failure Mode Effect Analysis*)

No.	Process activity element name	Failure mode	Potential failure	Cause of failure
1.	Installation of further hull boards	Negligence and operator fatigue lead to defects	Lack of supervision at work	Careless operators
		Improper installation of hull boards	Operators work in a rush	Chasing time
		Irregular stages of work	There is no written soup and work guide	Lots of mistakes occur
		Boards are not sorted	There is no sorting of boards before processing	Board is not dry
		Loose hull board	The press tool is not working optimally	Lack of emphasis on hull boards during the assembly process
		Cracked hull board	The process of nailing is too deep	Rework and replacement of cracked boards
		Perforated hull board	Lack of accuracy in nailing the hull board	Board fault
		The board smoothing machine does not work optimally and is often damaged	Here is no machine maintenance schedule and the limitations of the smoothing machine	Wastage of processing time
		Uneven smoothing of boards	There is no cleaning of board powder before the machine is used	Accumulation of board powder in the machine
2.	Manufacture and installation of advanced ivories	Negligence and operator fatigue lead to defects	No supervision and heavy work	Careless operators
		Improper installation of ivory	There is no supervision in the process of installing ivory	Repeat work
		Unsorted wood	No wood sorting	The wood is not dry
		Black eyes wood	There is no sorting of the quality of the wood to be used	Additional work
		Not true to size	No written SOP	Erroneous measurements of the wood led to repetitive work in assembling the ivory
		Hollow wooden ivories	No supervision during wood drilling	Wood drilling error

	Cutting machine works less than the maximum	Lack of maintenance and old machines	Wasted cutting time and uneven cutting
	Uneven wood smoothing machine	Whether or not there is checking before using the machine and the lack of work facilities	Repetition of work

Table 5. Analysis FMEA (*Failure Mode Effect Analysis*)- continued

No.	Process activity element name	Current process control	S	O	D	RPN
1	Installation of further hull boards	No relevant oversight	6	7	7	294
		No relevant oversight	6	5	6	180
		No relevant oversight	6	6	8	288
		There is no checking of the board before use	7	6	7	294
		No relevant oversight	6	8	8	384
		There is no inspection during the process	5	7	6	210
		Lack of supervision	6	6	8	288
		There is no check before the machine is used	6	5	8	240
		There is no check before the machine is used	6	6	7	252
2	Manufacture and installation of advanced ivories	No relevant oversight	6	6	7	252
		No relevant oversight	6	6	7	252
		There is no checking of wood before it is processed	6	5	6	180
		There is no checking before the wood is processed	6	5	6	180
		Lack of supervision in the measurement process	6	8	7	336
		No relevant oversight	6	6	7	252
		No relevant oversight	6	5	7	210
		No relevant oversight	5	5	8	200

Table 5 Analysis explains the RPN calculation to analyse the causes of failure resulting from defects in the shipbuilding process and to determine the priority of causes of defects by looking at the highest RPN value. After obtaining the protist causing the failure, it will provide suggestions for improvement.

3.3. Improvement

Phase The Improvement is the improvement stage in the DMAIC cycle. This stage is an advanced stage of the analysis that has been carried out previously, recommendations for these improvements which will later be carried out to be implemented at the cv vehicle works shipyard either in the near future or in the long term because it estimates the costs and conditions of the shipyard. The causal factors causing the defects are based on the analysis of cause effect diagrams and FMEA diagrams. While the analysis of defects in the process caused by the operator's work posture is based on an analysis of the assessment of the RULA table.

Table 6. Improvement Recommendations FMEA

No.	Process Activity	Failure Mode	Potential Failure	RPN	Improvement Recommendations	Rating
1.	Advanced hull board installation	Operator negligence and fatigue cause defects	Lack of supervision at work	294	Carry out periodic monitoring of work	3
		Improper installation of hull boards	Operators work in a hurry	180	Arrange the work agenda of the operator during the process	15
		Less regular stages of work	There is no written SOP and work guide	288	Make clear and written SOPs and work guidelines	5
		The boards are not sorted	There is no sorting of boards before processing	294	Sort the boards before they are produced to see if the boards are suitable for use or have not used an inspection sheet	4
		The hull board is loose	The press tool works less optimally	384	Replacement clamp press tool that is new and easier to install	1
		Cracked hull board	The nailing process is too deep	210	Supervise the operator while working	12
		Perforated hull board	Lack of accuracy in nailing hull boards	288	Give warning to operators to be more careful in doing their job	6
		Board smoothing machine working less than the maximum and often broken	There is no machine maintenance schedule and grinding machine limitations	240	Make a machine maintenance schedule at least once in each month and add at least one board smoothing machine	11
		Uneven plank smoothing	There is no cleaning of board powder before the machine is used	252	Clean the machine from powder before use	7
2.	Manufacture and installation of advanced frames	Operator negligence and fatigue causes defects	No supervision and hard work	252	Carry out supervision during work and add work facilities that help operators to reduce fatigue	9
		Installation of ivory is not quite right	There is no supervision in the process of installing ivory	252	Supervise periodically during the installation of ivory	8
		The wood is not sorted	There is no sorting of dry and undried wood	180	Sorting wood for dry and not yet dry wood using inspection sheets	16

