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Implementation of Lean Maintenance for Optimizing Duration of Overhaul Turbine Inspection (TI) at PT IP

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Abstract:- The increase in the number of national electricity customers which is increasing every year must be followed by the availability of sufficient supply of electrical energy from power plants so that there is no energy deficit. Maintenance and overhaul activities are carried out routinely on power plant main equipment so that it continues to be reliable and efficient. Turbine Inspection (TI) overhaul activity at a Gas Turbine Combined Cycle Power Plant is a type of periodic inspection activity carried out at the power unit operated by PT IP. Data on the history of TI overhaul implementation during the 2016 - 2021 period shows that there was a delay in completing the overhaul which resulted in loss of production opportunity. Identification of the causes of waste (waste) is carried out using a lean approach with a combination of the use of Root Cause Failure Analysis (Fishbone and 5W+1H) and Value Stream Mapping (VSM) tools. The primary data in this study is the result of direct field observations and interviews with experts. Secondary data comes from previous TI overhaul implementation history data. The results of data analysis are used to make Current State Mapping (CSM) including the potential for existing waste. Decreasing the duration of TI overhaul is more focused on Critical Path activities which have elements of waste and have a significant influence on the total duration of TI overhaul work. Activity identification falls into the Non-Value Added (NVA) category, and Necessary Non-Value Added (NNVA) is used as the basis for making Future State Mapping including corrective steps that must be taken to optimize the overhaul duration to be used in the next OH TI. The total duration of the next TI overhaul, namely GT 4.2 TI 2022 after the implementation of the FSM and all improvement steps that have been made, is close to the standard duration given by the manufacturer, which is 22 days.

Keywords:- *Turbine Inspection (TI), Loss Production Opportunity, Waste, Lean, Value Stream Mapping.*

I. INTRODUCTION

The power generation sector is one of the critical sectors for the government. This sector plays an important role in ensuring that all processes of infrastructure development, economic growth and national industry can run well. This is because the growing industrial growth requires the availability of sufficient electricity supply. In addition, the increasing number of electricity users from time to time also increases the need for a large supply of electricity.

PT IP is a subsidiary of PT PLN Persero which was established in 1995 and has a Head Office location in Jakarta. PT IP has a main core business, namely as the Operation & Maintenance of power plants in Indonesia. The type of power plant operated by PT IP analyzed in this study is Gas Turbine Combined Cycle Power Plant.

Reliable and efficient power plant operational performance is urgently needed to ensure that the national electricity supply can be fulfilled optimally. One of the crucial activities that is generally carried out periodically to ensure that the performance of the power plant remains optimal is overhaul. According to [1], Overhaul is one of the planned maintenance activities carried out to ensure that every equipment used in a power plant is still functioning properly. According to [2], one of the important targets in implementing an overhaul is achieving the target time for completion of the overhaul work. This is because if there is a delay in completing overhaul activities, it can result in huge losses for the company, as well as the wider community. This kind of loss phenomenon will certainly be experienced by PT IP if there is a delay in completing the overhaul activity. Based on historical data on the completion of overhaul work at Power Plant O&M Companies, it is known that the most delays in overhaul completion occur in the Turbine Inspection (TI) overhaul type. This type of overhaul is carried out once every 2.5 years for each block in the generator to inspect the equipment in the Gas Turbine. Loss of production opportunity caused by delays in completion of TI overhaul for the 2016 – 2021 period amounted to 755.06 billion rupiah. This loss is very large and will have an impact on reducing the annual revenue target of PT IP and PT PLN Persero. Therefore, it is necessary to make efforts to prevent delays in completing the overhaul which results in repeated company losses. Furthermore, if the available electricity capacity at the power plant cannot meet the electricity needs of the community (electrical energy deficit), then this condition can disrupt the stability of electricity distribution and causing power outages in various areas.

