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Research Article

Cost-Integrated Lean Maintenance to Reduce Maintenance Cost

Putu Dana Karningsih, Winda Puspitasari, Moses Laksono Singgih

Department of Industrial and Systems Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya 60111, East Java, Indonesia

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CORRESPONDENCE

Phone : +62811315235

E-mail : moseslsinggih@ie.its.ac.id

A B S T R A C T

The company has always prioritized cost reduction. In this study, the researchers aimed to decrease maintenance costs by actively eliminating expensive non-value-added processes. The study employed Process and Time Driven Activity Based Costing to integrate cost with the activities performed. By conducting maintenance value stream mapping, the researchers identified various forms of waste, such as centralized maintenance, ineffective data management, poor inventory management, inadequate maintenance, under-utilization of resources, and waiting time for maintenance resources. Several alternative improvement options were proposed, and the Pugh method was used to compare and select the most promising alternatives or combinations of alternatives. The third alternative, which involves conducting internal training and implementing standard operating procedures for maintenance technicians, supervisors, and machine operators, as well as integrating an IT system for maintenance and creating an equipment and spare parts inventory database, was chosen as the highest-ranking option. The results showed that this approach reduced processing time for administrative activities, lowered corrective maintenance costs, and improved maintenance efficiency for both preventive and corrective maintenance.

INTRODUCTION

Smooth production processes ensure the successful manufacturing of quality products, timely completion, and cost efficiency. Industrial machinery is essential for a successful manufacturing industry. Regular maintenance is necessary for smooth operation. So, maintenance strategies have been proposed to extend equipment life and improve reliability. Unplanned downtime can hamper deliveries to customers and damage the company's reputation.

Nursanti et al. [1] highlighted the importance of effective maintenance activities for uninterrupted production by reducing waste. Tinga [2] noted upkeep costs are linked to downtime duration. The increase in downtime was caused by Non-Value-Added (NVA) activities or waste in maintenance operations. One of the waste elimination strategies is the application of lean thinking in all activities. Anshori and Mustajib [3] reported that maintenance impacts production availability, rates, quality, costs, and safety. These aspects will then affect the company's profitability.

The researchers conducted this study at a Steel Smelting Factory. The factory has implemented a maintenance policy that includes thorough documentation in the form of records, documenting instances of damage, downtime, and repair duration. The maintenance division manages these records, capturing various factors that contribute to downtimes, such as waiting for personnel and the procurement of outdated spare parts. Furthermore, maintenance activities can impact the availability of production machines, with longer downtime suggesting the presence of waste that affects both production and maintenance processes, leading to inefficiencies. To assess the efficiency of maintenance activities, the Lean maintenance approach can be adopted. Lean maintenance reduces waste, optimizing resource usage. Mostafa, et al. [4] stated that Lean maintenance is the application of lean principles to Maintenance, Repair, and Overhaul (MRO) operations. This can reduce unscheduled downtime by optimizing maintenance support activities and maintenance overhead. This approach covers maintenance activities and their related issues.

In addition to addressing maintenance process efficiency, management must consider financial calculations as a gauge of efficiency, providing valuable insights for making economic decisions. To accomplish this, the study employs Process and Time Driven Activity Based Costing, which builds upon the value stream mapping conducted during the lean maintenance phase and incorporates the element of time. The integration of these two aspects entails connecting value stream information with cost considerations. It is imperative to assess economic

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aspects alongside technical aspects to provide pertinent information to management when making improvement decisions. While previous research has primarily focused on implementing lean concepts in maintenance activities, there has been limited exploration of how these concepts impact resulting costs. Hence, the objective of this study is to compare the efficiency level attained in maintenance activities, as measured by Overall Equipment Effectiveness (OEE) within the framework of Lean Maintenance, while considering the corresponding incurred costs.

METHOD

This study uses maintenance value stream mapping, process and time driven activity based costing, and Pugh's method. Each method has its output in assessing the efficiency of the observed maintenance activities. The following are the research stages explained using the flowchart shown in Figure 1.

