Improving Overhaul Process on Steam Power Plants using Lean Thinking and LCA

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Abstract. Due to the limited availability and the increasing Price of both High and Medium rank coal, the pressure of providing a lower electricity price causes Indonesian Electricity Power Producer into using low-rank coal as their primary fuel (Coal Switching Program). The success of the coal switching program undertaken by the PTN Power Plant also had another impact on the condition of the equipment. Low-calorie coal with high water content disrupts to generate material which not infrequently also causes derating of the unit. Derating that occurred causes a decrease in the value of EAF (Equivalent Availability Factor) of PTN power plant from 93.07 in 2017 to 90.21 in 2018 and 89.74 (estimated EAF) in 2019. To maintain the EAF value is still above the amount of 90% or still at the Top 10% NERC then improvement is needed. Waste management process using lean thinking approach with value stream mapping and 5S visual management methods collaborated with life cycle assessment is an effective way to optimize EAF from plant outage or overhaul. With this method, it can maximize the 2019 EAF value to 90.84%, identify the environmental impacts that arise in the overhaul process and determine the best improvement recommendations.

1. Introduction

Business competition in the growing electricity generation industry requires each company to continue to make improvements and improve its performance. The Indonesian power generation industry, especially on the island of Java, is currently still dominated by coal-fired steam power plants. To be able to meet the electrification ratio in accordance with the PLN RUPTL 2019 – 2028 [1] as shown in figure 1, an increase in the construction of a steam power plant with ultra-supercritical technology, environmentally friendly and using low-calorie coal types (4000 - 4700 kcal).
This condition requires a steam power plant with old technology and who have passed its economic age to innovate. PTN steam power plant is one of the steam powerplants that innovate to be able to compete with other steam power plant that uses new technology. It is done by changing the value of coal consumption (from high calorie to low calorie) or commonly called Coal Switching in 2018. The success of the coal switching innovation undertaken by the PTN steam power plant also had another impact on the condition of the equipment. Low-calorie coal with high water content disrupts to generate material which not infrequently also causes derating of the unit. Derating is caused by equipment disruption, which takes a long time in the repair process such as broken coal feeder belts, plugging silos and gearbox mills that are damaged due to weak coal conditions. Derating that occurred causes a decrease in the value of EAF (Equivalent Availability Factor) of PTN steam power plant from 93.07 in 2017 to 90.21 in 2018 and 89.74 (estimated EAF) in 2019 [2]. To maintain the EAF value is still above the amount of 90% or still at the Top 10% NERC then improvement is needed.

Lean is an ideal method for optimizing the performance of the overhaul process system because it is able to identify, measure, analyze and find solutions to improve or improve performance comprehensively. The lean approach focuses on efficiency without reducing the effectiveness of processes, including increasing value-added operations, reducing waste, and being able to meet customer needs [3]. Based on the description above, the waste management process using lean thinking approach with value stream mapping and 5S visual management methods in collaboration with life cycle assessment is an effective way to optimize EAF in terms of plant outage or overhaul.

2. Theory

2.1. Power plant performance indicators

Power Plant Performance Indicators are indispensable in the operation of generating units. The accuracy of calculation data, the speed and accuracy of information is support and input to management decision making in managing/managing the generating unit. According to the 2007 DKP-IKP Protap which refers to SPLN K7.001: 2007. Inactive is the status of the unit not ready for operation for a long time because the unit is released for economic reasons or other reasons not related to plant equipment/installations. Whereas Active consists of the various operating status of generating units up to four levels (SPLN K7.001: 2007). Then the generator performance indicator (IKP), namely EAF (Equivalent Availability Factor) The total readiness of the operating generating unit can be calculated using the following equation:

$$EAF = \frac{AH - (EFDDH + EFDH + ESDH)}{PH} \times 100\%$$

Keterangan:
EAF = Equivalent Availability Factor
AH = Availability Hour
EFDH = Equivalent Forced Derated Hours
2.2. Lean