The focus of the authors in this study is to analyze the waste that occurs during the implementation of TI overhaul by implementing the concept of Lean Maintenance using Value Stream Mapping (VSM). Lean Maintenance is a concept that aims to increase the efficiency and effectiveness of maintenance activities by eliminating waste that exists during maintenance activities. In addition, the concept of Lean Maintenance can be used as a tool to find out what work is Value Added (VA), Non-Value Added (NVA), and Necessary Non-Value Added (NNVA) in a maintenance activity. Lean maintenance is a process or journey in achieving continuous improvement. This system focuses on adding value and reducing waste in the maintenance process so that maintenance lead time can be reduced [3].

II. LITERATURE REVIEW

A. Gas Turbine Combined Cycle Power Plant

According to [4], Gas Turbine Combined Cycle Power Plant is a merger between Gas Turbine Power Plant and Steam Turbine Power Plant. Steam Turbine Power Plant utilizes heat energy and steam from exhaust gases from combustion in the Gas Turbine Power Plant to heat water in the HRSG (Heat Recovery Steam Generator) so that it becomes dry saturated steam. This dry saturated steam will be used to rotate the turbine blades. The gas produced in the combustion chamber at Gas Turbine Power Plant will drive a turbine and then a generator, which will convert it into electrical energy.

B. Gas Turbine Overhaul

The Gas Turbine (GT) operated by PT IP has 3 types of overhaul maintenance, namely Combustor Inspection (CI), Turbine Inspection (TI) and Major Inspection (MI). Each type of overhaul has a different scope of work and duration. CI is carried out to determine the condition of the Combustor Parts of the Gas Turbine. TI is carried out to determine the condition of the Turbine Parts of the Gas Turbine. MI is carried out to determine the condition of all parts of the Gas Turbine, namely the Combustor, Turbine and Compressor [5].

C. Lean Maintenance

According to [3], Lean maintenance is a process or journey in achieving continuous improvement. This system focuses on adding value and reducing waste in the maintenance process so that maintenance lead time can be reduced. Meanwhile, according to [6], several sources of waste usually consist of inaccurate procedures, inaccurate planning, too much and unused inventory such as components, materials and equipment, even facilities that are not used properly, as well as wasted time, transportation , as well as excess labor. Meanwhile, according to [7], Lean can be defined as a business philosophy, a systematic approach to identify and eliminate waste or non-value added activities through continuous improvement. This concept aims to create a smooth flow of products along the process value stream and eliminate all types of waste.

D. Waste

According to [8], there are 8 types of waste in terms of maintenance, including: Defect, Over Production, Waiting, Not Use, Transportation, Inventory, Motion, and Excess Process. Meanwhile, according to [6], waste can be defined as all work activities that do not provide added value in the process of transforming inputs into outputs along the value stream. Previous research related to waste analysis in other industrial fields have been carried out by [9] and [10].Waste in the production process according to [11] is as follows:

- Overproduction is type of waste caused by excessive production
- Waiting is type of waste due to waiting for the next process.
- Transportation is an important activity but does not add value to a product. Transportation is the process of moving material or Work In Process (WIP) from one work station to another work station.
- Excess processing is type of waste when the work method or sequence of work (process) used is deemed inadequate and flexible.
- Inventories is type of waste due to lack of inventory or too much material,
- Motion is type of waste due to an unnecessary activity/movement that does not add value and slows down the process so that the lead time becomes longer.
- Defects are products that are damaged or do not comply with specifications. This will lead to a less effective rework process.

E. Root Cause Analysis (RCA)

According to [12], RCA is one of the tools used in problem solving initiatives to help the team find the root cause of the problem that is currently being faced. According to [13], there are several steps that must be taken in conducting a root cause analysis, including:

➢ *Identify the problem*

In identifying problems, you must pay attention to events that cause a high impact or loss, so it is very necessary to take corrective action.

➢ *Explain what happened*

In this step, the researcher conducts a re-analysis by collecting data, information and facts about the incident to understand what problems actually occurred.

➢ *Identify the causal factors*

In step 3 this is used to dig deeper into what problems occur and find out why these problems occur.

➢ *Identify root causes*

Conduct a thorough analysis of the problem factors that identify the root causes of the problem. This can be done by digging deeper into the root causes by asking the question "why" repeatedly until the root cause is known, this technique is known as the "five (5) why analysis" method.

