# Application of Lean Tools in Planned Maintenance: Case Study of a Coal Handling Plant at a Thermal Power Station

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## Abstract

In today's highly competitive business environment every company thrives to increase its overall production and profit. Maintenance related costs contribute to some of the major expenses related to running a business. In other words, maintenance activities share significant operating costs in an organisation. Reducing maintenance costs without affecting the plant performance improves the profitability of an organisation. Reduction in maintenance costs can be effectively achieved by means of reducing the non-value-added costs and activities involved in the maintenance process. Lean thinking can be incorporated into maintenance activities through application of its principles, practices and tools. In this paper, preventive maintenance activities related to a coal handling plant at a thermal power station are assessed using value stream mapping (VSM) tools in order to identify maintenance wastes and to demonstrate the association between maintenance wastes and the Lean Manufacturing tools. The current state map revealed that non-value adding activities contributed to 16.25% of the total maintenance time. Improving the status quo would see the overall plant availability including the generating plant improve by 0.158%. Although this appears insignificant, the loss in generation due to unavailability of the coal plant has an impact. The power plant generates an average of 90 GWh a year and a 0.158% plant availability will translate to a gain of 142 200kWh annually translating to USD14220 at a cost of USD0.10 per kWh

## Keywords
Lean Manufacturing, Value Stream Mapping, Lean Maintenance, Coal Handling Plant

## 1. Introduction

In order to attain world class performance, companies strive to improve their equipment availability, overall productivity, safety and product quality. Many manufacturers are turning to lean manufacturing as a tactic to augment profits and cut unnecessary expenses. Companies are reducing the non-value-adding activities in all forms for each and every process in the entire organization. The maintenance function plays a pivotal role in the achievement of the strategic objectives of an organisation (Fraser, 2014). The maintenance process serves the production facilities to ensure high productivity. Maintenance refers to proactive and reactive activities performed in order out to retain an equipment or a facility to the acceptable operating conditions according to Faccio, Persona, Sgarbossa, and Zanin (2014) in Mostafa, Lee, Dumrak, Chileshe, and Soltan (2015). This implies that the primary function of maintenance is to make machined reliable and safe. When this happens the quality of output of the machine increases and the value of the asset is also preserved. Previously the maintenance function has been considered as expense to the organisation and was relegated to reactive functions that are usually executed under the emergency situations such as machine breakdown. Nowadays maintenance is being recognised as an investment that requires a proactive strategic element of revenue generation for organisations. According to Khazraei and Deuse (2011), twenty-first management now understands the role of maintenance in critical elements of production plants such as product quality, safety requirements, and operating budget levels. Lean tools can be employed improve the productivity of maintenance activities by reducing wastes in maintenance. Value Stream Mapping (VSM) and 5 S are the most efficient tools of lean thinking and have proved their value in increasing process transparency and visibility (Klotz, Horman, Bi, and Bechtel, 2008) and its benefits in reducing lead time and inventory in different areas (Abdulmalek, Rajgopal, and Needy, 2006). VSM has been used as a practical method of visualising the condition and interaction of actions (Wenchi, Wang, Wang, and Chong, 2015). Maintenance costs are directly proportional to the downtime hours and hence an increase in the downtime hours due to non-value adding maintenance activities can alarmingly increase the maintenance costs. Therefore, it is essential to identify the value from the asset perspective which can improve its availability and reliability through efficient maintenance. Mapping the maintenance value stream which fundamentally consists of all the collective activities to deliver the maintenance service helps in improving the maintenance value stream by abolishing the waste which assist in minimising the lead time.