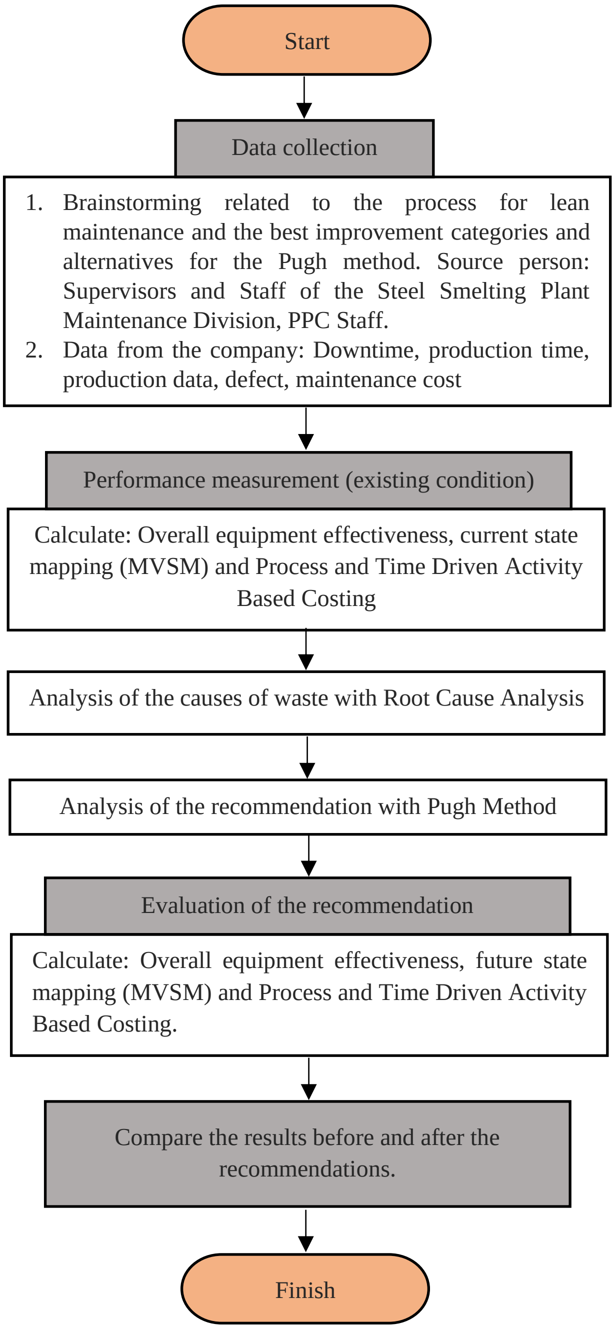

Figure 1. Research Flowchart

Lean Maintenance

Lean thinking has become popular in various sectors, such as food, manufacturing, and process. Lean methods can ensure success in manufacturing efficiency and maintenance. Kolanjiappan [5]states that the purpose of Lean Maintenance is to minimize waste or reduce activities that do not add value to the customers. Duran et al. [6] minimize waste leads to improved inventory management.

During the maintenance process, it is possible to discover seven primary categories of waste, which are:

1. Improper maintenance: excessive preventive maintenance and at a suboptimal frequency
2. Waiting for maintenance resources: awaiting tools, documentation, parts, and technicians.
3. Centralized maintenance: spare parts are far from workstations, making them difficult to access.
4. Poor maintenance: rework, which affects maintenance costs and service quality.
5. Inefficient task sequencing and programming: maintenance interventions are not properly planned.
6. Unavailability of spare parts: there is no supply of spare parts that are needed.
7. Movement of no value: searching for spare parts, equipment, documents, and so on.

Maintenance Value Stream Mapping

A Maintenance Value Stream Map (MVSM) is a method used to describe the flow of maintenance activities to identify waste in maintenance activities [7]–[13]. The MVSM method is differentiated based on the map created, namely the current state map and the future state map (proposal). Based on the map that has been made, activities that do not have added value (non-value added) and have value added can be identified as time in each process flow. According to Kurniawan [14], maintenance efficiency can be evaluated through three categories in MVSM. The first category includes activities that add value, such as Mean Time To Repair (MTTR). MTTR measures the time required for equipment repair and maintenance. The second category comprises activities that do not add value, including Mean Time To Organize (MTTO). MTTO measures the time needed to coordinate tasks at the beginning of maintenance repairs. Last, the third category is Mean Time To Yield (MTTY), which measures the time required to produce a good part after maintenance:

$$\% \text{ Maintenance Efficiency} = \frac{\text{MTTR}}{\text{MTTR+MTTO+MTTY}} \times 100\% \quad (1)$$

Overall Equipment Effectiveness

According to Supriatna et al. [15], equipment performance plays a crucial role in the production process. OEE evaluates equipment performance. Equipment failure can lead to downtime, reducing equipment availability, and increasing maintenance costs. Meanwhile, loss of speed affects performance and quality. The OEE value of world-class companies is above

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85%. Supriatna et al., [15] calculated this OEE based on three main ratios, namely the availability rate, performance rate, and rate of quality. The following explains the three ratios:

Availability Rate

The availability rate is a ratio of the available time for machine and equipment operating activities. Availability is the ratio of the operation time, by eliminating equipment downtime against loading time.

$$\text{Availability rate} = \frac{\text{Loading time} - \text{downtime}}{\text{Loading time}} \times 100\% \quad (2)$$

Performance Rate

Performance rate is a ratio that describes the ability of the equipment to produce goods. The formula for measuring this ratio is:

$$\text{Performance rate} = \frac{\text{Output x ideal cycle time}}{\text{Loading time}} \times 100\% \quad (3)$$

Quality Rate

Quality rate is a ratio that describes the ability of equipment to produce products according to standards. The formula used for measuring this ratio is:

$$\text{Quality rate} = \frac{\text{Processed amount} - \text{defects amount}}{\text{Processed amount}} \times 100\% \quad (4)$$

The OEE value is obtained by multiplying the three main ratios mathematically with the following formula:

OEE (%) = Availability (%) x Performance rate (%) x Quality rate (%) (5)

Process and Time Driven Activity Based Costing

We will analyze the maintenance process using Maintenance Value Stream Mapping to identify and classify each activity as either value-added or non-value-added. Furthermore, we will calculate the costs associated with each of these activities [18]–[22]. Value-added costs are generated by calculating the direct costs of each process or activity such as labor costs, material costs, and purchasing replacement components and the cost of using the machine while non-value-added costs are generated by calculating the costs of waste generated such as costs of losses because of cessation of the production process.