➢ *Design and determine the improvement plan*

Design and determine improvement plans to fix a problem and prevent the problem from happening again in the future.

➢ *Measuring the results of the improvement evaluation.*

Corrective actions used to reduce or eliminate root causes must be re-evaluated whether the plan is effective in reduce or prevent a problem from reoccurring.

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F. Value Stream Mapping (VSM)

According to [14], Value Stream Mapping is a tool used to describe the system as a whole and the value streams in it. In addition, Value stream mapping serves as a visualization of the activity process in the form of a mapping flow chart which is useful for mapping activities that provide added value in realizing lean processes. According to [15], Value Stream Mapping can be used to identify activities that do not add value to customer value and identify waste that occurs. Companies must be able to eliminate non-value-added activities, increase value added activities and accelerate processes by eliminating waste that affects the process. According to [16], Value Stream Mapping is a tool used in lean maintenance analysis to describe each step in maintenance activities using a flowchart. Value Stream Mapping serves to describe activities that produce added value and those that do not produce added value. In addition, Value Stream Mapping also serves to identify and calculate waste of time and costs. Value Stream Mapping will then identify waste and implement process improvements in order to achieve maximum productivity. In general, Value Stream Mapping is very useful for increasing company productivity to make it more effective and efficient. There are 4 stages to create a Value Stream Mapping according to [17], namely:

➢ *Identify the observed object*

At this stage identification of customer needs is carried out.

➢ *Create a Current State Map for the observed object*

The Current State Map is an overview of the current work process with process details and data related to the process. To draw a Current State Map, the first thing to do is observe the physical flow of production along with process details and data related to that process. Next, begin to describe the material flow starting from the end customer (backward). The flow of data information is also described, and the system pull and push is determined.

➢ *Develop a Future State Map*

The Future State Map is an illustration of the desired work process based on the evaluation results of current activities on the Current State Map. To produce a Future State Map, it is necessary to evaluate the current performance as reflected in the Current State Map. In conducting the evaluation, several things can be identified, including: waste, non-value-added activity, etc. The results of this evaluation are used as the basis for making the Future State Map.

➢ *Develop work steps to achieve the Future State Map*

At this stage, work planning is carried out to produce the value planned in the Future State Map.

III. RESEARCH METHODS

The method used in this research is a Quantitative Descriptive method. The descriptive analysis method in this study was used to analyze the process flow of overhaul activities and identify what waste is at each stage of the TI overhaul process. In addition, quantitative methods are used to measure waste in the form of delays in completion of overhaul Turbine Inspection (TI) work at PT IP using the Lean concept. The use of the Quantitative Descriptive method is expected to be able to provide output of research results that can be used as managerial implications for PT IP's management. The population in this study were employees from PT IP who came from the MSU team as executors of TI work and Owners from the Maintenance or Maintenance division (40 people) and Engineering (10 people) with position levels ranging from executor level to Manager level. Therefore, the total population in this study is 50 people. The sampling procedure used in this research is non-probability with purposive sampling technique. Determination of the sample in this study was carried out by determining the target of the most suitable population elements to be used as key informants, namely the senior executive level up to the Manager at PT IP with a total of 10 people. The selection of key informants in this study used several considerations including tenure, division, experience as an TI overhaul leader, position level and certification. Data collection methods (primary data and secondary data) used in this study are as follows:

➢ *Primary Data*

Primary data in this study were collected through direct observation of the TI overhaul process in the field and interviews with experts as key informants in this study. The experts will assist the author during the process of analyzing causes and repair plans to overcome delays in completing TI overhaul work.

➢ *Secondary Data*

The secondary data used in this study came from PT IP company documents, for example TI overhaul work history data and several references sourced from the internet.