## 2. Overview of Lean Tools

Lean Manufacturing is a philosophy that comes with a set of techniques and tools that reduce or eliminate the unnecessary wastes in processes. Examples of such lean tools include visual management systems (VMS), set-up time reduction, Single Minute Exchange of Dies (SMED), the 5S methodology for sorting, streamlining, shining, standardising and sustaining, Value Stream Mapping (VSM) and Total Productive Maintenance (TPM) (Díaz-Reza, García-Alcaraz, Martínez-Loya, Blanco-Fernández, Jiménez-Macías, and Avelar-Sosa, 2016). Through the application of such tools, organizations can be able to reduce costs and personnel involvement in processes (Bayou and De Korvin, 2008). The first step is to quantify the leanness of a process in this case the degree of leanness in maintenance. This is followed by the development of a prescription plan focusing on waste reduction in maintenance. One important factor for promoting this reduction is the implementation of standardized procedures that, once defined, will guarantee the correct and successful use of maintenance resources (Dora, Kumar, and Gellynck, 2016). Duran, Capaldo, and Duran (2017) applied lean tools to improve maintenance efficiency in thermoelectric power plants. VSM is of particular importance to this study hence it is further reviewed in detail.

### 2.1 Value Stream Mapping

One of the primary lean tools that was found in literature and has been effectively used in evaluating non-value-adding activities is Value Stream Mapping (VSM). It is a tool that helps in visualising a system by the representation of information and material flow. It also creates a common language about a process, by which purposeful decisions can be made to eliminate the non-value adding activities. A collection of all activities, value-adding and non-value-adding are included in a value stream and are required to bring products through the main flows, starting from raw materials and ending with the customers (Rother and Shook, 2003). The ultimate goal of VSM is to identify and eliminate the waste in the stream. VSM uses a predefined set of standardised icons to describe a highly complex system in attractable 2-D format, which simplifies the system wide facilities insight and understanding and thus provides a common language for communication of the insight (McManus and Millard,2002). A three-step methodology is commonly adopted with first step being to identify a particular product or product family for potential improvement. The second step is to then construct a current state map which captures how things are currently done as a snapshot by walking along the actual processes. The future state map in created in the third step to illustrate how the system behaves after the inefficiencies are removed. The future state map is the basis to make necessary changes (El-Haik, and Al-Aomar, 2006).

## 3. Maintenance Overview in Thermal Power Plants

Maintenance refers to reactive or proactive actions that are required to keep equipment at maximum operating condition (Faccio et al, 2014)). The actions are usually carried out according to a certain maintenance strategy. The maintenance strategy should be developed together with the manufacturing systems strategy to ensure harmony between production and maintenance functions (Mostafa et al, 2015). In the case of a power plant, it is built to provide reliable electricity to consumers. Thermal power plants in particular consist of a set of sophisticated systems which must have the highest level of availability (Junior, Bezerra, Leite, Moya and Rodríguez, 2017). The obsolescence of these systems increases the risk of breakdowns because of higher mechanical wear associated with the high temperatures and chemical products used for the production of electric energy (Fonseca, Holanda and Reyes, 2015). Most electrical systems operate closer to their rated capacity. Therefore, any failures can result in reliability reductions of the electrical systems that may cause catastrophic social and economic losses. A balance between reliability and cost is required. In power plants and other industries, the maintenance function seeks to reduce the costs associated with maintenance along with increasing availability. Several strategies have been developed and employed to achieve these goals, such as Total Productive Maintenance (TPM), Root Cause Analysis (RCA) ((Bhangu; Pahuja and Singh, 2015), Preventive Maintenance, Reliability Centred Maintenance (RCM) (Dos Santos and Do Nascimento, 2009) among others. On the other hand, one of the most important tools for optimisation and cost reduction in maintenance, is the implementation of an effective and complete predictive maintenance program ((Bhangu; Pahuja and Singh, 2017). Predictive maintenance relies more on condition monitoring to determine the appropriate timing for maintenance intervention. Improved operation and maintenance of thermal power plants can be achieved through integrated monitoring systems that continuously monitor the intrinsic variables of the various processes to reveal the true condition of specialized components and systems. The classification of the maintenance strategies shown in Figure 1 was proposed by Mostafa et al (2015).

