# Lean Maintenance Roadmap

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ScienceDirect

Procedia Manufacturing 2 (2015) 434 – 444

Procedia MANUFACTURING

2nd International Materials, Industrial, and Manufacturing Engineering Conference, MIMEC2015, 4-6 February 2015, Bali Indonesia

# Lean maintenance roadmap

Sherif Mostafa[a]*, Jantanee Dumrak[b] and Hassan Soltan[c]

[a] *School of Natural and Built Environment, University of South Australia, GPO Box 2471 Adelaide, South Australia 5001, Australia*
[b]*Global Project Mangament Program, Torrens University Australia, Torrens Building, 220 Victoria Square, Adelaide, SA 5000, Australia*
[c]*Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University, Mansoura 35516 Egypt*

**Abstract**

Maintenance shares significant operating costs in an organisation. It is considered as a main pillar of the organisational performance. Lean thinking can be incorporated into maintenance activities through applying its principles and practices. Lean maintenance is a prerequisite for lean manufacturing systems. The exhaustive literature review has been conducted to collect the up-to-date maintenance strategies and activities, lean principles and practices in the lean maintenance process. The scope of this paper includes eight types of waste (non-value added maintenance activities), maintenance value stream mapping and a scheme of lean maintenance practices. The output of this paper is a proposed roadmap to apply lean thinking in a maintenance process.


Selection and Peer-review under responsibility of the Scientific Committee of MIMEC2015

*Keywords:* Maintenance strategies; lean manufacturing; lean maintenance; maintenance value stream mapping; lean maintenance roadmap

## 1. Introduction

Maintenance has become a significant contributor towards achieving the strategic objectives of organizations in today's competitive markets [1]. Maintenance process is for serving the production facilities to guarantee high productivity [2]. The process comprises planned and unplanned actions carried out to retain a physical asset to the acceptable operating condition [3]. It aims at increasing the value of the reliability, safety, availability and quality of a production plant, equipment or building in economic costs. Over the previous decades, maintenance role has been considered as a necessary evil from the management of an organization. For these organizations, maintenance operation is limited to corrective function that executed in emergency conditions. However, this attitude is no longer

* Corresponding author. Tel.: +61 8 830 21269; Fax: +61 8 830 22252.
*E-mail address:* Sherif.Mostafa@mymail.unisa.edu.au


Selection and Peer-review under responsibility of the Scientific Committee of MIMEC2015
doi:10.1016/j.promfg.2015.07.076

acceptable and maintenance role is recognized as a strategic element of revenue generation for organizations. This role is affecting some critical elements in a production plant including product quality, safety requirements and operating budget levels of an organization [4].

The cost of maintenance activities could be ranged from 15% to 70% of the total production costs [1, 5]. The cost is considered as the second largest after energy costs of the operational budget [6]. In the United States, the estimated cost of maintenance increased from $200 billion in 1979 to $600 billion in 1989. Maintenance activities account for, on an average, 28% of the total cost of finished goods [7]. The machinery has become highly automated and very technologically complex (i.e. depends on sensor-driven management systems that provide alerts, alarms and indicators). Consequently, maintenance costs are expected to be even higher in the future. The maintenance costs are directly proportional to the downtime (DT). The DT is the time interval when equipment/system is down until it is back to normal working condition [8]. The increasing of DT is due to the Non-Value Added (NVA) activities or wastes within the maintenance operations. One of waste elimination strategies is the application of lean thinking in all activities between suppliers and customers (value stream). The first step in lean integration is to identify the customer value and the NVA. Under a maintenance value stream, any maintenance service is considered as a final product. The lead time in the maintenance value stream is presented as DT.