Besides the process, the time factor is also considered in this cost analysis by using Time Driven Activity Based Costing. Time Driven Activity Based Costing uses a time-based equation to assign costs to activities. The following is the procedure for applying the Process and Time Driven Activity Based Costing method:

1. Identify activities, sub-activities, and economic resources which include labor, raw materials, and others.
2. Calculation of the cost of supplied capacity and practical capacity in parallel. The cost of capacity supplied is data on the cost of a department. While practical capacity is the actual time a department completes an activity.
3. Calculating capacity cost rate (CCR). Calculations at this stage are carried out with the following equation:

$$\text{Capacity Cost Rate} = \frac{\text{Cost of Capacity Supplied}}{\text{Practical Capacity of Resource}} \quad (6)$$

4. Formulate the time equation (time equation).
5. Calculating the total cost by multiplying the CCR by the time required for each activity, the equation is as follows:

$$TC_{ij} = CCR_i \times N_{ij} \quad (7)$$

6. The author categorizes this formula by the type of activity carried out. Analysis costs that focus on the next process and time driven activity based costing could be counted based on category activity:

Total cost = TCij (VA) + TCij (NVA) (8)

PUGH'S

Pugh's method is a matrix diagram to compare several alternatives to find the best alternative that meets predetermined criteria [23]. This matrix compares several alternatives available with predetermined criteria [24]–[28]. Decision-making using the Pugh matrix using several alternatives, as in the following example, Table 1.

The Pugh matrix involves evaluating multiple alternatives based on specific criteria to select those that meet the desired requirements. Qualitative alternative optimization is employed in the Pugh matrix by combining the concepts of two or more alternatives. When assessing alternatives, if an alternative is better than the standard, it is marked with a positive "+" sign and assigned a weight of +1. If an alternative is worse than the standard, it is marked with a negative "-" sign and assigned a weight of -1. If an alternative is the same as the standard, it is marked with an "S" and assigned a weight of 0.

Table 1. Pugh Matrix

	Alternative A	Alternative B	Alternative C	Alternative D	Alternative BC	Alternative BD
Criterion 1	S	+	S	+	+	+
Criterion 2	S	-	S	+	S	+
Criterion 3	S	S	S	+	S	+
Criterion 4	S	-	+	+	+	+
Criterion 5	S	-	+	+	+	+
Total +	0	3	2	5	5	7
Total -	0	5	1	4	0	2
Total Score	0	-2	1	1	5	5

To create a Pugh matrix, decision-makers can perform the following five stages:

1. Identify and determine the selection criteria.
2. Determine the alternative that will be used as a baseline or standard in each criterion and will be marked with an "S" for alternatives that are the same as the standard or baseline that has been determined.
3. Make a comparison of each alternative option against the criteria that have been determined with the baseline or alternative standard by adding the score to the available matrix.
4. Perform calculations on all alternative scores where the alternative with the highest weight is the selected alternative. In determining the selection of alternatives, it is also necessary to consider hybrid or combined alternatives so that the selected alternative is a qualitative optimization.
5. Validate all alternatives and predetermined criteria.

RESULTS AND DISCUSSION

Observations on Existing Conditions

Monitoring is conducted on two aspects: maintenance activities comprising preventive maintenance and corrective maintenance at one of the production facilities. Preventive maintenance activities are performed on sand reclamation machines, while corrective maintenance activities involve hanger shot blast kazo machines, specifically the replacement of impeller blade components.

Based on the results of observations on preventive maintenance activities, the results show that there are non-value-added activities from the Mean Time To Organize (MTTO) with an estimated time of 45 minutes for administrative activities such as reporting and awaiting the allocation of resources and equipment. In addition, activities included in the value-added category are the Mean Time to Repair (MTTR) with an estimated time of 60 minutes (Figure 2).

Based on the observations, the non-value-added activities of the Mean Time To Organize (MTTO) with an estimated time of 60 minutes from administrative activities such as reporting and awaiting resource allocation and a delay of 180 minutes because of the unavailability of spare parts and components required so that it takes time to perform the search and procurement process. There is 1 activity that is Mean Time to Yield (MTTY) for 5 minutes due to setup. In addition, the repair or Mean Time to Repair (MTTR) runs for 88 minutes (Figure 3).

The following are the Maintenance Efficiency results from the current state mapping:

% Maintenance Efficiency $= \frac{MTTR}{MMLT}$ x 100%

% Maintenance Efficiency (Preventive Maintenance) = $\frac{60}{105}$ x 100%= 57%

% Maintenance Efficiency (Corrective Maintenance) = $\frac{88}{333}$ x 100%= 26%

By performing the current state mapping of maintenance value stream mapping for both preventive and corrective maintenance activities, it becomes possible to identify the existing waste and determine its root causes. Table 2 shows the identification and analysis of the causes of the waste that occurs.

The OEE metric evaluates equipment effectiveness with availability being impacted by downtime from maintenance. The research focuses on two maintenance activities, so OEE is calculated separately for each machine. Table 3 shows the Calculation of Availability Rates and Table 4 shows the Calculation of Performance Rates.