Lean is a continuous effort to eliminate waste, increase value-added products (goods and services) and provide value to customers (customer value) [4]. According to Hines & Taylor (2000), the principle of lean thinking is to look for ways to process value creation in the best possible order, arrange these activities without interruption, and explain more and more effectively. Lean thinking provides a way to get closer to fewer people, equipment, time and space, but get closer to consumers [3]. In addition, this approach can reduce unnecessary inventory, increase knowledge about the production process, save costs, reduce defects so that quality increases, reduce production lead times and reduce waste [5]. There are five basic principles of lean:

1. Identify product values based on customer perspectives.
2. Identify the mapping value stream for each product.
3. Eliminating waste that does not add value from all activities along the value stream.
4. Organizing so that material, information, and products flow smoothly and efficiently throughout the value stream process using a pull system.
5. Continue to look for techniques and tools for improvement (improvement tools and techniques) to achieve excellence and continuous improvement.

2.3. Value stream mapping

Value stream mapping is a visual method for mapping the production lines of a product which includes material and information from each work station [6]. Using value stream mapping means starting with the big picture in solving problems not just in a single process and making improvements as a whole and not only in specific methods [6].

![Value Stream Mapping](image)

**Figure 2.** Value stream mapping

2.4. 5S visual management

5S is a tool derived from Lean tools used to change the effectiveness and efficiency of a process. Such a huge benefit is gained by implementing this tool because it has an educational work environment so that all work activities run in accordance with what should occur. Visual Management is the key to successful 5S implementation. The purpose of visual management is to make the situation clear just by
seeing it with as little as possible observation or time. In the application, there are five programs including [4]:

1. Seiri (Sort) / Sorting
2. Seiso (Shine) / Cleaning
3. Seiton (Set in Order) / Structuring
4. Seiketsu (Standardize) / Standardization
5. Shitsuke (Sustain) / Habituation

2.5. Life Cycle Assessment (LCA)
Life Cycle Assessment (LCA) is an approach used to analyze the impact of an environmental product during the product life cycle. The Life Cycle Assessment concept is based on the idea that an industrial system is inseparable from the environment in which the industry is located. Life cycle assessment is generally an approach to measure environmental impacts caused by products or activities starting from taking raw materials, followed by production and use processes, and ending in waste/waste management.

3. Discussion and analysis

3.1 Equivalent availability factor

| Table 1. Equivalent availability factor |
| Year | PH | SH | RSH | FOH | MOH | POH | EMDH | EFDH | EAF |
| 2017 | 8760 | 8026.733 | 148.7 | 97.425 | 64.817 | 422.33 | 9.656 | 12.95 | 93.07 |
| 2018 | 8760 | 7892.05 | 74.983 | 42.608 | 123.75 | 626.61 | 2.304 | 62.71516 | 90.21 |
| 2019 | 8760 | 4094.85 | 69.517 | 61.567 | 118.067 | 636 | 0.834 | 82.84 | 89.74 |

The table above shows the EAF value of PTN Power Plant units from 2017 to 2019 (before and after coal switching program). Where is seen the condition of the decline in the EAF value caused by the increasing amount of EFDH. Therefore, to maintain the EAF value to remain above 90% (still included in the NERC standard), it is necessary to accelerate the overhaul process in 2019. In the process, PTN power plant implements a SE (serious Inspection) overhaul program which requires 53 days of repairs based on history the last job. For this reason, in order to be able to maintain the EAF value above 90%, waste management is needed by using the concept of lean manufacturing as follows:

1. The prognosis of EAF entity value 2019 with the State Power Plant SE for 53 days (with derating conditions do not occur):

\[
\text{EAF} = \frac{AH - EDH}{PH} \times 100\%
\]
\[
= \left(\frac{PH - (FOH + MOH) - (EFDH + EMDH)}{PH}\right) \times 100\%
\]
\[
= \left(\frac{8760 - (64.817 + 61.567 + 118.067) - (626.61 + 0.834)}{8760}\right) \times 100\%
\]
\[
= 8760 - 915.83 / 8760 \times 100\%
\]
\[
= 89.74\%
\]