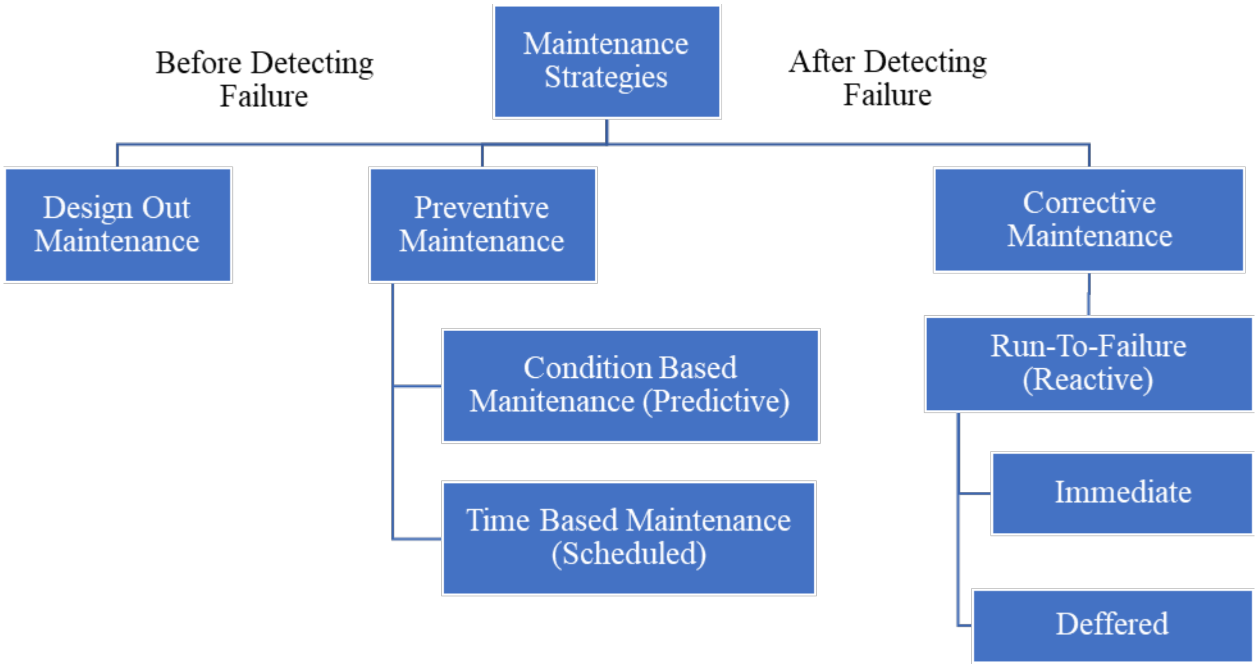


Figure 1: Maintenance Strategies (Mostafa et al, 2015).

There are three generic classes of maintenance strategies that are Corrective Maintenance, Preventive Maintenance and Design-Out Maintenance (DOM). Corrective maintenance is also known as failure-based maintenance, emergency maintenance, firefighting maintenance, or breakdown maintenance. The concept of corrective maintenance strategy is based on fix-it when it breaks (Márquez, 2007). Preventive Maintenance (PM) is carried out before failure happens. It is intended to reduce the chances of failure or performance reduction (Fouladgar, Yazdani-Chamzini, Lashgari, Zavadskas, and Turskis, 2012). There are two categories of Preventive Maintenance namely Time-Based Maintenance (TBM) or Scheduled Maintenance or Planned Maintenance and Condition Based Maintenance (CBM) or Predictive Maintenance. In scheduled maintenance, the maintenance activities are performed based on fixed operating time interval or number of output units without considering the current condition state of the item. On the other hand, CBM is based on performance and parameter monitoring (e.g. corrosion and electric current monitoring, lubricant and vibration analysis, leak and crack detection, and ultrasonic testing) to predict failure (Khazraei & Deuse, 2011). Lastly,Design-Out-Maintenance (DOM) focuses on improving the design of a product in order to eliminate the cause to maintenance. DOM makes maintenance easier during the life cycle of a product. DOM is based on the successive design corrections derived from the maintenance knowledge. It is appropriate for items with high maintenance cost, which arises because of defective design or operation outside design specifications (Waeyenbergh & Pintelon, 2004).