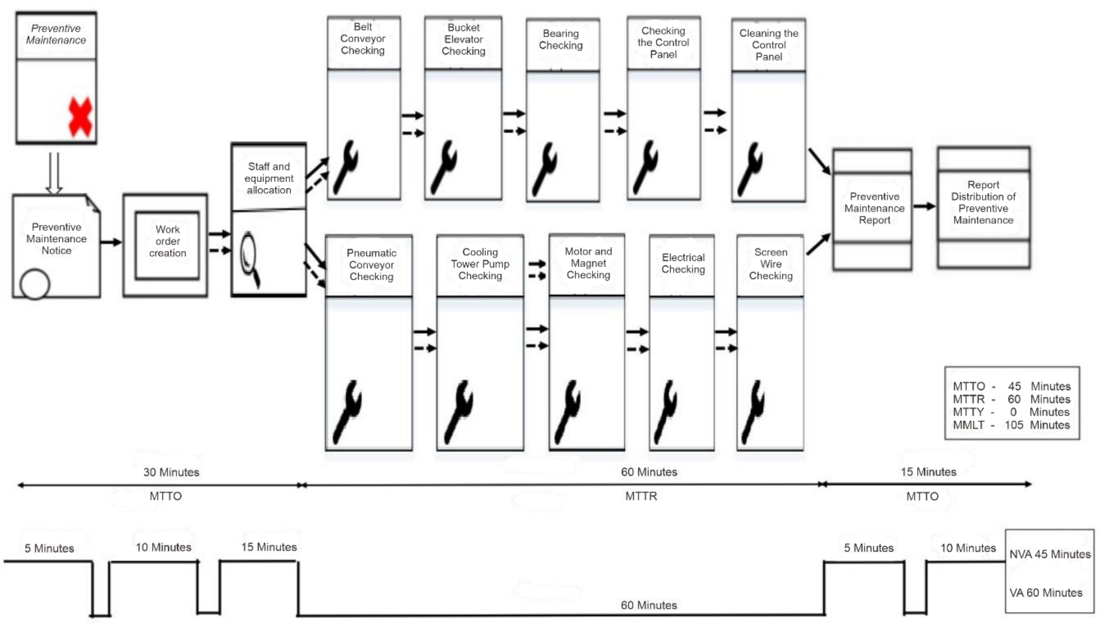

Figure 2. Current State Mapping Preventive Maintenance

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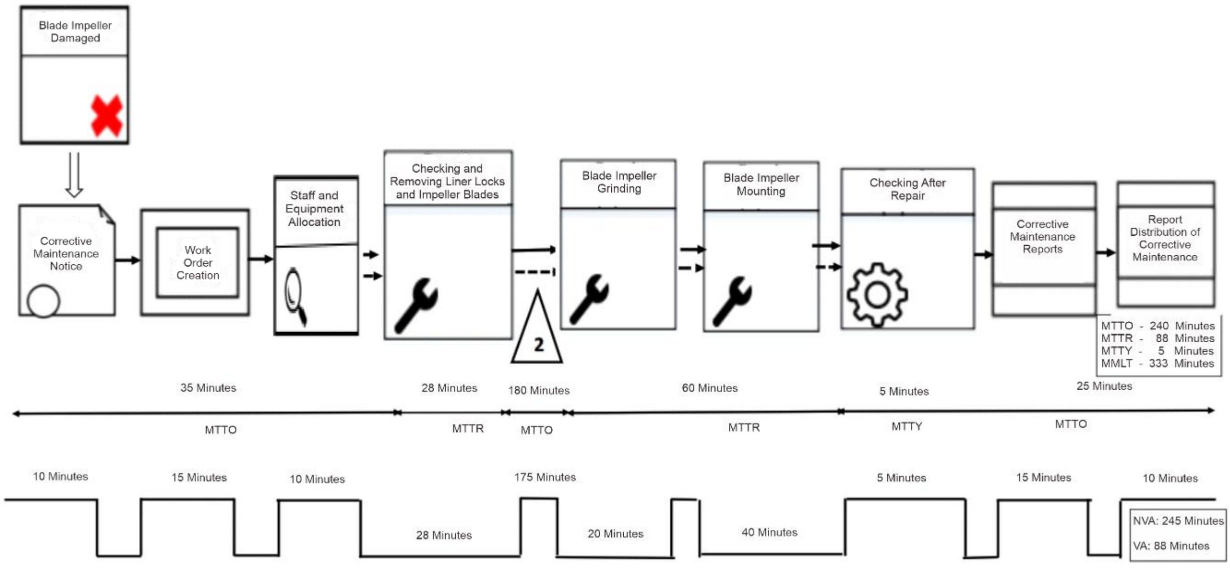

Figure 3. Current State Mapping Corrective Maintenance

Table 2. Identification and Analysis Results Cause of Waste

Category Waste	Sub Waste	Root Cause
Centralized maintenance	There is a different understanding about way and order the best in the maintenance process	No training program specifically made by the department human capital for personnel and operators and nothing standard specially made for department maintenance or repair machines, especially in cases frequent repairs occur
	Documentation incomplete repair	There is no specific HR in charge of parts documentation
Ineffective Data Management	Repair recap and submission of repairs are still done manually	Limitations cost in filing manufacturing vendors IT systems desired by the department maintenance
Poor Inventory Management	Nothing _ component Spare parts available at Warehouse	Limitations costs allocated by the Company so that the department maintenance prefers to buy when case damage occur
	Manufacture and adjustment of spare parts done _ technician himself _ maintenance	
Poor Maintenance	Activity preventive maintenance that was not carried out in accordance timetable	There are internal problems in the Company so that efficiency is carried out towards the needs of employees
	Technicians need to set up the machine several times when they are done with maintenance	There are no specific programs created by the human capital department and no specific standards are created maintenance department for machine repairs, especially in case of frequent repairs
Under Utilization of Resources	Taking component spare parts or equipment repeated maintenance	Nothing _ recording goes out to enter usage equipment inventory for the department maintenance
Waiting for Maintenance Resources	SPV takes time to look for available technicians	There the company's internal problems so do efficiency to power work in the department maintenance

The Quality division does not have any records of defects for the KZ sand reclamation machine or the Kazo hanger shot blast machine. This is attributed to their incapability of causing product defects, which adds value to these machines. Once the data is retrieved, we can calculate the OEE value as indicated in Table 5.