2. The prediction of EAF entity value 2019 with the State Power Plant SE for 45 days (with derating conditions do not happen):

\[
\text{EAF} = \frac{AH - EDH}{PR} \times 100\%
\]
\[
= \left(\frac{PH - (FOH + MOH) - (EFDH + EMDH)}{PH}\right) \times 100\%
\]
\[
= \left(\frac{8760 - (64.817 + 61.567 + 118.067) - (626.61 + 0.834)}{8760}\right) \times 100\%
\]
\[
= 8760 - 719.83 / 8760 \times 100\%
\]
\[
= 90.84\%
\]
3.2 Lean

1. Big mapping picture

To make it easier to do waste management on the PTN power plant overhaul system, a big mapping picture was created with the process following the SE standard, which took 53 days as follows:

![Diagram of research methodology](image)

**Figure 3. Flow diagram of research methodology**

Based on the results of the value stream mapping in Figure 3, it can be seen that there is waiting between the shutdown process leading to an overhaul of 5.6%, this condition is caused by waiting for the boiler cooling process naturally for three days or 72 hours. In addition, there was also waiting after the overhaul work process was completed leading to the commissioning and
startup unit by 2.8%, this condition was due to the operation of preparation for going to the commissioning and startup unit.

2. Process activity mapping

| No. | Activity                                      | Time (hour) | Time (day) | Activity           | Classification |
|-----|----------------------------------------------|-------------|------------|--------------------|----------------|
| A   | Shutdown Unit                                |             |            |                    |                |
| 1   | Shutdown Unit                                | 24          | 1          | v                  | v              |
| 2   | Natural Cooling                              | 72          | 3          | v                  | v              |
| B   | Overhaul Main Turbine                        |             |            |                    |                |
| 1   | Material Transfer                            | 8           | 1          | v                  | v              |
| 2   | Crane Setting                                | 8           | 1          | v                  | v              |
| 3   | Disassembly Turbine                          | 24          | 3          | v                  | v              |
| 4   | Disassembly Generator                         | 24          | 3          | v                  | v              |
| 5   | Turbine & Generator Inspection               | 24          | 3          | v                  | v              |
| 6   | Turbine & Generator Part Replacement         | 48          | 6          | v                  | v              |
| 7   | Assembly turbine                             | 24          | 3          | v                  | v              |
| 8   | Assembly Generator                            | 24          | 3          | v                  | v              |
| 9   | DCS Installation                             | 48          | 6          | v                  | v              |
| 10  | Electric Inspection                           | 24          | 3          | v                  | v              |
| 11  | Cleaning Condenser                            | 24          | 3          | v                  | v              |
| 12  | Overhaul Main Turbine Waste Management       | 24          | 3          | v                  | v              |
| C   | Overhaul Aux. turbine                        |             |            |                    |                |
| 1   | Material Transfer                            | 8           | 1          | v                  | v              |
| 2   | Disassembly Boiler Feed Pump                 | 32          | 4          | v                  | v              |
| 3   | Boiler Feed Pump Inspection                  | 96          | 12         | v                  | v              |
| 4   | Assembly Boiler Feed Pump                    | 32          | 4          | v                  | v              |
| 5   | Disassembly Cooling Water Pump               | 16          | 2          | v                  | v              |
| 6   | Cooling Water Pump Inspection                | 32          | 4          | v                  | v              |
| 7   | Assembly Cooling Water Pump                  | 16          | 2          | v                  | v              |
| 8   | Disassembly Pumps                            | 48          | 6          | v                  | v              |
| 9   | Pumps Inspection                             | 48          | 6          | v                  | v              |
| 10  | Assembly Pumps                               | 48          | 6          | v                  | v              |
| 11  | Valve Inspection                             | 96          | 12         |                    |                |
| 12  | DCS Installation                             | 48          | 6          | v                  | v              |
| 13  | Electric Inspection                           | 44          | 5.5        | v                  | v              |
| 14  | Overhaul Aux. Turbine Waste Management       | 24          | 3          | v                  | v              |
| D   | Overhaul Boiler dan Aux. Boiler              |             |            |                    |                |
| 1   | Material Transfer                            | 8           | 1          | v                  | v              |