Investigation into the applicability of lean principles in maintenance in the previous research is minimal. Davies and Greenough (2010) emphasized on the necessity of conducting more research on applying lean manufacturing principles in maintenance operations. The recent studies have attempted to relate lean thinking with the maintenance strategies. Ghayebloo and Shahanaghi [9] formulated a model to determine the minimal level of maintenance requirement and satisfying reliability level through using the lean concept. Tendayi and Fourie [10] used a combined approach of Quality Function Deployment (QFD) and Analytic Hierarchy Process (AHP) to evaluate the importance of a set of maintenance excellence criteria and prioritize the lean tools against these criteria. Soltan and Mostafa [11] introduced a framework for measuring maintenance strategies based on lean and agile components, i.e. waste removal and responsiveness. However, an integrative structure of lean thinking (e.g. principles, practices, waste identification and value stream mapping) within the maintenance activities has not been fully established. The shortcoming provides an opportunity for this paper to propose a proposed roadmap for lean integration in the maintenance process. This paper adopts the hypothesis of Womack and Jones [12] that lean principles can be applied to any sector.

The structure of this paper is organized into six sections. The next section is literature review on maintenance strategies and activities, and lean principles and practices within the maintenance process. The third section demonstrates the research methodology. The fourth section discusses the maintenance process from lean perspectives. This includes maintenance value stream mapping, eight types of non-value added activities occurred in the maintenance process and lean practices for maintenance activities. The fifth section proposes a scheme for lean maintenance practices. The scheme is structured into two levels: the four bundles and 26 lean practices. The last section contains a conclusion of the paper and proposals for future research.

## 2. Research Methodology

The two main objectives of this paper are: 1) to identify and document maintenance strategies and activities, and 2) to develop a proposal for a roadmap of lean maintenance. To achieve these objectives, the paper employed a systematic review of literature in order to explore the publications related to lean manufacturing concepts, maintenance strategies and maintenance activities. The literature review consists of three stages including: 1) establishing search criteria, resources screening and, extracting and synthesizing the selected resources; 2) grouping and analyzing lean manufacturing and maintenance strategies; and 3) developing a lean maintenance roadmap. In the first stage, the resource selection criteria were established to determine the timeframe of the selected literature works and suitable databases. It was decided that the literature reviewed in this study was to be obtained from the year 2000 to 2015 from main academic databases namely ScienceDirect, EBSCOhost, Emerald Insight, IEEEXplore, Inderscience, ProQuest, Sage Full Text Collections, Springer, and Taylor and Francis. In resource screening, the search terms restricted to the title and key words containing lean maintenance, lean principles and maintenance, and lean practices and maintenance were utilized to lead to the potential publications. The initial results revealed 114 articles that had potential to be included in this study. After adjustment for duplications, the literature was examined for relevancy to the study. This process involved scrutiny of the abstracts from the obtained articles. The examination results of literature showed 50 related articles to this study. To extract and synthesize the selected literature works, thematic analysis was employed to identify, analyze, interpret and report the related data to the research [13]. The filtered articles were explored to conceptualize the phenomenon under the study. According to Joffe [14], this type of analysis discerns issues associated to the studied topic. As a result, this stage allowed the concepts and knowledge on lean maintenance to be grouped according to specific themes. In the second stage, the concepts of lean manufacturing and maintenance extracted from the selected literature works were grouped and analyzed to identify relationships and missing links between lean practices and maintenance strategies. The results obtained from this stage contributed to development of the lean maintenance roadmap in the next stage (Stage 3).

## 3. Research findings

From thematic analysis applied, the concepts related to lean maintenance were grouped and reported in four categories: maintenance strategies, maintenance activities, lean manufacturing and lean maintenance. Each result category is discussed below:

