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Value Stream Mapping of Maintenance Activities at Thermal Power Plants

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***Abstract* –** Value Stream Mapping (VSM) is an important component of the *Lean* philosophy that is aimed at systematically identifying wasteful processes, and is used to emphasize doing more with less. In this paper the usage of Value Stream Mapping (VSM) is used successfully by manufacturing organizations to identify areas of waste, has been discussed in detail. This paper also discusses the application of VSM to maintenance activities at a 210MW thermal power plant. A simulation model has been built and the approach to eliminating waste has also been discussed. Simulation results showed encouraging results with increased availability and revenues of more than $8 million every year combined besides other intangible benefits.

Keywords - *Lean* Maintenance, Value Stream Mapping (VSM), Total Productive Maintenance (TPM)

I. INTRODUCTION

Traditionally, manufacturing organizations were of the belief that a combination of corrective and preventive maintenance of manufacturing equipment was best to maximize production. In the undesirable event of an equipment failure, corrective maintenance activities were performed to restore its basic functional capabilities, and bring it back to a working state. Preventive maintenance, on the other hand, included time-based (performing maintenance activities at regular, planned intervals) and condition-based maintenance (performing maintenance on the equipment based on data/ information about its current state, also referred to as reliability-centered maintenance). Opportunistic maintenance has also been used to maximize availability of equipment in the past.

The last decade of the 20th century saw a good amount of effort spent on researching and implementing Total Productive Maintenance (TPM) and introduction of the term Lean Maintenance. Since then several authors have defined the term. A most complete definition of has been provided in [1], where Lean Maintenance has been defined as "a proactive maintenance operation employing planned and scheduled maintenance activities through TPM practices using maintenance strategies developed through application of condition monitoring decision logic and practiced by empowered action teams using the 5S process, weekly Kaizen improvement events, and autonomous maintenance together with multi-skilled, maintenance technician-performed maintenance through the committed use of their work order system and their computer managed maintenance system (CMMS) or enterprise asset management (EAM) system. They are supported by a distributed, lean maintenance / MRO storeroom that provides parts and materials on a just-in-time (JIT) basis and backed by maintenance and reliability engineering group that performs root cause failure analysis (RCFA), failed part analysis, maintenance procedure effectiveness analysis, predictive maintenance (PdM) analysis, and trending and analysis of condition monitoring results."

Reference [2] and [3] provides great insight into working of lean manufacturing organizations while [4]-[7] have discussed implementation of lean practices for maintenance activities.

II. Why Lean Maintenance

Irrespective of the domain the term *Lean* is used to emphasize doing more with less. This means, for a given output, the quantity of input(s) used is less than in a traditional environment. *Lean* thinking encourages value addition to the organization by removing wastes. According to [8], there are 7 types of wastes in maintenance; they include:

1. Over production: Excessive preventive maintenance would fall under this category.
2. Waiting: Failed equipment continues to remain in a failed state for want of spares or manpower to fix it.
3. Transportation: Maintenance people often spend a lot of time walking around the workshop in search of spares or tools that are often placed at far off locations.
4. Process Waste: Maintenance staff often work only on the activity they have been assigned to, overlooking potential opportunity to quickly perform maintenance activities on other parts of the equipment. Redundant maintenance activities also fall under this category.
5. Inventory: Maintenance department often keep a large number of spares just in case it is required to fix a breakdown. Holding inventory is a waste of space as well as it locks large sums of money in inventory.
6. Motion: Unnecessary movement of repair gangs, materials and tools
7. Defects: Improperly fixed equipment tends to fail sooner than later requiring additional work to be performed.

Fig. 1 shows the thoughts behind the *Lean* concept [9]