| 2   | Cooling Boiler                               | 72          | 3          | v                  | v              |
| 3   | Assembly Scaffolding                         | 24          | 3          | v                  | v              |
| 4   | Disassembly boiler pipe                      | 48          | 6          | v                  | v              |
| 5   | Boiler Inspection                            | 23          | 3          | v                  | v              |
| 6   | Boiler Pipe Parts Replacement                | 96          | 12         | v                  | v              |
| 7   | X-Ray                                       | 16          | 2          | v                  | v              |
| 8   | Leak Test                                    | 12          | 1          | v                  | v              |
| 9   | Disassembly Pulverizer                       | 24          | 3          | v                  | v              |
| 10  | Pulverizer Inspection                        | 24          | 3          | v                  | v              |
| 11  | Pulverizer Parts Replacement                 | 48          | 6          | v                  | v              |
| 12  | Assembly Pulverizer                          | 24          | 3          | v                  | v              |
| 13  | Disassembly Fan                              | 24          | 3          | v                  | v              |
| 14  | Fan Inspection                               | 24          | 3          | v                  | v              |
| 15  | Fan Parts Replacement                        | 48          | 6          | v                  | v              |
| 16  | Assembly Fan                                 | 24          | 3          | v                  | v              |
| 17  | DCS Installation                             | 48          | 6          | v                  | v              |
| 18  | Electric Inspection                           | 30          | 3          | v                  | v              |
| 19  | Overhaul Boiler & Aux. Boiler Waste Management| 24          | 3          | v                  | v              |
| E   | Overhaul Coal & Ash Handling                 |             |            |                    |                |
| 1   | Material Transfer                            | 8           | 1          | v                  | v              |
| 2   | Cleaning ESP                                 | 24          | 3          | v                  | v              |
| 3   | ESP Inspection                               | 48          | 6          | v                  | v              |
| 4   | ESP Parts Replacement                        | 120         | 15         | v                  | v              |
| 5   | CEMS Inspection                              | 24          | 3          | v                  | v              |
| 6   | CEMS Parts Replacement                       | 48          | 6          | v                  | v              |
| 7   | DCS Installation                             | 48          | 6          | v                  | v              |
| 8   | Electric Inspection                           | 48          | 6          | v                  | v              |
| 9   | Overhaul Coal & Ash Handling Waste Management| 32          | 4          | v                  | v              |
Based on PAM in table 2 obtained the results of operations with classification value-added are 2 activities, services with no value-added are 2 activities. Transfer activities which classified as necessary non-value added are 4 activities. Inspection activities which have value-added are 27 activities, while inspection activities which classified as necessary non-value added are 14 events. Storage activities which classified as necessary non-value are 4. And for the delay activity which classified as necessary non-value added are 2 activities.

3. Determination of critical waste by borda count method

Determination of critical waste that is overproduction, defects, unnecessary inventory, inappropriate processing, excessive transportation, waiting and unnecessary motion by using the Borda Count Method (BCM).

Table 3. The results of the seven waste BCM

| Waste               | Manager of Maintenance | SPV S Outage | SPV S Mech. | Mech. Engineer | Outage Eng. |
|---------------------|------------------------|--------------|-------------|----------------|-------------|
| Overproduction      | -                      | -            | -           | -              | -           |
| Defects             | 2                      | 4            | 2           | 5              | 1           |
| Unnecessary Inventory| 7                      | 6            | 6           | 3              | 3           |
| Inappropriate Processing | 5                   | 3            | 3           | 3              | 2           |
| Excessive Transportation | 6                 | 2            | 2           | 6              | 4           |
| Waiting             | 6                      | 5            | 4           | 7              | 5           |
| Unnecessary Motion  | 5                      | 5            | 5           | 7              | 7           |

Based on the results of the waste 7 BCM questionnaire in table 3, the ranking results are searched using the calculation of value and scores in table 4.