The data analysis method used in this study is as follows:

- The stages of identifying waste, in this study are intended to obtain information about any waste that occurs in the TI overhaul process by making direct observations in the field. This stage aims to understand the process flow that is running and classify it into value-added processes and non-value-added processes.
- Create a Current State Map (CSM) for the TI overhaul process starting from unit shutdown to unit handover to operations. A good understanding of each TI overhaul process is very important to make a good and effective Future State Map plan.
- Conduct a Root Cause Analysis using Fishbone Diagrams and Why Analysis to identify the root causes and waste of TI overhaul implementation.
- Evaluate all data collected to determine improvement ideas to overcome waste during TI overhaul implementation.
- Creating an appropriate and effective Future Stream Map (FSM) to deal with existing waste.
- Evaluation of the implementation of the Future Stream Map (FSM) against the target of completing the TI overhaul work.

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IV. RESULT AND DISCUSSION

A. Current State Mapping (CSM)

Current State Mapping is made to find out how the workflow of the Overhaul Turbine Inspection (TI) starts from the Disassembly, Inspection and Assembly stages. In addition, every activity in the TI overhaul will be thoroughly analyzed to ensure the forms and work flow of all activities Turbine Inspection. Current State Mapping is made based on the results of direct field observations and interviews with experts.

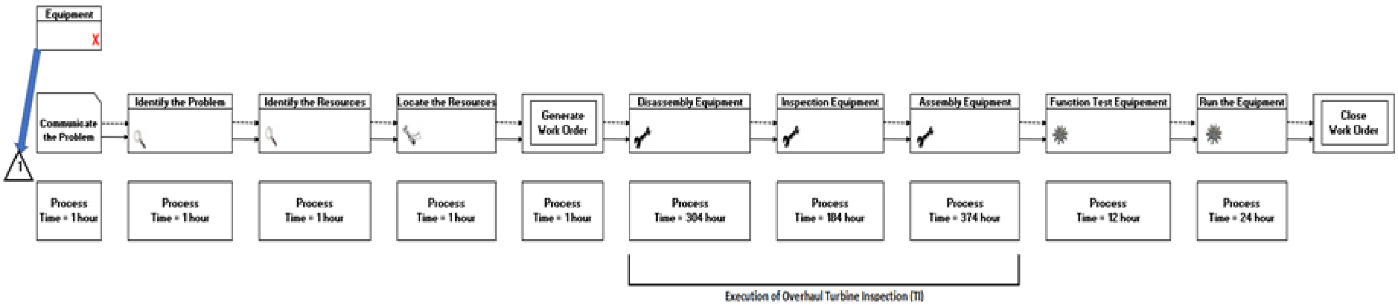

Fig 1. Overview Flow Chart of Overhaul TI in PT IP

Figure 1 above shows how Current State Mapping is the TI overhaul process starting from making WOs to Close WOs that have been made. In general, the administrative process of implementing an TI overhaul starts with creating a Work Order (WO) from the user to the executor, namely the MSU team until the WO status changes to Closed.

The waste criteria described in the previous chapter can be abbreviated as DOWNTIME (Defect, Overproduction, Waiting, Not Utilizing Employees, Transportation, Inventories, Motion, Excess Process) carried out by comprehensive activity analysis. The process of identifying the type of waste that occurs is carried out by combining the results of observations in the field, the results of interviews with experts and the existing Current State Mapping. Experts were asked to provide an assessment of several categories of waste in the 2016 - 2021 period. The weight of each category will be calculated based on the number of experts who vote in each category which will then be multiplied by the scores in each category and a percentage will be made to find out the ranking of each category based on the judgment of the experts. The following is the result of the expert's assessment of several categories of causes of waste in the implementation of TI overhauls.

Table 1. Waste on TI Overhaul Activities.