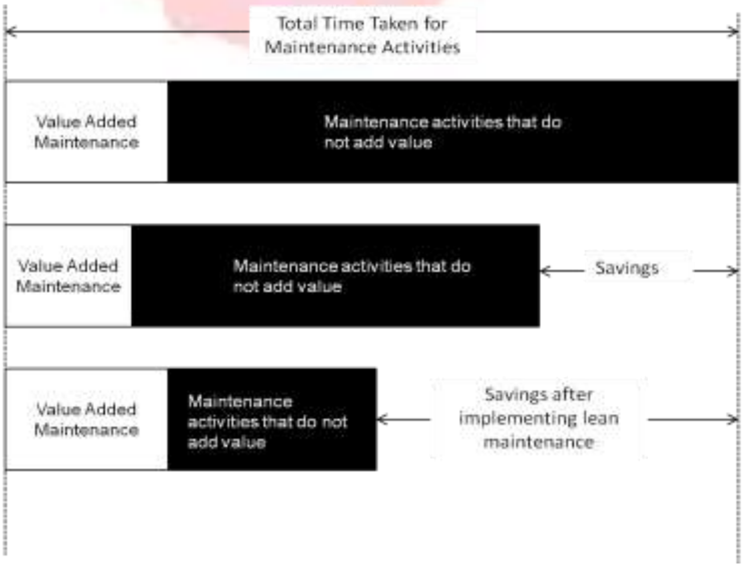

Fig. 1. Lean Maintenance Philosophy

III. VALUE STREAM MAPPING

The primary objective is, therefore, to remove waste. One of the first steps to follow as part of Lean implementation is Value Stream Mapping (VSM). VSM helps in visualizing a system by the representation of information and material flow and has been described in detail in [10]. This tool helps identify areas of waste. By performing some additional basic quantitative analysis it helps eliminate these wasteful processes or activities. VSM uses a set of standard notations – in this paper the notations defined in [10] have been used. Production equipment fails at random time periods or intervals. On failure, the Operator communicates the same to the Maintenance Department. The Maintenance Supervisor inspects the failed equipment and diagnoses the problem and advises the Maintenance Clerk to create a work order (W.O.). The creation of the work order includes locating a repair crew, a set of spares, if any, and tools. When all resources – spares, tools and repair crew - are available, the failed equipment is repaired. The equipment then returns to the working state. The work order is then closed. In this process wastes occur in form of waiting times – these are shown in form of triangles in Fig. 2. Wastes also occur in form of performing tasks that precede starting of the actual repair activity on the failed equipment. These are shown below the rectangles in Fig 2. These times may be deterministic or may follow a probabilistic distribution.

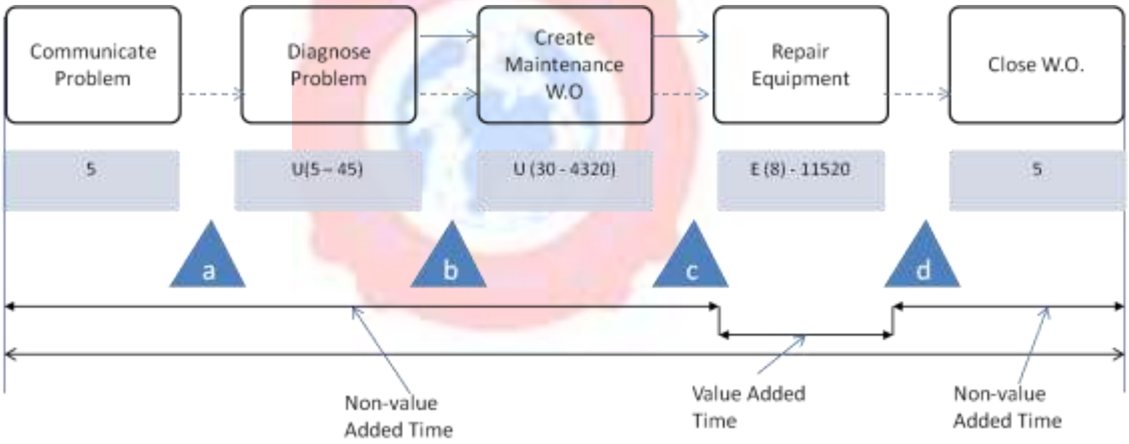

Fig. 2. VSM for a pulverizer of a Thermal Power Plant

IV. APPLYING VSM TO MAINTENANCE ACTIVITIES AT A THERMAL POWER PLANT

The principles of VSM were applied to maintenance activities to a sub-system of a 210MW thermal power plant. More information about maintenance activities at the specific power plant can be reviewed in [11] and [12].

Fig. 2 shows the VSM for the case application. The pulverizer of the fuel sub-system has several failure modes; however, for this study we have used the mill internal component that has 4 failure modes. A description of these failure modes along with the probability of occurrence is given in Table 1.

TABLE I
VSM for a pulverizer of a Thermal Power Plant

Section	Distribution	Parameters (Hours)	Failure Mode	Probability of Occurrence
Mill Internal	Exponential	3415	a. Ring Failure / breakage	0.08
			b. Ball breakage	0.08
			c. Stirrup bolt failure	0,08
			d. Foreign matter inside	0.76

Table 2 shows the characteristics of maintenance activities including the waiting time before the start of actual repair activity. While waiting times follow a Uniform distribution, most of the repair times follow an exponential distribution. The Ring Breakage failure mode requires the entire mill to be disassembled. When such a failure occurs, the maintenance supervisor performs opportunistic maintenance activity. This activity takes a fixed duration of 20 days (or 28800 minutes)

TABLE II
Characteristics of Maintenance Activities - Productive & Non-Productive Durations

Process	Distribution	Parameters (minutes)
Communicate Failure to Maintenance Department	Uniform	05, 10
Delay a	Uniform	05, 10
Diagnose Problem	Uniform	05, 45
Delay b	Uniform	05, 10
Create Maintenance W O (Includes Delay c)	Uniform	30, 4320
Repair Time (by failure modes)		
a. Ring Failure / breakage	Constant	28800
b. Ball breakage	Exponential	5640
c. Stirrup bolt failure	Exponential	891
d. Foreign matter inside	Exponential	513.6
Delay d	Uniform	05, 10

Using the information shown in Tables 1 and 2, a simulation model was built to mimic the behavior of the mill internal and benchmark the current performance (before application of lean concepts) and study the benefits (after application of lean concepts). One of the primary requirements of any lean project is to identify the ultimate customer and the value derived by the customer. In this case, the ultimate customer is the consumer and the value derived can be analogous to equipment availability. Key statistic, therefore, would be

Availability – which is defined as the probability that equipment would be in an operating state when used in a realistic operating environment.