Table 4. Value calculation for BCM

| Value | Score |
|-------|-------|
| 1     | 7     |
| 2     | 6     |
| 3     | 5     |
| 4     | 4     |
| 5     | 3     |
| 6     | 2     |
| 7     | 1     |

Then the results obtained from 7 ratings waste in the production process in PLTU PTN, can be seen in the following table 5.

Table 5. Critical waste ranking results

| Waste                  | TOTAL | Ranking |
|------------------------|-------|---------|
| Overproduction         | 0     | 7       |
| Defects                | 14    | 6       |
| Unnecessary Inventory  | 25    | 3       |
| Inappropriate Processing| 16    | 5       |
| Excessive Transportation| 20    | 4       |
| Waiting                | 27    | 2       |
| Unnecessary Motion     | 29    | 1       |
Based on the results of the Borda Count Method, it is found that the three highest critical waste ratings are unnecessary motion with a score of 29, waste waiting with a score of 27 and waste unnecessary inventory with a score of 25. This occurs because the third waste has waste impact significantly on the power plant overhaul process PTN, which is not ergonomic workstation arrangement, the tool/component beyond the reach of a technician, there is miscoordination, as well as material that exceeds the storage volume.

3.3 Life cycle inventories

In the PAM list, there is a waste management activity that is a breakdown in table 3 using the Life Cycle Inventory method:

| Area                  | Boundaries | Waste                      |
|-----------------------|------------|----------------------------|
| Main Turbine          | Hazardous Waste | Lubricant                  |
|                       |            | Welding Electrodes         |
|                       |            | Contaminated cotton waste  |
|                       | Solid waste | Masker                     |
|                       |            | Scrap metal                |
| Auxiliary Turbine     | Waste water | Aux. Turbine cleaning      |
|                       |            | Domestic waste water       |
|                       | Hazardous Waste | Lubricant                  |
|                       |            | Contaminated cotton waste  |
|                       |            | Welding Electrodes         |
|                       |            | Plastic                    |
|                       | Solid waste | Masker                     |
|                       |            | Scrap metal                |
| Boiler & Aux. boiler  | Waste water | Boiler blowdown            |
|                       |            | Aux. boiler cleaning       |
|                       |            | Slagging spray             |
|                       |            | Domestic waste water       |
|                       | Hazardous Waste | Lubricant                  |
|                       |            | Contaminated cotton waste  |
|                       |            | Welding Electrodes         |
|                       |            | Plastic                    |
|                       | Solid waste | Masker                     |
|                       |            | Scrap metal                |
|                       | Radiation  | X-Ray                      |
| Coal & Ash Handling   | Waste water | Coal run off pond          |
|                       |            | Ash run off pond           |
|                       |            | Domestic waste water       |
|                       |            | Cleaning area              |
|                       | Gas emission | Coal dan Ash Dust         |
|                       |            | Ash transport              |
|                       | Hazardous waste | Fly ash & bottom ash     |
|                       |            | Lubricant                  |
|                       |            | Contaminated cotton waste  |
|                       |            | Welding Electrodes         |
|                       |            | Plastic                    |
|                       | Solid waste | Masker                     |
|                       |            | Scrap metal                |
From life cycle inventory results in table 3, they are grouped into several types of waste depending on the location of the overhaul. Waste that appears is hazardous waste, wastewater, gas emission, solid waste, and radiation. Of the five types of waste that arise, the results show that hazardous waste requires special handling in its disposal process. Where hazardous waste must be disposed of through exclusive parties who have special permits for the management of B3 waste from the government. The cesspool process requires cost in accordance with the total waste, as shown in tables 4 and 5.