### 3.1 Lean Thinking in Maintenance

In order to appreciate the impact of Lean Tools in Maintenance it is essential to superimpose the lean principles and tools in order to attack the six big losses in maintenance that were identified through Total Productive Maintenance (TPM). Waeyenbergh and Pintelon (2004) identified the six categories of losses in TPM which as:

1. Breakdown losses
2. Set-up and adjustment losses
3. Minor stoppage/idling losses
4. Reduced speed losses

5. Defects/rework losses
6. Start-up losses

The effectiveness of TPM strategy with regard to these six losses is measured using overall equipment effectiveness (OEE). The measurement of OEE is a function of the availability, performance efficiency, and quality. The application of the lean principles should therefore ensure that wastes are eliminated with regards to the six big losses (Mostafa et al, 2015). In terms of the maintenance function, waste elimination can be categorized as: reduction of over maintenance, more and better organization is spare parts warehouses, better maintainability (shorter Mean Time to Repair—MTTR), better maintenance organization and maintenance procedures standardization. Figure 2 summaries the maintenance wastes according to lean manufacturing principles.

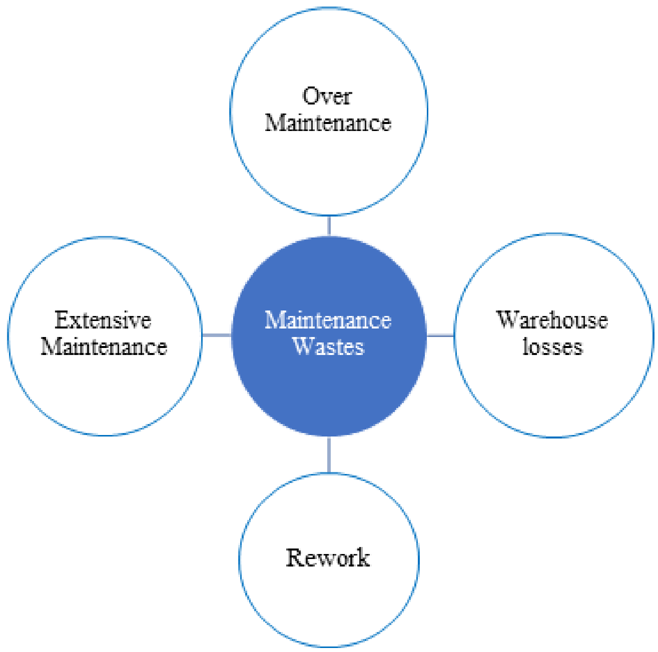


Figure 2: Wastes in Maintenance

## 4. Problem Setting and Methodology

The Thermal Power Plant under study was ISO 9001:2015, ISO 14001:2015 and ISO 18001:2007 certified at the time of the study. The power plant had a total installed capacity of 90 MW which is generated from three 30 MW generators. However, due to low plant availability, the plant was producing an average of 15MW. The low availability and reliability were attributed to the old age and high maintenance requirements. One of the most critical plant at the time was the coal and ash handling plant. This is where coal is received, processed and conveyed in to the plant to facilitate generation of electricity. This plant became the case study and VSM was used to identify and eliminate sources of waste. The methodology followed is shown in Figure 3.


Figure 3: Procedure for performing the value stream mapping

### 4.1 Current State Map

The VSM method was employed to determine the current state, identify waste and develop the future state. This is depicted in the Figure 3. The application of this technique was performed in the process of coal handling plant preventive maintenance. Measurement of the times of each activity during maintenance, interviews with mechanical supervisors and photographic record of the activities were carried out. Table 1 summaries the observations that were carried out during the maintenance activities related to the coal handling plant. This formed the basis of the current state map shown in Figure 4.