### *3.1. Maintenance Strategies*

Maintenance includes all activities required to keep an asset at maximum operating condition. The activities are generally carried out according to a certain maintenance strategy. The maintenance strategies have been developed in the same direction to the development of manufacturing systems [15]. In the early days, maintenance had been mainly concentrated around corrective maintenance. This was the perception for that maintenance as a necessary evil (i.e. repairs and replacements were tackled when needed and no optimization) as well as lack of awareness on the downtime. Later, maintenance became a full-scale function, instead of production sub-function. At the present time, maintenance management becomes a complex function, encompassing technical and management skills, while still requiring flexibility to cope with the dynamic business environment. Maintenance strategies have gradually changed from preventive maintenance (including Condition-Based Maintenance (CBM) and Time-Based Maintenance (TBM)), Design-Out Maintenance (DOM) and Total Productive Maintenance (TPM). The classification of maintenance strategies based on the time of maintenance activities and failure include corrective maintenance, preventive maintenance, and design-out maintenance [16]. In the corrective maintenance, the intervention of maintenance activities is performed after the failure occurrence. On the other hand, the intervention is before the failure occurrence in the preventive maintenance. Maintenance strategies can be diversely categorized. Interchangeable names have been demonstrated in the existing literature. The most common three strategies are discussed below.

#### *3.1.1. Corrective Maintenance*

Corrective maintenance is known as failure based maintenance, emergency maintenance, fire-fighting maintenance, or breakdown maintenance. The concept of corrective maintenance strategy is based on fixing after failure [17]. Corrective maintenance is the conventional maintenance strategy appeared in many industries. It has employed in maintenance operations due to knowledge shortage on the equipment failure behaviours [18]. Corrective maintenance can be carried out immediately or deferred by appropriate maintenance technicians whom are contracted to assess the situation and fix the repairs. In situations where failure is not critical (i.e. plenty of downtime is available) and values of assets are not of a great concern, the corrective mode of maintenance may prove to be an acceptable option. However, the market competition, environmental and safety issues force the maintenance managers to search for more efficient maintenance strategies besides corrective maintenance [15].

### 3.1.2. Preventive Maintenance

Preventive Maintenance (PM) is carried out according to prescribed criteria. It intends to reduce the probability of failure or degradation of functioning of an item [19]. PM can be divided into Time-Based Maintenance (TBM) and Condition-Based Maintenance (CBM). In the TBM, 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/or parameter monitoring (e.g. vibration monitoring, lubricating analysis and ultrasonic testing) [4, 20]. CBM could be described as a process that integrates technology and human skills using a combination of all available diagnostic and performance data, maintenance history, operator logs and design data to determine the likelihood of a potential failure. As a result, CBM requires a high initial cost for acquiring and installing the necessary sensors and monitoring technology [21].

### 3.1.3. Design-Out Maintenance

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 [22]. DOM is based on the successive design corrections derived from the knowledge of maintenance. It is appropriate for items with high maintenance cost, which arises because of defective design or operation outside design specifications. The DOM concept is used in some parts of motor vehicles such as permanent bearing (bearing using solid lubricant and permanently sealed) [23].

## 3.2. Maintenance activities

Maintenance is defined as a combination of technical, administrative and managerial activities during the life cycle of an item. It aims to retain or restore its functional state [24]. The maintenance strategies consist of a set of sequential maintenance activities [25]. Most common maintenance activities can be listed as:

- Inspection: check for conformity by measuring, observing, or gauging the relevant characteristics of an asset.
- Monitoring: manual or automatic activities performed to observe the actual state of an asset. It evaluates any changes in the parameters of the asset with time.
- Routine maintenance: regular elementary maintenance activities which usually do not require special qualification, authorization(s) or tools such as cleaning, tightening of connections, checking liquid level, and lubrication.
- Overhaul: a comprehensive set of examinations and actions carried out in order to maintain the required level of availability and safety of the asset. An overhaul may be performed at prescribed time intervals or number of operations, and may require a partial or complete dismantling of the asset.
- Rebuilding: action following the dismantling of the equipment and the repair or replacement of those components that are approaching the end of their useful life and/or should be regularly replaced. The objective of rebuilding is normally to provide the equipment with a useful life that may be greater than the lifespan of the original equipment.
- Repair: physical action taken to restore the required function of faulty equipment. It includes fault diagnosis, fault correction and function check-out.