| Waste                        | Treatment | Unit | 2016 Total Waste | 2017 Total Waste | 2018 Total Waste | 2019 Total Waste |
|------------------------------|-----------|------|------------------|------------------|------------------|------------------|
| Lubricant                    | Reused    | Ton  | 40.32            | 31.86            | 34.65            | 34.65            |
| Contaminated cotton waste    | Dismissed | Ton  | 0.109            | 0.443            | 0.296            | 0.859            |
| Batteray                     | Dismissed | Ton  | 0.042            | 0.016            | 0.016            | 0.016            |
| Welding Electrodes           | Dismissed | Ton  | 0.025            | 0.025            | 0.025            | 0.025            |
| Plastic                      | Dismissed | Ton  | 0.05             | 0.05             | 0.05             | 0.05             |

| Waste                        | Treatment | Cost/ton | 2016 Cost | 2017 Cost | 2018 Cost | 2019 Cost |
|------------------------------|-----------|----------|-----------|-----------|-----------|-----------|
| Lubricant                    | Reused    | 0        | 0         | 0         | 0         | 0         |
| Contaminated cotton waste    | Dismissed | 165,000  | 1,798,500 | 7,309,500 | 4,884,000 | 14,173,500 |
| Batteray                     | Dismissed | 330,000  | 1,386,000 | 528,000   | 528,000   | 528,000   |
| Welding Electrodes           | Dismissed | 110,000  | 275,000   | 275,000   | 275,000   | 275,000   |
| Plastic                      | Dismissed | 110,0000 | 550,000   | 550,000   | 550,000   | 550,000   |

4. Recommendations

4.1. Improvements / recommendation to critical waste waiting
1. To overcome the risky waste, unnecessary motion is recommended to arrange the tools and materials following the rules of 5S adjusted to the work scope with a distance not far from the work area.
2. To overcome the waiting critical waste, it is recommended to hold regular meetings that are followed by each project leader per area and make regular updates on work realization.
3. Overcome the critical waste unnecessary inventory is recommended to include the logistics & inventory division in the process of material procurement planning and making schedule overhauls.

4.2. Improvements recommendation to waste management
1. Providing a temporary disposal site adjusted to the type of waste in the overhaul process that is placed in each area in accordance with 5S rules.

| Types of Waste | Definition of the type of critical wastage | Cause of critical wastage | Proposed Improvement | 5S Visual Management |
|----------------|--------------------------------------------|---------------------------|----------------------|----------------------|
| Inappropriate Processing | Waste sorting | Negligence of technicians, helper and supervisory team | 1. Preparation of waste TPS according to the work area 2. The mark or label the type of waste at each | 1. Seiton / Set in order 2.Seiri / Sortir |
| Waiting | Waiting for the waste sorting process | Lack of knowledge related to the type of waste | Training and socialization on the type of waste | Shine / Cleaned |
2. In hazardous waste, the results show that contaminated cotton waste has increased a significant amount of waste. So, it is recommended to resize contaminated cotton waste to reduce the amount of waste generation that arises.

3. To minimize waste based on gas emissions from the transportation process, it is recommended to make changes to the fuel used in lifting equipment from diesel to biodiesel (B20, B35 - B100).

5. Conclusions
Based on the results of analysis and discussion carried out in the research at the PTN power plant, several conclusions can be drawn as follows: Based on the results of PTN Power plant EAF calculation prognosis, to keep EAF value at the Top 10% NERC, the overhaul process that was previously planned for 53 days is recommended to be 45 days by eliminating the process waste that occurs in overhauls. The results of waste identification problems that occur based on VSM, PAM and BCM, it is known that overhaul there is waste unnecessary motion with overhaul with a score of 29, waste waiting with a score of 27 and unnecessary waste inventory with a score of 25. The results of waste identification that appears in the overhaul process based on LCI, it is known that the overhaul process is hazardous waste, solid waste, waste water, gas emission and radiation. Of the five types of waste that arise, hazardous waste and solid waste require special handling because it also creates process waste in overhauls. In a significant hazardous waste causing waste generation is contaminated cotton waste. So, it is recommended to resize contaminated cotton waste to reduce the amount of waste generation that arises.

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