Activity mapping progresses by examining maintenance costs. This cost analysis will focus on time and process, namely value-added activities and activities that are not value-added. The cost calculations are conducted for two maintenance activities, namely preventive maintenance and corrective maintenance. In both activities, there are resource pools, namely direct labor, overhead, and lost costs. Table 6 shows the Calculation of Capacity Cost Rate (CCR).

Table 3. Calculation of Availability Rates

Month	KZ Sand Reclamation Machine			Kazo's Hanger Shot Blast Machine		
	Loading Time (Hours)	Downtime (Hours)	Availability	Loading Time (Hours)	Downtime (Hours)	Availability
January	490	27	0.94	357,83	32	0.91
February	479	37	0.92	320	28	0.91
March	476	31	0.93	451.2	19	0.96
April	471	23	0.95	551,23	20	0.96
May	473	17	0.96	360.63	15	0.96
June	503	25	0.95	405.35	22	0.95
July	446	33	0.93	555,36	16	0.97
August	478	21	0.96	246.31	18	0.93
September	474	35	0.93	250.3	20	0.92
October	468	31	0.93	112	8	0.93
November	425	28	0.93	367.55	12	0.97
December	467	27	0.94	450,11	10	0.98

Table 4. Calculation of Performance Rates

Month	KZ Sand Reclamation Machine				Kazo's Hanger Shot Blast Machine			
	Loading Time (Hours)	Production Amount (Units)	Ideal Cycle Time (Hours)	Performance	Loading Time (Hours)	Production Amount (Units)	Ideal Cycle Time (Hours)	Performance
January	490	260	1,500	0.80	357,83	189	1,000	0.53
February	479	216	1,500	0.68	320	281	1,000	0.88
March	476	216	1,500	0.68	451.2	302	1,000	0.67
April	471	180	1,500	0.57	551,23	386	1,000	0.70
May	473	180	1,500	0.57	360.63	260	1,000	0.72
June	503	180	1,500	0.54	405.35	256	1,000	0.63
July	446	180	1,500	0.61	555,36	397	1,000	0.71
August	478	182	1,500	0.57	246,31	182	1,000	0.74
September	474	194	1,500	0.61	250.3	143	1,000	0.57
October	468	182	1,500	0.58	112	62	1,000	0.55
November	425	180	1,500	0.64	367.55	221	1,000	0.60
December	467	176	1,500	0.57	450,11	262	1,000	0.58

Table 5. Calculation of OEE

Month	KZ Sand Reclamation Machine				Kazo's Hanger Shot Blast Machine			
	Availability	Performance	Quality	OEE (%)	Availability	Performance	Quality	OEE (%)
January	0.94	0.80	1	75,21	0.91	0.53	1	48,23
February	0.92	0.68	1	62,56	0.91	0.88	1	80.08
March	0.93	0.68	1	63,24	0.96	0.67	1	64,32
April	0.95	0.57	1	54,15	0.96	0.70	1	67,2
May	0.96	0.57	1	54,72	0.96	0.72	1	69,12
June	0.95	0.54	1	51,3	0.95	0.63	1	59.85
July	0.93	0.61	1	56,73	0.97	0.71	1	68,87
August	0.96	0.57	1	54,72	0.93	0.74	1	68,82
September	0.93	0.61	1	56,73	0.92	0.57	1	52,44
October	0.93	0.58	1	53,94	0.93	0.55	1	51,15
November	0.93	0.64	1	59,52	0.97	0.60	1	58,2
December	0.94	0.57	1	53,58	0.98	0.58	1	56,84
Average				**58.04**	**Average**			**62.09**

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Table 6. Calculation of Capacity Cost Rate (CCR)

No.	Economic Pool	Economic Resources	Amount	Capacity Cost Supply (Rupiah)	Practical Capacity (Hours)	Capacity Cost Rate (Rp/Hour)
1	Overheads	Preventive Maintenance	1	Rp101,000	1.75	Rp57,714
		Corrective Maintenance	1	Rp2,543,100	5,6	Rp454,125
2	Direct Labor	SPV Maintenance	1	Rp300,000	8	Rp37,500
		Technician Maintenance	1	Rp215,000	8	Rp26,875
3	Lost Cost	Production				Rp112,500,000

Table 7. PUGH'S Matrix

No	Criteria	Alternative						
		1(S)	2	3	1 & 2	1 & 3	2 & 3	1,2,3
1	Cost	0	-	+	-	0	-	-
2	Process Speed	0	+	+	+	+	++	++
3	Process Accuracy	0	0	0	+	+	0	++
Sum of +		0	1	2	2	2	2	4
Sum of -		0	1	0	1	0	1	1
Sum of 0		3	1	1	0	1	0	0
NetScore		0	0	2	1	2	1	**3**

In corrective maintenance, CCR includes value-added overhead and direct labor and added to lost costs, namely operational consequences because of downtime that occurs, and non-value added CCR is lost costs. In preventive maintenance, CCR value added is overhead and direct labor. The company does not consider the costs associated with preventive maintenance as they are carried out as per the agreed production schedule to avoid operational losses. The losses are calculated separately by the company. The following is the calculation of the CCR of the two activities:

Capacity Cost Rate (PM)

Value Added Process = Rp57,714 + Rp37,500 + Rp26,875
= Rp122,089 per hour

Capacity Cost Rate (CM)

Value Added Process = Rp454,125 + Rp37,500 + Rp26,875
+ Rp112,500,000
= Rp113,018,500 per hour

Non-Value Added Process = Rp112,500,000 per hour

In addition, a time formula has been developed for each activity and sub-activity to indicate the duration of both preventive and corrective maintenance in this scenario.