## 3.3. Lean manufacturing

Lean means efficient use of the available resources by cutting the non-value added (NVA) activities [26]. Lean manufacturing is a collection of practices that work together synergistically to create a streamlined, high quality system that produces finished products at the pace of the customer demand [27]. Waste is defined as any activity that adds cost to a product or service without adding value from a customer's perspective. Waste may be identified in three major types: unobvious waste, less obvious waste and obvious waste [28]. de Treville and Antonakis [29] identified obvious waste examples such as unnecessary inventory, unneeded processes, excessive setup times, unreliable machines, and rework. They argued that the less obvious waste occurs as result of variability sources such as process times, delivery times, yield rates, staffing levels and demand rates. Ohno [30] identified seven original types of waste within the Toyota Production System (TPS). Womack and Jones [12] added the eighth type of waste. The discussion of each waste type is as following:

1. Overproduction: producing items too much or too soon, resulting in excess inventory
2. Defects: frequent errors in paperwork or material/product quality problems resulting in scrap and/or rework
3. Inappropriate processing: using inappropriate set of tools, procedures or systems, often when a simpler approach may be more effective.
4. Excessive transportation: excessive movement of information or materials, resulting in wasted time and cost
5. Waiting: long periods of inactivity for people, information or goods, resulting in poor flow and long lead times
6. Unnecessary motion: poor workplace organization, resulting in poor ergonomics, e.g., excessive bending or stretching and frequently lost items
7. Excess inventory: excessive storage and delay of information or products, resulting in excess inventory and costs, leading to poor customer service
8. Underutilization of employee: Unused employee creativity and skills to improve the processes and practices this refers to wasting the available knowledge, experience or skill of the staff/workforce by under-employing them or not using them in the proper department.

*3.4. Lean maintenance*

Lean maintenance term was coined in the last decade of the 20$^{th}$ century. Smith [31] defined lean maintenance as "a proactive maintenance operation employing planned and scheduled maintenance activities through total productive maintenance (TPM) practices using maintenance strategies developed through application of reliability centered maintenance (RCM) decision logic and practiced by empowered (self-directed) action teams…..". Lean maintenance generates a desirable outcome by minimizing consumption of inputs [32]. Lean maintenance represents adopting lean principles into the Maintenance, Repair and Overhaul (MRO) operations. It could reduce unscheduled downtime through optimizing maintenance support activities and maintenance overhead. The lean tools are representing the lean principles for the implementation process [33]. To effectively achieve lean maintenance improvement, key lean tools such as Value Stream Mapping (VSM), 5S, visual management need to be employed [31, 32]. A comprehensive lean tools developed for maintenance activities within an organization include 5S, TPM, overall equipment effectiveness (OEE), Kaizen, Poka-Yoke, process activity mapping, Kanban, computer managed maintenance system (CMMS), Enterprise Asset Management (EAM) system and Takt time [31, 34].

Despite the benefits of lean maintenance mentioned earlier, the literature review conducted for this paper found that previous research works on investigating the applicability of lean principles into maintenance were marginal. This proposition has been mentioned in Davies Davies and Greenough [34] emphasizing on the necessity of conducting more research on practically applying lean manufacturing principles in maintenance operations. It was discovered that the previous studies mainly focused on ranking the maintenance strategies based on some specific scope. Ghayebloo and Shahanaghi [9] formulated a model for determining the minimal level of maintenance requirements and satisfying reliability level through the use of the lean concept. Tendayi and Fourie [10] used a combined approach of quality function deployment (QFD) and Analytic Hierarchy Process (AHP) to evaluate the importance of maintenance excellence criteria and priorities the lean tools up on these criteria. The latest study of Soltan and Mostafa [11] introduced a framework for measuring maintenance strategies based on lean and agile components, i.e. waste removal and responsiveness. However, the study cannot provide sufficient practical application of lean concept in the maintenance process. The paucity of practical application in the existing lean maintenance studies provides an opportunity for this paper to expand the prevailing knowledge into a new roadmap for lean integration in the maintenance process.