Assumptions used in the simulation model are as follows:

- Necessary spares parts are available locally or in one of the central stores; however they need to be located and shipped to the failed pulverizer for maintenance activities to begin.
- Repair gangs are available on hand – however, they need to be re-directed from their current place of work to the failed pulverizer. Incomplete maintenance is not allowed.
- Mill Internal is restored to "as-good-as-new" state once maintenance is complete.

A statistically requisite number of simulation runs were performed using the model in a "as-is" situation, and the availability was measured. The mean availability of the mill internal was about 48 percent. Several changes were made to eliminate wastes and these included:

- relocating repair crews closer to the mills to reduce waiting time
- clearing displaying location/ maps of where spare parts are kept to reduce wastage in locating spares
- involving the equipment operator in maintenance activities which enabled reduction in time for failure diagnosis
- changing some of the spare parts ordering policies which reduced amount of inventory held in spares

The availability was simulated after making the changes after studying the VSM, and the simulation results showed the mill availability increased to 53%, or an increase in revenue by about $8.2 million every year. Fig 3 shows the changes in availability of the mill before and after VSM related changes were made.

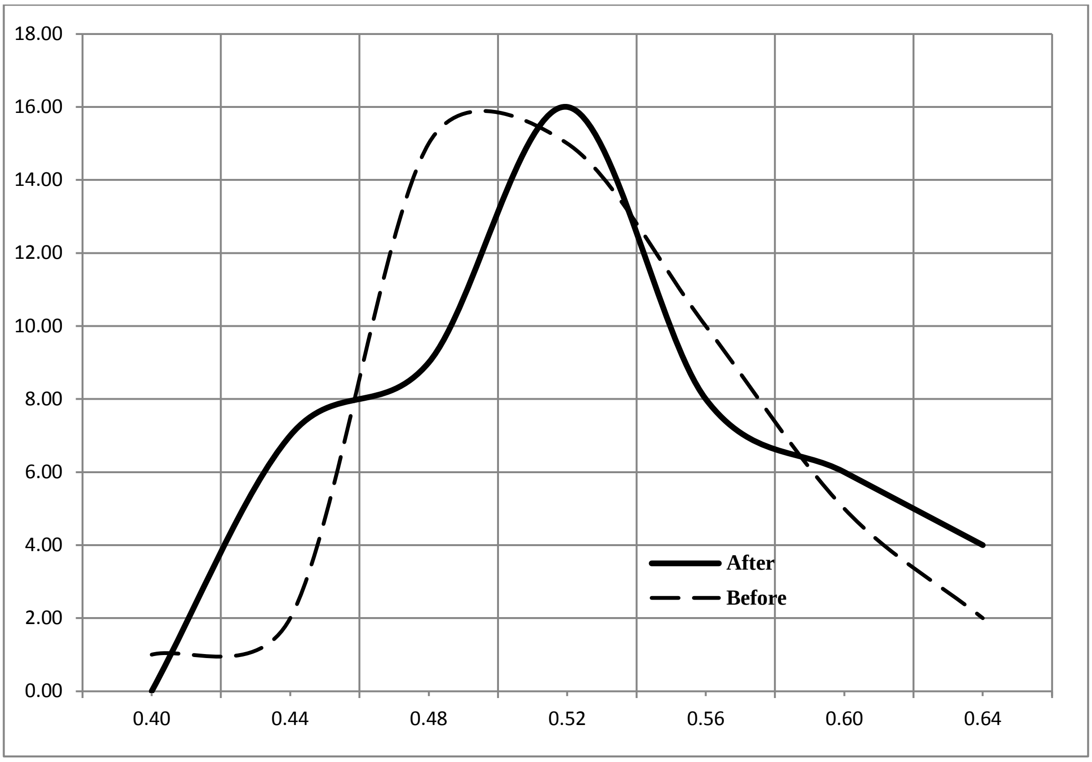

Fig. 3 Simulation Results - *Before* and *After* Lean Implementation

V. CONCLUSION

Value Stream Mapping (VSM) has been utilized by several organizations to identify and remove wastes from the production processes. In this paper we have demonstrated the use of the same technique to identify and eliminate wastes from maintenance activities of a thermal power plant. A simulation model was built to mimic the behavior of the maintenance activities before and after the VSM study. Simulation model used stochastic waiting and repair times. The simulated results showed a significant improvement in availability of the equipment and a huge revenue earning potential of about $8 million each year. Further research in this area can be conducted by combining spare parts ordering policies (multi-echelon, (S-1,S) and the like) , designing of an right sized repair crew as well as removing the assumption that the repairing the equipment brings it back to "as-is-new" condition.

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