Npm = 45 X1 + 60 X2 (in minutes)
Ncm = 245 X1 + 88 X2 (in minutes)
= 0.75 X1 + 1 X2 (in units of hours)
= 4.08 X1 + 1.47 X2 (in hour unit)

So the total cost calculation is:

The Total Cost of Preventive Maintenance

TC_{ij} (VA) $=(CCR_i \times N_{ij})$
= (Rp122,089 x 1 hour) = Rp122,089

No there is a calculation TC_{ij} (NVA) due no there are cost consequence operations calculated by the Company.

The Total Cost of Corrective Maintenance

TC_{ij} $= (CCR_i \times N_{ij})$ VA+$(CCR_i \times N_{ij})$ NVA
= (Rp113,018,500 x 1.47) + (Rp112,500,000 x 4.08)
= Rp625,137,195

Improvement Recommendations

We utilize Pugh's method to select the alternatives in this process. We will compare the outcomes of selecting alternatives from the two methods to determine the most favorable improvement alternative. This selection will use the PUGH matrix method using three criteria to determine the best alternative. In this study, the selection criteria used were cost, speed, and accuracy of the process. The following are three improvement alternatives: (1) Internal training on machinery maintenance and repair protocols for technicians, supervisors, and operators; (2) Develop e-Maintenance integrated with the IT system; (3) Creating a special database for inventory of equipment and spare parts.

Evaluating improvement alternatives and selection criteria to identify the best alternatives. The following is an alternative suitability weighting with the criteria shown in Table 7. The company believes that implementing all three measures can enhance the efficiency of the existing maintenance process and mitigate the root causes of the analyzed waste. Moreover, the company determines that these measures are financially feasible and anticipates significant benefits from positive changes to the current maintenance system.

Comparison of Existing and Improved Conditions

To assess the impact of the recommended improvements, a comparison is made between the current state and the repair conditions of the company. This comparison aims to estimate the changes in the existing conditions before and after implementing the recommendations. Three aspects are evaluated in this comparison: the future state map of ongoing maintenance activities, the effect on overall equipment effectiveness, and the associated costs. Figure 4 shows the Future State Mapping Preventive Maintenance and Figure 5 shows the Future State Mapping Corrective Maintenance.

A future VSM is prepared based on estimates to determine changes from the recommendations. Improvements didn't affect NVA activities but reduced repair times. Table 8 shows a comparison of the time from the existing condition and the estimate after the repairs.

After that, the maintenance efficiency obtained in the condition after the repair is as follows:

