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A review on lean maintenance through various implementations of total productive maintenance models

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ABSTRACT

TPM is the main tool used to perform lean maintenance and studies have shown significant increase in business performance upon successful implementations. This paper mainly reviews the lean maintenance through effective implementations of TPM. This includes the background of lean maintenance, objective of TPM, benefits of implementing TPM, TPM models, implementation barriers and factors of success to overcome these barriers. Recommendations for improving the cost effectiveness for TPM implementations are also included in this paper.

1. Introduction

Lean has been practiced mainly in evolving industries to escalate their productivity which is required to boost their competitive advantage in today's dynamic world. This management philosophy was made known during the 1990s which originated from the reconstructed version of Toyota Production System (TPS) (Womack et al., 1990).

The concept of lean arises from the removal of unnecessary wastes that contribute to productivity and profits maximization. Wastes can be classified into three main types, namely, Muda, Muri and Mura in Japanese. Muda was first identified as the seven wastes which include transport, inventory, motion, waiting, overproduction, over process and defects (Ohno, 1988).

Meanwhile, Muri focuses on minimizing unreasonable works and Mura emphasizes on the effectiveness of the implementation strategies. To establish a lean culture in an industry, there are many types of lean tools available such as Seiri, Seiton, Seiso, Seiketsu, and Shitsuke (5S), Just-In-Time (JIT), Total Quality Management (TQM), Kanban, Kaizen, Total Productive Maintenance (TPM) and etc.

In addition to the elimination of process wastes or inventories of raw materials, wastes produced from machineries or equipment must not be ignored. The differences between lean manufacturing and lean maintenance is that lean manufacturing focuses on improving the quality of products by reducing defective products and lean maintenance involves improvement in both reliability and quality of equipment by reducing mechanical downtime. In other words, lean maintenance is a prerequisite to lean manufacturing since, to achieve high quality standards products, the equipment must be in good condition so there is no causalities in the manufacturing processes.

To establish TPM in an industry that practices traditional methods such as breakdown or reactive maintenance is a Herculean task. TPM focuses on the improvement in reliabilities of equipment through proactive strategies that fulfill the eight pillars which include focused improvement, autonomous maintenance, planned maintenance, quality maintenance, cost deployment management, early equipment management, training and education and safety health environment.

Thus, formulation of new maintenance strategies is required to replace the current firefighting maintenances with proactive maintenances.

The objective of the review presented is to discover the importance of TPM in contributing to business performances upon successful implementation of TPM in various industries. This paper also discusses on various TPM models that are used in TPM implementation in various industries. This paper further reviews on the success factors and the implementation barriers of TPM.

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2. Background

2.1. Background of lean maintenance

Many organizations have started practicing lean tools such as Six Sigma, Kanban, 5S, Kaizen and JIT to reduce unwanted wastes in production. However, organizations tend to pay more attention to the production rather than the maintenance. This is because maintenance of equipment is associated with indirect costs which cannot show immediate profit gains as compared to the production. Nevertheless, without scheduled maintenances, unexpected breakdowns, defects, and process downtimes will arise and will interrupt the production. Therefore, some organizations have started to practice lean maintenance aside from lean manufacturing. The problem faced by most companies that tried to implement lean maintenance is that the operators are reluctant to hold any responsibility for the machines. This includes the ignorance upon detecting sudden changes in behavior of machines in which the failure can be prevented if they inform the maintenance team beforehand.

2.2. Objective of TPM

The objective of TPM is to incorporate the maintenance aspects into productivity. To ensure the objective is fulfilled, the production teams will also have to hold equal responsibility for the factory equipment because of its contribution towards productivity. TPM is known as a management strategy that was first originated from the combinations of Preventive Maintenance (PM), quality and total involvement of employees (Gupta et al., 2006; Brandt and Tjarning, 2006; Venkatesh, 2007). TPM can also be known as a tool or strategy that links elements of a good maintenance program to achieve high level of overall equipment efficient (OEE) (Williamson, 2000). The 8 elements of TPM include:

1) Routine maintenance: Production operators hold the responsibility to be in charge of keeping the equipment lubricated and clean on a routine basis.
2) Scheduled maintenance: Maintenance tasks are planned and scheduled based on predicted failures to provide a better control on the equipment inventories.
3) Continuous improvements: The reliability of the machine and maintenance processes are improved at a continuous basis and constantly being monitored and evaluated to ensure sustainability of the improvements.
4) Quality maintenance: Product defects are taken into considerations during maintenance process to ensure that the root causes for causing the defects are removed by adopting various tools or techniques.
5) Trainings of peoples: Trainings are provided to all employees including managers to have a better understanding on TPM so that TPM goals can be achieved.
6) Safety and health environmental considerations: Safety and health environmental consideration are placed at top priority to ensure a safe and healthy workplace which complies with the standard set by the government.
7) Equipment management: Modification and design of new systems that improves the reliability of equipment.
8) Applying TPM techniques: Techniques such as root cause analysis, 5-whys and failure more and effect analysis (FMEA) are used in administration functions for effective scheduling and planning to aid production and maintenance processes.