Table 1: Maintenance Activities

| **Item** | **Activity/Task** | **Time (Hrs)** | **Identified Waste (Hrs)** |
|---|---|---|---|
| 1 | Work Order Sending | 0.10 | 0.00 |
| 2 | Plant Decommissioning | 0.20 | 0.00 |
| 3 | Materials Collection | 0.65 | 0.30 |
| 4 | Work Preparation | 0.20 | 0.10 |
| 5 | Gearbox Opening | 2.57 | 0.00 |
| 6 | Drive System Cleaning | 1.23 | 0.23 |
| 7 | Coal Feeder Cleaning and Greasing | 2.95 | 0.58 |
| 8 | Gearbox Gasket Fabrication | 1.63 | 0.63 |
| 9 | Cleaning Tippler and Calibrating | 2.87 | 0.00 |
| 10 | Greasing and Oil Top | 0.85 | 0.50 |
| 11 | Boxing (Closing) | 0.70 | 0.00 |
| 12 | Tippler Test | 0.30 | 0.00 |
| 13 | Work Order Closure | 0.15 | 0.00 |
| **Total** | | **14.40** | **2.34** |

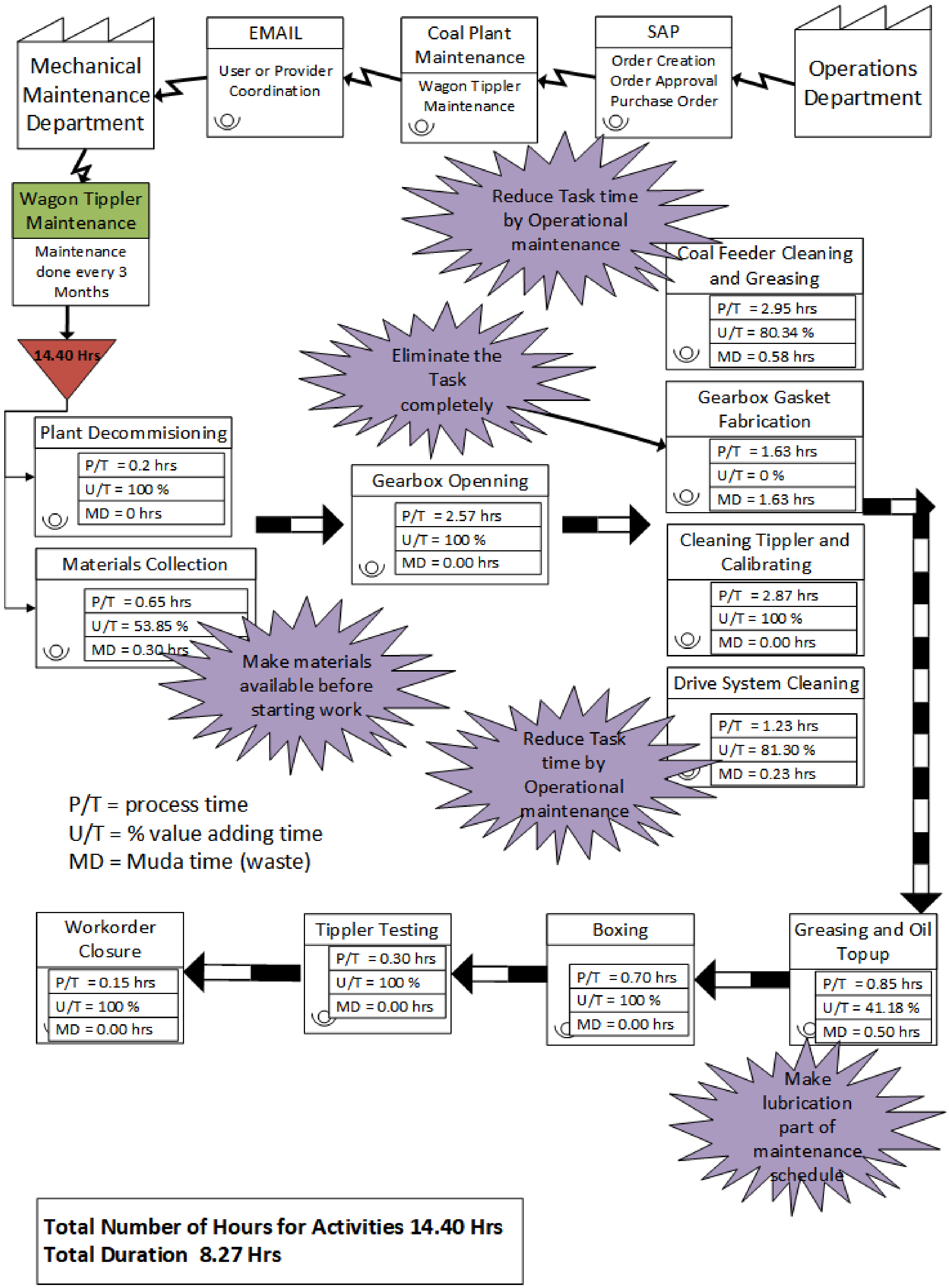


Figure 4: Coal Handling Plant Planned Maintenance Current State Map

### 4.2 Proposed Improvements and Recommendations

An analysis of the activities revealed that Coal Feeder Cleaning and Greasing, Cleaning Tippler and Calibrating, Gearbox Opening. Gearbox Gasket Fabrication and Drive System Cleaning are the activities that contribute to 80 % of the maintenance downtime as shown by the Pareto chart in Figure 5. Considerable time is invested both in preparing tools and in finding those that are not in the corresponding inspection place. About 11.32 % of the total time is wasted in fabricating the gaskets of the gearboxes opened. Close to 4 % of the time was wasted in removing coal particles on the weighing system. In total 16.25 % was the non-value adding time for the coal handling plant maintenance operation under study.

After the analysis, the following recommendations were made;

1. All tools, materials and spare parts to be used must be transferred to the equipment sector before it is taken out of service.
2. Make available on the shop floor the appropriate gaskets for the coal feeder and pyrite traps.
3. The bolts and nuts required must be readily available on the shop floor.
4. Search or development of a tool to clean the coal feeder as it operates.
5. Greasing and cleaning to be part of the machine operation routine