% Maintenance Efficiency (Preventive Maintenance) = $\frac{60}{80}$ x 100% = 75%

% Maintenance Efficiency (Corrective Maintenance) = $\frac{88}{119}$ x 100 = 74%

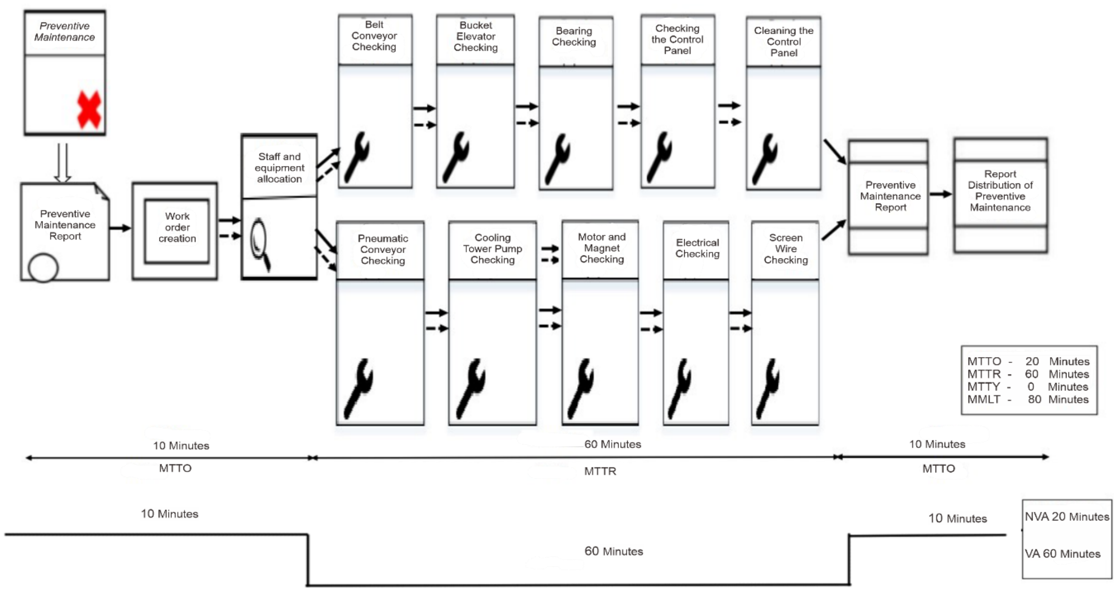

Figure 4. Future State Mapping Preventive Maintenance

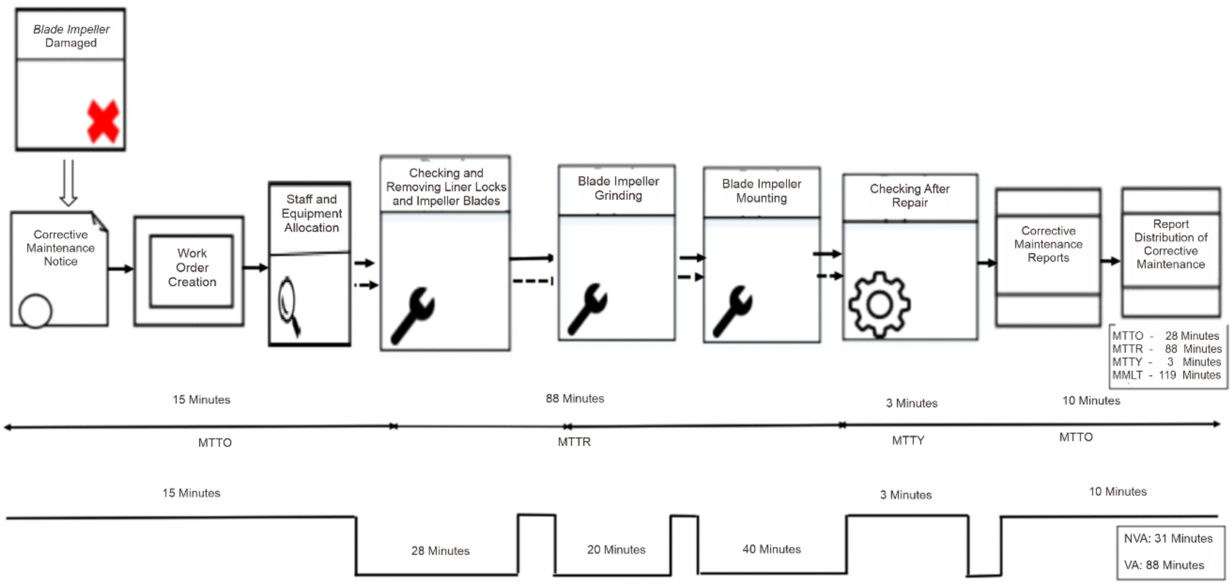

Figure 5. Future State Mapping Corrective Maintenance

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Table 8. Comparison of Existing and Repair Time from Activity Maintenance

Activity	MTTO (Minutes)	MTTR	MTTY	MMLT
Preventive Maintenance (Before)	45	60	0	105
Preventive Maintenance (After)	20	60	0	80
Corrective Maintenance (Before)	240	88	5	333
Corrective Maintenance (After)	28	88	3	119

After calculating the results, it has been determined that the efficiency of preventive maintenance has increased by 18%. It can be achieved by 75% after repairs and by 57% in existing conditions. In corrective maintenance, it also increased by 48% whereas previously it was 26% and after repairs, it is estimated to reach 74%.

In the proposed improvement, the estimated time for processes that are non-value added can be reduced to 25 minutes, especially for those that are organized or administrative in nature. Hence, when calculating the comparison of equipment effectiveness using OEE, the approach is to subtract the reduction in time per incident per month from the previous downtime. This enables the identification of estimated repair results. In this OEE calculation, only the availability aspect is affected by the changes, as the performance rate and quality rate remain unaffected by downtime. Therefore, the calculated values for performance and quality rates remain the same. The calculations are illustrated using examples from the month of January.

Machine Sand Reclamation KZ (Existing)

Availability rate = $\frac{490 \text{ Hours} - 27 \text{ Hours}}{490 \text{ Hours}}$ x 100% = 94 %

Machine Sand Reclamation KZ (Repair)

Availability rate = $\frac{490 \text{ Hours} - 23 \text{ Hours}}{490 \text{ Hours}}$ x 100% = 95%

Machine Hanger Shotblast Kazo (Existing)

Availability rate = $\frac{357{,}83 \text{ Hours} - 32 \text{ Hours}}{357{,}83 \text{ Houra}}$ x 100% = 91%

Machine Hanger Shotblast Kazo (Repair)

Availability rate = $\frac{357{,}83 \text{ Hours} - 28 \text{ Hours}}{357{,}83 \text{ Hours}}$ x 100% = 92.2%

Here is an example of the OEE calculation for January for the KZ Sand Reclamation Machine and the Kazo Hanger Shotblast.

Machine Sand Reclamation KZ (Existing)

OEE (%) = (0.94 x 0.80 x 1) x 100% = 75%

Machine Sand Reclamation KZ (Repair)

OEE (%) = (0.95 x 0.80 x 1) x 100% = 76%

Machine Hanger Shot Blast Kazo (Existing)

OEE (%) = (0.91 x 0.53 x 1) x 100% = 48%

Machine Hanger Shot Blast Kazo (Repair)

OEE (%) = (0.92 x 0.53 x 1) x 100% = 49%

The overall equipment effectiveness increased by 1%. Although the availability aspect did not increase significantly, the reduction in time can still have a positive impact despite its minor value. The cost calculation remains the same, except for the time equation. The following is the time equation calculation after repair:

Ncm = 31 X1 + 88 X2 (in unit minutes)
Npm = 20 X1 + 60 X2 (in unit minutes)
= 0.52 X1 + 1.47 X2 (in unit hours)
= 0.33 X1 + 1 X2 (in unit hours)

So that the total cost is:

The Total Cost of Preventive Maintenance

TC $_{ij}$ (VA) = $(\mathrm{CCR_i} \times \mathrm{N_{ij}})$
= (Rp122,089 x 1 hour)
= Rp122,089

No there is a calculation TC $_{ij}$ (NVA) due no there are cost consequence operations calculated by the Company.