## **4.** A Proposed Roadmap for Lean thinking in maintenance

This section introduces an attempt to propose a roadmap for adopting lean thinking into the maintenance process. The roadmap adopts the hypothesis of Womack and Jones [12] that lean principles can be deployed to all organizations. Lean principles have been increasingly extended to industrial and service sectors. This is known as lean thinking which refers to the thinking process of lean [35, 36]. The roadmap proposed in this paper is designed based on the five lean manufacturing principles stated by Womack and Jones (2003) as demonstrated in Figure 1. Some authors including Karim and Arif-Uz-Zaman [37] developed lean implementation methodology based on the five lean principles. Mostafa et al. [33] stated that lean practices/tools represents lean principles in the implementation process.

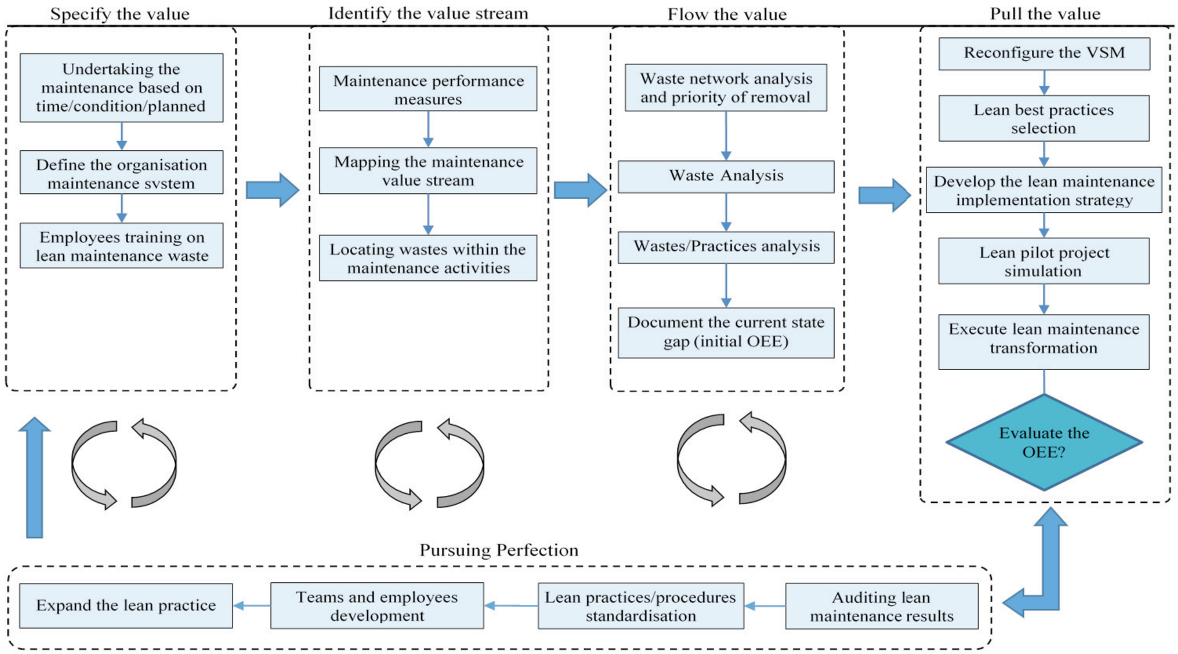


Fig. 1. Proposed lean maintenance roadmap

The roadmap introduced in this paper could be considered as a beginning step for integrating lean principles with maintenance processes. It can be used for different purposes: for an organization pursuing to transfer lean to its maintenance department or other organizations starting lean transformation from the maintenance department. The roadmap is more flexible and can be adjusted according to any maintenance strategy. It could be worked simultaneously and complementary with previous roadmap developed for shop floor area. As the roadmap is comprehensive for the maintenance processes.