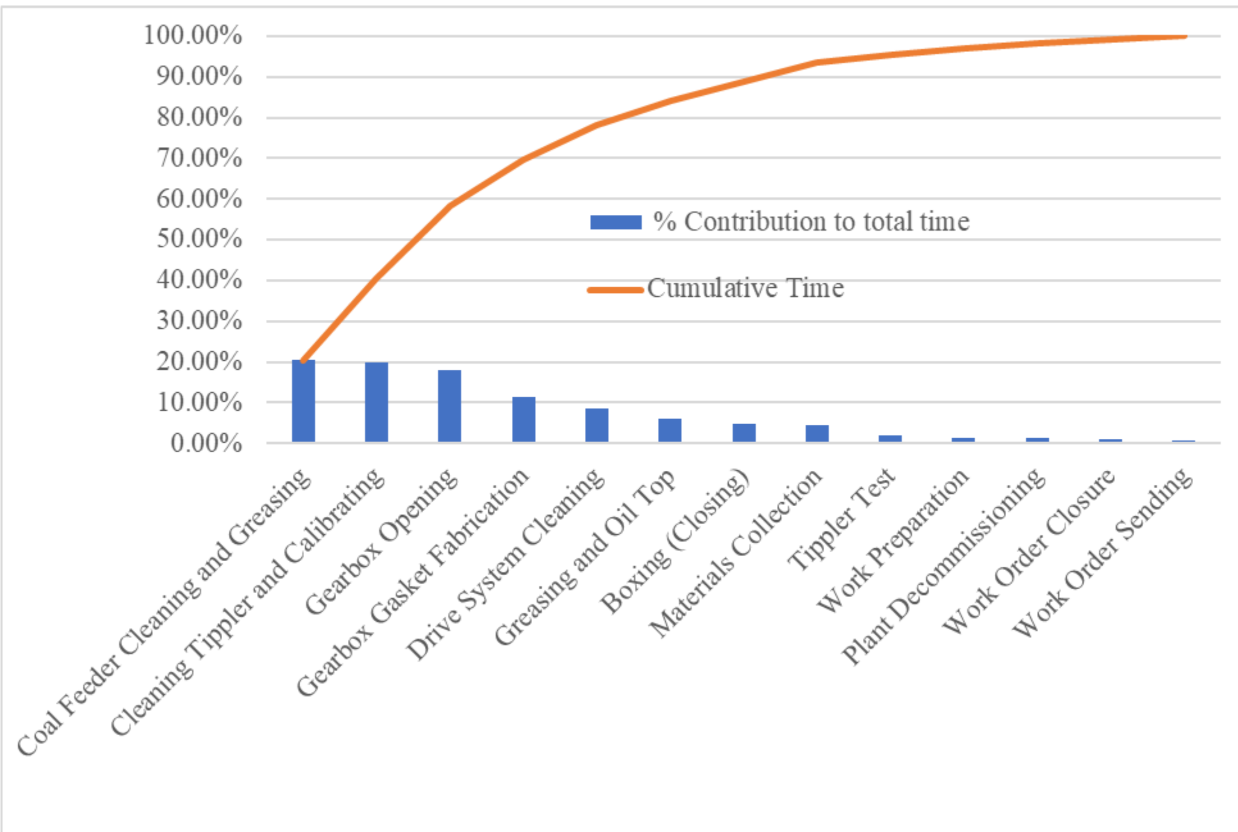


Figure 5: Pareto Chart of the activities

## 5. Future State Map

Projecting the results and reductions obtained in the implementation of the VSM and 5S methods, an improvement of 16.25 % in the availability is expected on the coal plant as shown by the Future State Map in Figure 6. The plant availability including the generating plant improved by 0.158 %. Although this does not appear to be a significant figure, the loss in generation due to unavailability of the coal plant is highly significant. The power plant generates an average of 90 GWh a year and a 0.158% plant availability will translate to a gain of 142 200 kWh annually translating to USD14 220 at a cost of USD0.10 per kWh. These savings are realised by only applying VSM and 5S strategies to the coal plant alone. If it is to be implemented to all the maintenance activities, then the savings will be 20 -30 times more.