The Total Cost of Corrective Maintenance

TC $_{ij}$ = $(\mathrm{CCR_i} \times \mathrm{N_{ij}})$ VA+$(\mathrm{CCR_i} \times \mathrm{N_{ij}})$ NVA
= (Rp113,018,500 x 1.47) + (Rp112,500,000 x 0.52)
= Rp224,637,195

Table 9 shows the Comparison of Existing and Repair Costs of Maintenance Activities.

Table 9. Comparison of Existing and Repair Costs of Maintenance Activities

Description	Amount Before	After	Difference
Preventive maintenance	Rp2,089	Rp122,089	Rp0 (0%)
Corrective maintenance	Rp625,137,195	Rp224,637,195	Rp400,500,000 (64%)

The goal of maintenance is to minimize downtime and cost. This research evaluates and provides recommendations using cost-integrated lean maintenance methods. This approach combines lean principles to identify value-added and non-value-added activities, analyze the root causes of waste, and select recommendations to eliminate or minimize waste. The Pugh method is used to pick the best improvement, factoring in both technical and economic aspects.

The calculation of costs is an essential part of this research, using process and time-driven activity-based costing. This analysis helps determine the costs associated with the maintenance process, distinguishing between value-added and non-value-added activities. Evaluation of cost allows the maintenance team to estimate expenses.

Undoubtedly, the cost is a significant consideration for the company when deciding. The research pinpointed the underlying causes of waste, mainly lack of funds. Lean maintenance methods speed up the maintenance process and offer timely and accurate suggestions. This approach allows the company to consider ways to improve that are both cost and time-efficient.

CONCLUSION

The efficiency of the ongoing maintenance process is an important thing to note because it is undeniable that the longer the maintenance runs, the longer the production downtime will be, and can cause losses. Lean maintenance is the right tool to use so that all the waste that occurs in the maintenance process can be minimized. This research focuses on efficient processes regardless of the maintenance strategy drawn up by the Company to maintain the reliability of its machines. Based on the results of the waste found, several proposed improvement alternatives have been prepared and the PUGH method is used to compare between alternatives or a combination of alternatives, and the highest score is selected for the combination of the three alternatives, namely carrying out Internal Training and standard maintenance standards for maintenance technicians, Supervisors, and Machine Operators, manufacturing maintenance integrated IT systems and creation of equipment and spare parts inventory databases. The results obtained are reduced processing time on administrative activities, reduce corrective maintenance costs, and increased maintenance efficiency both preventive maintenance and corrective maintenance.

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NOMENCLATURE

VA	Value-added activities
NVA	Non value-added activities
TC	Total cost
Npm	Expiration fee during one planning period (Rp/year)
Ncm	Time from activity corrective maintenance
X1	Amount activities included in the non-value added category
X2	Amount of activities included in value-added category
MRO	Maintenance, Repair, and Overhaul
OEE	Overall Equipment Effectiveness
MVSM	Maintenance Value Stream Map
MTTR	Mean Time To Repair
MTTO	Mean Time To Organize
MTTY	Mean Time To Yield
CCR	Capacity Cost Rate

AUTHOR(S) BIOGRAPHY

Putu Dana Karningsih

Putu Dana Karningsih is an Assistant Professor, and Head of Manufacturing Systems Laboratory of Industrial and Systems Engineering Department at Institut Teknologi Sepuluh Nopember (ITS) Surabaya, Indonesia. She earned B.Eng. in Mechanical Engineering from the University of Indonesia (UI), Jakarta, Indonesia, Masters in Engineering Science and Ph.D. in Manufacturing Engineering and Management from University of New South Wales, Sydney (UNSW), Australia. Her research interests include manufacturing systems, lean systems, design for X, concurrent engineering, and supply chain risk management. Currently, she supervises postgraduate students with topics: design for modularity; lean warehouse; design for manufacturing and assembly; lean services, frugal innovation, and smart product development.

Winda Puspitasari
Winda Puspitasari received her Bachelor's degree from Safety and Health Engineering Department, Politeknik Perkapalan Negeri Surabaya (PPNS) and earned her Master degree from the Industrial and Systems Engineering Department, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia. Her job experience was almost three years in the areas of quality, health, and environment department. Her research interests are quality, productivity, and industrial management.

Moses Laksono Singgih is a Professor at the Department of Industrial and Systems Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia. He received his Bachelor's and Master's degree from Industrial Engineering Department, Institut Teknologi Bandung (ITB), Indonesia. He received Ph.D. from the University of Queensland, Australia. His research interests are productivity, quality, and smart manufacturing systems. Currently, he supervises postgraduate students with topics: a design for manufacturing and assembly (DFMA); quality management; lean six sigma; internet of things; sharing economy; circular economy and product-service systems**.** His publications can be found at https://www.researchgate.net/profile/Moses-Singgih

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