No.	Category	1	2	3	4	5	Score	Rangking
1	*Defect*	0	9	1	0	0	21	7
2	*Overproduction*	10	0	0	0	0	20	8
3	*Waiting*	0	0	0	0	10	50	1
4	*Not Utilizing employees knowledge, Skill and Abilities*	0	0	0	2	8	48	3
5	*Transportation*	0	0	0	3	7	47	4
6	*Inventories*	0	0	0	1	9	49	2
7	*Motion*	0	8	2	0	0	22	6
8	*Excess Processing*	0	0	2	8	0	38	5

Table 1 above shows that the sequence of waste in OH TI activities occurs mostly in Waiting, Inventories, Not Utilizing employees, Transportation, Excess Processing, Motion, Defect, Overproduction. The results of the assessment from the experts above will be used as a reference for the process of identifying the root cause of waste during the TI overhaul implementation. In addition, information and data in Table 1 will be used as a reference for making corrective steps as well. The experts and writers will carry out further analysis to determine corrective steps that must be taken to overcome the existing problems. Therefore, the selection of experts as key informants in this research is an important factor that determines the accuracy of the results of the identification and analysis of all research data.

B. Root Cause Analysis

The Root Cause Analysis (RCFA) tools used for waste analysis in TI overhaul are Fishbone Diagrams and 5W+1H.

➢ *Fishbone Diagram Analysis*

Data analysis using Fishbone diagrams aims to find all possible causes through an interview process with experts. Common problems began to be grouped and focused in more detail and depth to explore the root causes of the problems. In a two-way discussion between the author and the experts, the writer's duty is to utilize all the experience possessed by the experts to find the root of the problem and look for corrective steps to be taken.

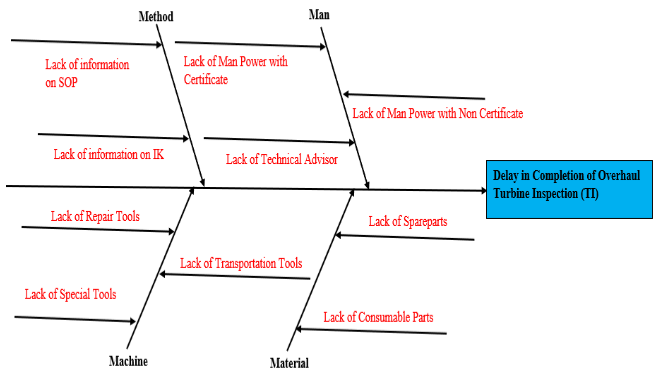

Fig 2. Fishbone Diagram of Waste Analysis

Figure 2 above shows that the results of the analysis using the Fishbone Diagram tool found that the main cause was by writing down all the sub causes that might occur in the main cause group, namely Man, Material, Machine, Method. Furthermore, the sub causes in the main cause group are selected which have the most significant impact on the delay in completing the TI overhaul implementation. In general, the main problems that cause problems during TI overhaul implementation are human resources, budget, tools and parts. Therefore, discussions with management to discuss what are the action plans and strategies to overcome all these problems are very important to do. This is because, management plays an important role in terms of budget allocation that will be needed to overcome all existing problems.

Table 2. Improvement Plan of Overhaul TI

No.	Waste	Problem	Improvement Plan
1	Waiting	Waiting for the process of loosening the casing turbine bolts due to the finding of damage to the turbine casing bolts (Machine & Materials)	1. Replace the bolt type with the upgrade type. 2. Prepare the required special tools and repair tools.
		The process is waiting for the results of the judgment from the Technical Advisor (TA) regarding the measurement of turbine clearance (Man)	1. Inform the estimated time required for judgment by the TA. 2. Transferring idle manpower to other work activities
		The process of installing a waiting fuel branch pipe so that there are workers who are unemployed when Alignment Blade Ring (Man)	Starting the activity of installing the fuel branch pipe during the blade ring alignment process
2	Inventories	Consumable parts are not available which can interfere with the progress of the OH (Material)	1. Provide additional consumable parts for TI overhaul. 2. Coordination with other generating units for other additional options
		Critical spare parts that are not available in the Warehouse (Material)	1. Provide critical parts for IT overhaul. 2. Coordination with other generating units for other additional options
3	Not Utilizing employees knowledge, skill, and ability	Work progress is delayed due to limited technicians who have good skills and experience in the field (Man)	1. Provide TA mechanic Day and Night Shift to support during OH. 2. Conducting On Job Training (OJT) programs to generate local TA
4	Transportation	Delivery of Hot Gas Path Parts (HGPP) Roll In which is too close to the installation schedule (Method)	Move parts to roll in to a location close to the GT lay down
		Delivery of parts that require machining in the Workshop (Machine)	Additional manpower to support machining work in the Workshop
		Delivery of special tools and repair tools that take too long (Machine)	Submission of investment budget for procurement of additional special tools and repair tools
5	Excess Processing	Repeated blade ring alignment work (Man)	Prepare experienced TAs or technicians to support during the alignment process