The proposed roadmap is divided into five stages as shown in Figure 1. Specify the value is the first stage that focuses on defining an organization maintenance system including activities, maintenance planning, strategies and maintenance crew. This stage also defines the employees training on lean maintenance wastes. The second stages is to identify the value stream. This includes all maintenance related activities and processes. The stage starts by mapping the maintenance value stream then locating the wastes sources. This stage ends with setting equipment performance measures such as availability, overall equipment effectiveness (OEE), and Mean-Time-Between-Failures (MTBF). The third stage is to flow the value through waste network analysis then waste practices analysis. This stage document the current state gap of the maintenance department.

The fourth stage is to confirm that the equipment is pulling the value through all maintenance processes. The execution of lean principles takes place in this stage. The stages involves some steps including reconfigure the VSM or design the future stream map, selection of lean best practices, develop the lean transformation strategy, and evaluate the OEE. The last stage is to pursue the waste elimination from maintenance processes. This could be achieved through auditing the lean maintenance results, standardize the lean practices and procedures, teams and employees developments and expand the lean practice. The following subsections explain the five major aspects of the proposed roadmap.

### *4.1. Maintenance value stream mapping*

VSM is used for visualizing the flows of information and material within the supply chain. VSM primarily helps an organizational management to recognize different forms of waste and its sources. One key metric of VSM is value added time percentage which measures Value Added (VA) activities with Non-Value Added (NVA) activities [38]. Standard icons for drawing the current and future VSM are available in Sullivan et al. [39]. These icons should be modified to fit the maintenance activities. They could represent all maintenance activities once the machine is down until it gets maintained and becomes up. These can be machine down, communication the problem, identification and allocation of the resources, generation the maintenance orders, fixing and testing the machine.

### *4.2. Maintenance wastes*

The first step in lean maintenance is to identify types of the waste in maintenance process [34]. The core concept of lean manufacturing is eliminating the seven cardinal forms of waste. This concept can be helpful in maintenance as well as in production. The seven cardinal types of waste in the maintenance process can be discussed in the same manner as in the eight waste types identified in the production system [34, 40].

- Unproductive maintenance: performing preventive maintenance (PM) and predictive maintenance (PdM) tasks at intervals more often than optimal results in the overproduction of maintenance work.
- Waiting for maintenance resources: the production department is waiting for maintenance personnel to perform the maintenance service. It involves waiting for tools, parts documentation and buy extra tools and store them near the job location.
- Centralized maintenance: centralization of the MRO stores that are far from the job, commonly used repetitive parts that have not been kitted, documentation that must be hunted down, and work orders for machines that are not available all cause excess transportation. Therefore, maintenance personals spend more time in motion and transportation which does not add value to the process.
- Poor inventory management: the MRO inventory contains needed materials and spares. Additionally, work in process inventories may be used to ensure availability of required materials. Inventory for a maintenance operation also includes the work order backlog. Excessive inventory of maintenance work results in slow response, unexpected breakdowns, and a high reactive labour percentage.
- Unnecessary motion: the wasted motion is usually concentrated around preventive maintenance tasks. Doing inspection monthly on a pump that has not changed status in three years should be extended longer to quarterly, semi-annually, or annually depending upon the criticality of that piece of equipment.
- Poor maintenance: performing incorrect repair is a source of poor maintenance. Incorrect maintenance requires several repeated times to complete the repair job correctly. This affects the maintenance cost and the quality of the product. Applying proper training and detailed procedures can assist in poor maintenance elimination.
- Ineffective data management: collecting unnecessary data or inadequate collection of important data such as failure rate, root causes…etc.
- Under-utilization of resources: maintenance technicians do NVA works.