	Black eyes wood	There is no sorting of the quality of the wood to be used	180	Sort wood quality using inspection sheets	17
	Not true to size	There is no written SOP	336	Make clear and written SOPs and work guidelines	2
	Hollow wooden ivory	There is no supervision when drilling wood	252	Supervise the operator while working	10
	Cutting machine works less than the maximum	Lack of maintenance and old machines	210	Schedule machine maintenance at least once a month and replace old machines	13
	Uneven wood smoothing machine	The lack of checking before using the machine and the lack of work facilities	200	Checking the machine before use and adding work facilities in smoothing wood such as places and worktables	14

Table 6 explains the recommendations for improving process quality based on FMEA analysis with the highest causes of failure can be seen in the RPN in the process of installing the highest advanced hull boards, namely tenuous hull boards with potential causes for the clamp press used to work less than optimally with an RPN value of 384 and the solution to the problem for recommendations for improvement is to replacement clamp press that is new and easier to install. Meanwhile, in the process of installing the ivory with an advanced level, namely not according to the size of the potential cause of the absence of a written SOP, the RPN value is 336 and the solution to the problem for recommendations for improvement is to make clear and written SOPs and work guidelines. Recommendations for improving operator work posture which often cause defects can be seen in Table 7.

Table 7. Recommendations for Improvement in Operator Work Posture

No.	Operator Activity	Score RULA	Risk Assessment	Reasons	Descriptions	Improvements
1.	Wood cutting activity	7	Tall	The cutting of wood is done standing up with a heavy load of the chainsaw machine > 5kg, which often causes the operator's hands to go numb and the formation of wood is less than optimal.	Investigate and implement changes for improvement	Designing ergonomic wood shaping and cutting tools
2.	Timber measurement activity	6	Currently	The process of measuring wood is done bending because there are not	Investigate further changes soon	Add facilities such as a worktable to

				enough facilities to help with measurements, so errors often occur, and the operator lacks accuracy due to fatigue		reduce errors in measurements
3.	Wood finishing activity	7	Tall	The process of measuring wood is done bending because there are not enough facilities to help with measurements, so errors often occur, and the operator lacks accuracy due to fatigue.	Investigate and implement changes for improvement	Adding facilities such as a worktable so that the operator can work to smooth the wood evenly
4.	Wood drilling	7	Tall	The wood drilling process is carried out bending because the drill is carried out on the product floor and still uses a hand drill machine, if the tool is used for a long time, it makes the operator's hands numb and back pain.	Investigate and implement changes for improvement	Make a special place for drilling wood and replace drill machines that are more ergonomic, such as bench drills.
5.	Installation of ship hulls	4	Low	The work on installing ship hulls that install bolts with manual ring locks causes the operator's hands to hurt frequently	further investigation, changes may be required	Replacing the key ring tool with an ergonomic tool
6.	Board cutting	7	Tall	Board cutting is done standing and bending due to the location where the wood is cut which is not suitable for the height of the operator and the weight of the cutting machine > 5 kg	Investigate and implement changes for improvement	Designing a cutting board according to the operator's height and designing an ergonomic board cutting machine
7.	Hull board installation	6	Currently	The work is done standing up using a hammer. Repeated work often causes the operator's hands to hurt	Investigate further changes soon	Add work facilities to help operators

3.4. Control

Stage control is the supervision stage through the integration of ergonomics and lean six sigma to ensure that the improvement stage will be applied or continuously carried out in the production process including the dominant problem that occurs, namely the activity elements of the process of installing advanced hull boards and making canopy frames.

- Conducting shipbuilding operator training programs for all shipbuilding workers.
- Check work facilities and add work facilities that help operators for operator comfort.
- Conduct operator training on how to operate tools and machines properly to reduce operator fatigue.
- Carry out machine maintenance and machine repair by making a machine maintenance schedule.
- Cleaning the production floor every week to provide operator comfort while working.
- Make notes and documentation of defects in the shipbuilding process.
- Checking the materials, tools and machines that will be used before the production process.
- Increase supervision of operators during the production process to reduce the number of errors that will occur.

4. Conclusion

In conclusion, using the RULA assessment method, this study indicated that 7 work postures that cause a decrease in the quality of the shipbuilding production process where 4 of them are high risk operator activities, namely wood cutting, wood refining, wood drilling, plank cutting and 2 work postures with moderate risk of operator activity, namely wood measurement, installation of hull boards and 1 low risk of working posture, namely installation of ship ivory. Load of chainsaw machine >5kg, which often causes the operator's hands to go numb and wood shaping is less than optimal with recommendations for improvement, namely designing ergonomic wood forming and cutting tools. Improving the quality of the process using lean six sigma obtained recommendations for improving the quality of the process based on the analysis of tools in the installation of advanced hull boards with the highest failure causes, which can be seen from the highest RPN, namely the advanced hull boards are loose with potential causes of the clamp press used to work less optimally with an RPN value of 384 with the solution to the problem for alternative recommendations for repair is to replace the clamp press which is new and easier to install.

Meanwhile, in the process of installing the ivory with an advanced level, namely not according to the size of the potential cause of the absence of an SOP, the RPN value is 336 and the solution to the problem for alternative recommendations for improvement is to make clear and written SOPs and work guidelines. On the basis of analysis results and improvements that have been made, suggestions can be given for the CV Wahana Karya. The vehicle for the work is increase supervision of the production process to reduce the number of errors made by operators. Also, conduct periodic training for each shipbuilding operator to minimize defects in the production process and checking the machine is still feasible or not for use.

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