Table 2 above shows what corrective steps must be taken to overcome all the causes of waste during TI overhaul. The results of data analysis through an interview process with experts using Fishbone Analysis found the main root causes of the Manpower, Material, Machine, Method problems. All information regarding the main root causes is used to determine corrective actions using Root Cause Analysis with the 5W+1H method.

Further discussion is carried out to optimize the duration of OH TI through waste analysis in several categories that have been identified previously. The discussion is carried out by analyzing the waste of all TI overhaul activities, especially on the critical path which can be seen in the TI Overhaul project process.

Fig 3. Presentation of TI Overhaul Corrective Actions during the Inspection Management Meeting.

Figure 3 above shows the condition of the Inspection Management Meeting which was attended by PT IP and JO MHI. The main consideration in selecting the Inspection Management Meeting to explain all corrective actions and also the action plan for the next OH TI is that the meeting is attended by top management representatives from each unit at PT IP. Therefore, the outcome and managerial implications of the results of this study are expected to be used more optimally by the management of PT IP.

C. Future State Mapping (FSM)

Future State Mapping will be made for each of the main activities of the Overhaul Turbine Inspection, namely Disassembly, Inspection and Assembly. In general, the number of activities including the duration of each TI overhaul stage starting from Disassembly, Inspection and Assembly is not too much different from the Current State Mapping that was made previously. However, there have been some changes in the number of activities and strategies chosen for FSM design, including:

- Perform work in parallel.
- Move manpower to another activity for activities that are still waiting.
- Ensuring the availability of tools (special tools & repair tools)
- Ensuring the availability of sufficient consumable and critical parts in the warehouse
- Modification of the delivery schedule and the location of the temporary placement of roll in parts to optimize the duration during the assembly stage.
- Considering findings and improvement previous OH TI.

Table 3. Determination of Action 5W+1H

DETERMINATION OF ACTION 5W+1H	
Participants: Related Authors, Experts and Managers.	
1. Man	
What: Problem	OH TI work progress that exceeds the time standard set by the manufacturer.
Why : The main cause	Lack of training and experts/leaders in overseeing all IT overhaul activities
Where : Location or Area	Gas Turbine area Combustor and Turbine
When : Schedule of Implementation	Next Overhaul TI
Who: PIC	Maintenance Manager, Engineering Manager, Human Resource (HR) Manager, Administration Manager
How: Corrective Action	• Recruitment of experienced new employees. • Organizing On Job Training (OJT) in cooperation with MHI. • Adding knowledge sharing items to Key Performance Indicator (KPI) targets to increase employee motivation and enthusiasm to continue learning. • Borrowing experienced executors from other areas as QC of IT OH implementation
Remarks: Corrective actions have been approved by management and have started to be implemented.	
2. Machine	
What: Problem	The progress of OH TI's work was hampered due to the specifications of the existing parts that were not good enough.
Why : The main cause	Existing parts specifications that have not used the upgrade type.
Where : Location or Area	Gas Turbine area Turbine
When : Schedule of Implementation	Target upgrade and implementation at the next OH TI
Who: PIC	Maintenance Manager, Engineering Manager, Human Resource (HR) Manager, Administration Manager
How: Corrective Action	• Submission of Operational and Investment Budgets for upgrading the specifications of parts needed by OH TI • Use of specification parts with gradual upgrade type
Remarks: Corrective actions have been approved by management and have started to be implemented.	
3. Method	
What: Problem	Less effective and organized sequence of OH IT activity flows
Why : The main cause	SOP and IK related to OH TI activities are still incomplete
Where : Location or Area	Gas Turbine area Combustor, Turbine and Exhaust
When : Schedule of Implementation	Next OH TI
Who: PIC	Maintenance Manager, Engineering Manager, Human Resource (HR) Manager, Administration Manager
How: Corrective Action	• Conduct regular and scheduled SOP and IK reviews with the MSU and MHI teams • Adding items for review or creating new SOPs and IK on employee KPI targets
Remarks: Corrective actions have been approved by management and have started to be implemented.	
4. Material	
What: Problem	OH TI's work progress was hampered due to unavailable parts and tools (special tools and repair tools).
Why : The main cause	Monitoring the readiness of parts for OH needs which are still not optimal
Where : Location or Area	Gas Turbine area and Warehouse
When : Schedule of Implementation	Next OH TI
Who: PIC	Maintenance Manager, Engineering Manager, Human Resource (HR) Manager, Administration Manager
How: Corrective Action	• Added monitoring of the readiness of parts needed by OH TI at each preparatory meeting such as P1 - P3. • Submission of Investment and Operational Budget for additional tools and parts needed by OH. • Coordination with other generating units as a backup plan
Remarks: Corrective actions have been approved by management and have started to be implemented.	