### 4.3. Lean maintenance practices

Reducing the NVA activities within maintenance can be accomplished through implementing lean practices [41]. The lean practices that suit the maintenance activities have been stated in previous studies. Smith and Hawkins (2004) identified the key lean tools including VSM, 5S, and visual management. Davies and Greenough (2010) developed a comprehensive lean tools template that represented possible lean activities within the maintenance process within an organization. The tools included 5S, TPM, OEE, standards, mapping, inventory management and visual management. Okhovat et al. [42] suggested six lean tools that fitted within the maintenance processes of an organization. These tools include visual control, 5S, seven wastes, Single Minute Exchange of Die (SMED) and Poka-Yoke (mistake proofing). Clarke et al. [40] targeted eight lean maintenance practices as a preparation for delivering lean project objectives in a pharmaceutical organization. A list of the references that includes lean maintenance practices are demonstrated in Table 1. The most frequently stated lean maintenance practices are briefly explained below.

Table 1. Related references of lean maintenance practices

| Reference | Lean maintenance tools/techniques |
|---|---|
| [43] | Standards, Poka-Yoke, root cause problem solving, process activity mapping, TPM, inventory management, story boarding, visual management, self-audits, 5S(CANDO), continuous improvement. |
| [32] | 5S, 7 Deadly Wastes, standardized work, VSM, Kanban, Jidoka, Poka-Yoke, JIT |
| [31] | Proactive maintenance, planned and scheduled maintenance, TPM, RCM, empowered action teams, 5S, Kaizen improvements, autonomous maintenance, multi-skilled maintenance technician, Work order system, Computer managed maintenance system (CMMS), Enterprise asset management (EAM), Distributed, Parts and materials on a just-in-time basis, Maintenance and reliability engineering group |
| [44] | Jidoka, Just-in-time, Heijunka, Kaizen |
| [34] | 5S, TPM, OEE, Standards, Mapping, Inventory Management, Visual Management, Root cause problem solving, Continuous improvement, Kaizen Activities, Poka Yoke, Process Activity Mapping, Self-Audits, Story boarding, Kanban, Scenarios, Takt Time, Lead Time mapping, Value Focused Thinking, Supplier Associations, Open Book Management |
| [40] | proactive maintenance, TPM, empowered action teams, SMED, 6S, Kaizen improvement, autonomous maintenance and distributed lean maintenance/MRO stores |
| [45] | FMEA, Root Cause Analysis (RCA), RCM, TPM,CMMS, 5S, PDCA |
| [42] | visual control, 5S, seven wastes, Single Minute Exchange of Die (SMED) and Poka-Yoke (mistake-proofing) |

#### 4.3.1. Distributed Maintenance, Repair and Overhaul (MRO) storeroom

The MRO stores are located to replace the centralized storeroom to make materials closer to their Point-Of-Use (POU). The stores employ standardized materials for common usage of application [46]. They operate based on planning and forecasting techniques to stabilize storeroom management. The storerooms require to develop a long-term machine facilities plan and Bills of Material (BOM) [31].

#### 4.3.2. Computerized Maintenance Management System (CMMS)

CMMS is used for measuring, managing, and analyzing the maintenance process. It includes MRO task planning and scheduling, inventory control and management, labor and material cost accounting, and asset historical data. CMMS uses software to effectively and efficiently plan and execute tasks required to maintain a company's operations to ensure maximum uptime of equipment critical to the production of finished goods [47]. To successfully plan a maintenance procedure, the user needs accurate information on the equipment to be maintained, its components, and ongoing production or workload requirements. The maintenance skills and time available must be matched against the workload, equipment items, and availability. Parts and supplies must be procured in advance, in a well-planned fashion, to complete maintenance tasks on schedule [48].

*4.3.3. 5S*

5S is a structured housekeeping and workplace organization program involving everybody in a work area. 5S consists of five activities: sort, straighten, shin, standardize and sustain. The 5S's are used to identify the hand tools, fixtures and spare parts that operators can locate, use and return them quickly, easily, and efficiently [49].

*4.3.4. Failure Mode and Effects Analysis (FMEA)*

FMEA is a systematic set of activities that identifies and evaluates potential failure modes of a system. It introduces actions that can eliminate or reduce chances of the failure occurring [50]. FMEA focuses on preventing non-conformities from a product, conducting a risk analysis on a system and process, and reducing customer dissatisfaction [45, 51]. A number of failure avoidance methodologies have been introduced including fault tree analysis, hazard analysis and critical control points, and reliability block diagram [52].