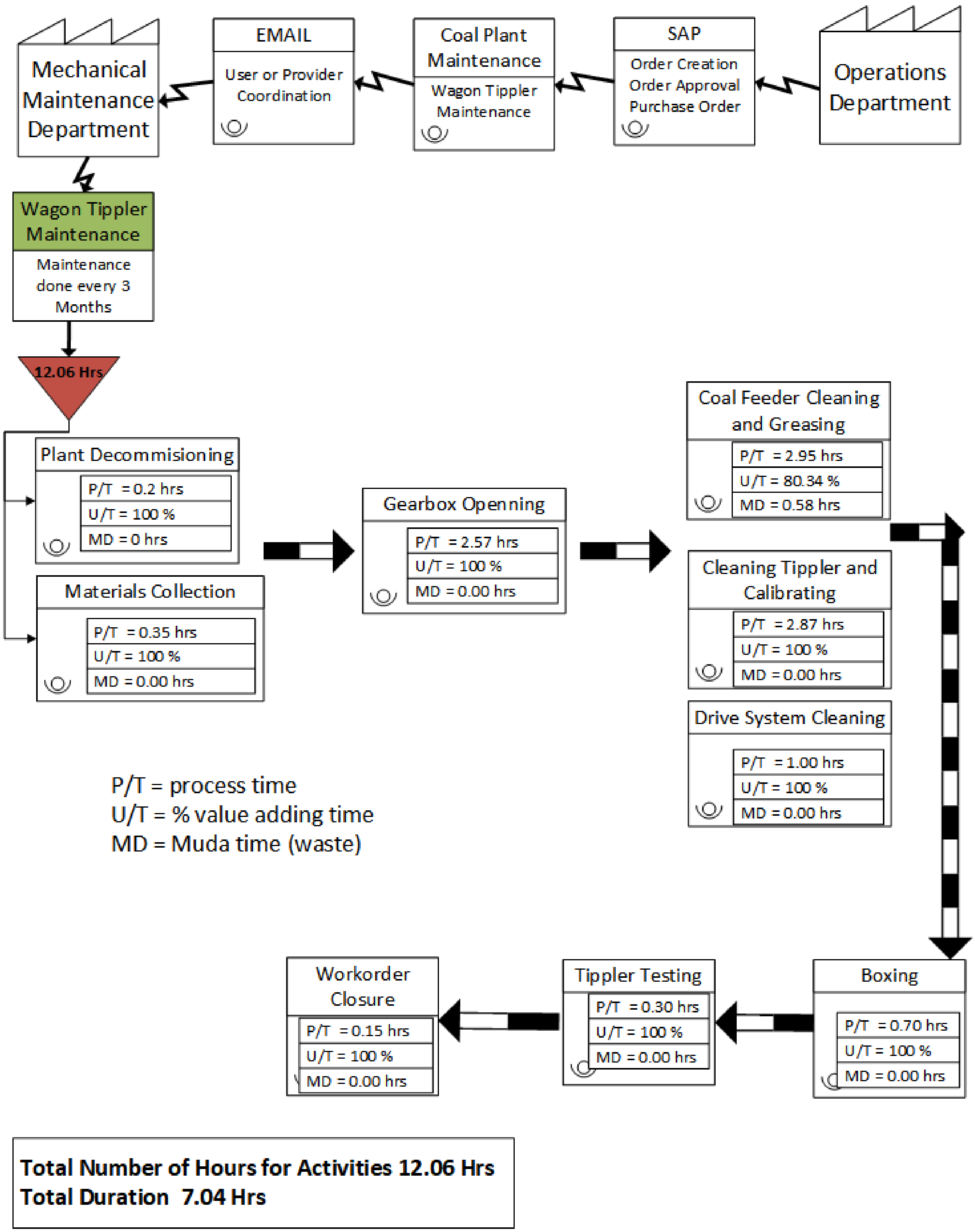


Figure 6: Coal Handling Plant Planned Maintenance Future State Map

## 6. Conclusion

Maintenance is a critical contributor to progressing towards world-class manufacturing of any organisation. It has rapidly grown into a very complex undertaking as technologies, competition, and product characteristics have evolved. In order to achieve world-class performance, the maintenance strategies should be linked to manufacturing strategies such as the lean concept. Applying an effective maintenance strategy can ensure a high degree of utilisation, reliability, and availability of manufacturing facilities especially in a continuous production process. VSM and Lean Maintenance provides an opportunity for effective maintenance. Moreover, it promotes the culture of continuous improvement aiming at maintenance excellence. Nevertheless, commitment and direct involvement of an organisational management along with employee training and teamwork development can be a catalyst to accelerate the transformation process. However, Lean Maintenance approach cannot just be a mirror image of a lean manufacturing approach because the business dynamics of asset maintenance and those of production are fundamentally different. Therefore, it is clear that there is a need to develop an effective process to collectively integrate and customise lean thinking into the maintenance with long-term strategic perspective.

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