Table 3 the use of the 5W+1H tools above was explained to all stakeholders such as the MSU team, PT IP and JO MHI during the Inspection Management Meeting. The following is documentation of the discussion of steps to improve TI overhaul during the Inspection Management Meeting.

The total duration for the disassembly stage can be reduced significantly if the duration of the work activity which is the main bottleneck, namely the activity of removing the turbine casing bolts, can be reduced. In addition, when viewed from the point of view of the number of activities, in general, no activity has been changed. However, when viewed from the duration of the work, there was a significant decrease in the duration of the work because repairs had been made during the removal of the turbine casing bolts. The FSM design for the Disassembly stage is made by considering several activities that fall into the NNVA and NVA categories. Based on the calculation results, the total duration of the TI overhaul implementation based on the results of the FSM design for all stages starting from Disassembly, Inspection and Assembly is 22 days.

D. Analysis of the Implementation of FSM in Next TI

Future State Mapping which has been made for each stage of TI overhaul (Disassembly, Inspection, and Assembly) and implemented in the next TI overhaul activity, namely GT 4.2 TI 2022. Presentation of research results in the form of FSM and several improvement steps have been explained during the Inspection Management Meeting, Kick Off Meeting and Daily Meeting from the GT 4.2 TI 2022 overhaul. In addition, monitoring of the implementation of the repair results was also carried out during the TI overhaul. This is done to determine the total duration of the Overhaul Turbine Inspection project after eliminating Non-Value Added at each stage.

Based on the results of the implementation of the next TI overhaul, the total duration of the OH TI GT 4.2 TI 2022 project after eliminating Non-Value Added was 22 days. This result is close to the standard duration given by the manufacturer, which is 21 days. The following is the actual schedule for the OH GT 4.2 TI 2022. The results of the implementation of OH TI improvements can be seen the impact of waste elimination which is the main goal of Value Stream Mapping, namely waste. As is the case in Inspection activities that are not in accordance with the standards and need to be adjusted to the standards. This does not change the duration of the project and the number of workers, because only the repair material specifications have changed.

Table 4 Managerial Implications of Research Results

Component	Before	After	Improvement
Total Overhaul Duration	34 days	22 days	The total duration of Overhaul after the study is close to the total standard duration.
Loss Production Opportunity	The 2016 – 2021 period is 755.06 billion	Period 2022 – 2023 15.1 billion	Loss Production Opportunity can be minimized significantly.
Man Power	Quite a lot of idle manpower	The use of man power is more effective	Better effectiveness of using manpower
Overtime	Budget allocation for overtime is high	Low budget allocation for overtime	Optimization of overtime costs
Spare Parts	Monitoring the readiness of spare parts is not optimal	Monitoring the readiness of spare parts on a regular basis	Better spare parts readiness
Standard Operating Procedure (SOP)	There is no routine SOP review yet	SOP review is carried out regularly	SOP is more complete and always updated
Work Instructions (IK)	IK review has not been added to employee KPI targets	IK review has been added to employee KPI targets	IK is more complete and always updated

E. Managerial Implications of Research Results

The managerial implication resulting from this research is to contribute to both PT IP and MHI companies which are the current workplaces in the form of documents that contain guidance or references during the implementation of the TI overhaul at the next PT IP. The following is an Executive Summary of the Managerial Implications of the results of this study.