*4.3.5. Maintenance and reliability engineering group*

Venkataraman [53] mentioned the statistics that indicate up to 70% of machine failures to be self-induced. The group involves discovery of the root cause failure analysis, failed part analysis, maintenance procedure effectiveness analysis and trending, and analysis of condition monitoring results [54, 55].

*4.3.6. Autonomous maintenance*

Autonomous or independent maintenance is commonly carried out by the operators of the machines rather than by dedicated maintenance technicians. Autonomous maintenance refers to repetitive maintenance such as equipment cleaning and lubrication that performed by the production line operator [31]. The maintenance manager and production manager need to agree on and establish policy to locate the performance of the production processes autonomous maintenance and levels and types of maintenance the operators as well as the flow of the work process for autonomous maintenance. Specific training in the performance of designated maintenance responsibilities must be provided to the operators prior to assigning the autonomous maintenance responsibilities.

*4.3.7. Overall Equipment Effectiveness (OEE)*

OEE is a performance measure that reflects health of equipment. It is a composite measure calculated from equipment availability, performance and the quality of output and expressed as a percentage. OEE is a very important measure within TPM as it forms the main key performance indicator (KPI). The autonomous maintenance teams use the OEE measure to drive their continual improvement efforts. The OEE calculation is performed using data from six big losses of equipment and processes. These losses include breakdowns, changeovers, minor stoppages, reduced speed, defects and setup scrap.

*4.3.8. Multi-skilled maintenance technicians*

Multi-skilled maintenance technicians are becoming more valuable in modern manufacturing plants which employed programmable logic controllers (PLCs), PC-based equipment and process control, automated testing, remote process monitoring and control, and similar modern production systems. Maintenance technicians who can test and operate these systems as well as make mechanical and electrical adjustments, calibrations, and parts replacement obviate the need for multiple crafts in many maintenance tasks. The plant processes should determine the need for and advantages of including multiple skills training in the overall training plan [31].

*4.3.9. Work order system*

This system is used to plan, assign, and schedule all maintenance works. It is also employed to acquire equipment performance and reliability data for development of equipment histories. The work order is the backbone of a proactive maintenance in organization's work execution, information input, and feedback from CMMS. All works must be captured on a work order—8 hours on the job equals 8 hours on work orders. Types of work orders include categories such as planned/scheduled, corrective, emergency, etc. The work orders can be a primary tool for managing labour resources and measuring department effectiveness [31].

## 5. Conclusion

Maintenance management is a critical issue amongst management activities of manufacturing organization. It has rapidly grown into a very complex undertaking as technologies, competition, and product characteristics evolve. In order to achieve world-class performance, the maintenance strategies should be linked to manufacturing strategies such as lean and agile manufacturing. Selection of an effective maintenance strategy keeps a high degree of utilization, reliability, and availability of manufacturing facilities especially in continuous production process. Further, the effective maintenance strategies reduce the scrap of materials, spare parts, and equipment. This paper introduces a proposed roadmap to apply lean thinking in the maintenance process. The eight types of non-value added maintenance activities have been included. A package of icons have been designed using Edraw Max® Software to capture the maintenance activities. The icons have been used to draw the current value stream map of the maintenance process in an organization. Moreover, the value stream map locates the sources of waste in order to design the future state map. A scheme has demonstrated lean maintenance practices in two levels: the four bundles contains JIT, TQM, HRM and TPM. Practices are assigned under each bundle. The scheme allows a measure of the lean maintenance performance in an organization using multi-criteria decision making (MCDM). Moreover, the scheme can be used to measure the association between the eight types of maintenance waste and the lean maintenance practices. It can be concluded that the success of the lean maintenance depends on the application of each bundle.

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