Table 4 shows how the impact compares before and after the research is carried out. In addition, several components experienced significant improvements, especially for the overhaul duration and loss production opportunity components. These two components are one of the important components and have always been the main focus for the management of PT IP during the TI overhaul. Therefore, the results of this research are highly appreciated by the management of PT IP and deserve to be used as a reference by other companies, namely PT PLN Nusantara Power. The concept generated by this study can also be used as a reference for the implementation of Gas Turbine overhaul activities with a scope other than TI, namely CI and MI. In addition, an important point generated by this study is that the resulting concept can be used as a reference by other companies such as PT Nusantara Power which uses a Gas Turbine type that is almost the same as that used at PT IP. Therefore, the Managerial Implications generated by this research can be of maximum benefit to more companies.

V. CONCLUSION

The following are the conclusions resulting from this research, including:

A. Waste that results in delays in the completion of TI overhaul work as follows:

➢ *Waiting*

- Waiting for the process of loosening the turbine casing bolts due to the discovery of damage to the turbine casing bolts.

- Waiting for the results of the judgment from the Technical Advisor (TA) regarding the turbine clearance measurement.
- The process of waiting for the fuel branch pipe installation work due to waiting for the blade ring alignment work.

➢ *Inventories*
- Consumable parts are not available which can interfere with the progress of the OH work.
- Critical spare parts that are not available in the Warehouse.

➢ *Not Utilizing employees*
- Work progress is delayed due to the limited number of technicians who have good skills and experience in the field.

➢ *Transportation*
- Delivery of Hot Gas Path Parts (HGPP) Roll In which is too close to the installation schedule.
- Delivery of parts that require machining at the Workshop.
- Shipping of special tools and repair tools takes too long.

➢ *Excess Processing*
- Repetitive blade ring alignment work.

B. Recommendations and corrective steps taken to overcome delays in the completion of TI overhaul work is to implement FSM and several corrective steps as follows:

➢ *Man*
- Recruitment of experienced new employees.
- Organizing On Job Training (OJT) in cooperation with MHI.
- Adding knowledge sharing items to Key Performance Indicator (KPI) targets to increase employee motivation and enthusiasm to continue learning.
- Borrowing experienced executors from other areas as QC of TI OH implementation.

➢ *Machine*
- Submission of Operational and Investment Budgets for upgrading the specifications of parts needed by OH TI
- Use of specification parts with gradual upgrade type.

➢ *Method*
- Conduct regular and scheduled SOP and IK reviews with the MSU and MHI teams
- Adding items for review or creating new SOPs and IK on employee KPI targets.

➢ *Material*
- Added monitoring of the readiness of parts needed by OH TI at each preparatory meeting such as P1 - P3.
- Submission of Investment and Operational Budget for additional tools and parts needed by OH.
- Coordination with other generating units as a backup plan.

C. Future State Mapping and all improvement steps that have been made are implemented in the next TI overhaul, namely GT 4.2 TI 2022. The results of the implementation of GT 4.2 TI 2022 show that the total duration of TI work is close to the standard provided by the manufacturer, namely 22 days. This shows that there are good managerial outcomes and implications from the results of this study for the authors and PT IP.

FUTURE WORKS

The following are some suggestions given in this study, including:

- The strategies and corrective steps produced in this study can be used in other scopes of work in Gas Turbine such as Combustor Inspection (CI) and Major Inspection (MI).
- The results of research conducted at PT IP can be used by other companies, namely PT PLN Nusantara Power which has a Gas Turbine of the same type as PT IP, namely the Mitsubishi Gas Turbine M701F type. This implementation will further emphasize the outcome and managerial implications resulting from this research.

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