2.3. Benefits of implementing TPM

Breakdown maintenance or reactive maintenance is the idea of repairing equipment after failing. This method can lead to major impacts on the production depending on the severities of the failure mode. Primary failure modes such as boiler or compressor breakdown will lead to a complete shutdown of the entire factory which will lead to large profit loss and thereby creating a need for scheduling PM. However, it is not possible to schedule PM to all the equipment in the entire plant due to scarcity of resources, especially to industries that do not practice PM traditionally.

To schedule and perform PM, it requires skills, knowledge, experiences and data documentations in addition to a massive financial support. There are various maintenance techniques such as root cause and failure analysis (RCFA), 5-Whys, and FMEA that can be used to establish a proper maintenance plan. Furthermore, informative data such as cluster map of equipment, OEE calculations, and relevant technical data must be present in order to schedule an effective PM (Safi and Mozzar, 2004; Brandt and Tjarning, 2006). Upon successful implementation of TPM, it brings various benefits to the organization such as the increase in business performance which was proven by Brah and Chong (2004) that shows positive correlation between TPM firms with business performance through various tests. Besides, implementing TPM enhances equipment reliability through effective maintenance programs by constantly tracking on key performance indices such as OEE. The increase in OEE indicates the improvement in availability, quality and performance of the equipment (Wakjira and Singh, 2012). Poduval and Pramod (2015) have also claimed that by introducing TPM, there will be an improvement in the quality of maintenance tasks.

3. TPM implementation approaches

3.1. TPM implementation methodology

Various TPM models were carried out to implement TPM in various types of industries. Each

model has its own advantages on the performance or the cost effectiveness of the model. From a case study of implementing TPM in a mine industry by Chlebus et al. (2015), its implementation started off by collecting and analyzing data on the types of system failure rates for machine components and also on the spare-part inventory. The framework which was used includes Kanban or also known as pulls system in their spare-part inventory. A pull system scheme and special storage for missing parts in the spare-part inventory are designed based on surveys. Besides that, the repair times of machines are also analyzed so that the maintenance processes can be standardized. By preparing standardize recipes, the maintenance processes are more organized and time efficient that allow better estimation of inventory and manpower required.

Another TPM model that was proposed by Sivaram et al. (2013) has integrated TPM with the well-known ISO 9001:2008 standard-based quality management system (QMS) known as the TPM 9001:2008 model. This model was constructed based on the similarities of TPM pillars with the clauses of ISO 9001:2008 QMS. It was mentioned that the elements of TPM are correlated with the ISO 9001 standard but not incorporated so it will not affect the ISO 9001 standard. This model introduces task-efficiency as audits for both TPM and ISO 9001 standard can be done as a whole.

Another case study in an automobile industry regarding to the implementation of TPM in a boring machine by Prabhuswamy et al. (2013) has shown significant improvement of OEE from 59% to 73.6% in one year period. The adoption of this model was done by performing Kaizen techniques as TPM implementation. Kaizen is also known as continuous improvement with the purpose to improve performance indicators over time and renew current standards. The methodology used in the case study was to perform cleaning and inspection on the boring machine concurrently. The key performance indicators used for the case study is OEE. Check-Act-Plan-Do (CAPD) cycle was used to identify lubricating points and surfaces, provide remedies on defective areas and set lubricating standards. From the results of this case study, the downtime and the OEE of the boring machine have improved by a significant amount every month which indicates the Kaizen event was successful.

Kumar and Gopal (2014) has introduced a framework by integrating Six Sigma culture with TPM to improve manufacturing performance in small medium enterprises. The framework is to incorporate TPM stages into the main elements of Six Sigma which is Define-Measure-Analyze-Improve-Control (DMAIC) cycle. In the framework, the Define stage is used to identify key performance indicators such as mean time before failures (MTBF) and mean time to repair (MTTR). This is to identify the problems encountered on the equipment knowledge, maintenance skills, and analytical technique. The next stage of the framework is Measure, which is used to measure the losses and defects through various statistical tools. The data measured will then be analyzed to determine possible factors contributing to the losses and defects. After the factors have been determined, corrective action plans will be constructed according to FMEA analysis and discussions among team leaders. The key performance indicators are taken at a continuous basis so that deviation can be observed and immediate actions can be taken to ensure the framework is under control. The advantages of integrating Six Sigma are to ensure the TPM elements are continued for long run, increase involvements of employees and shared documentations. This model was reinforced by Harsej and Yusof (2011) which links six common critical success factors between TPM and Six Sigma. These include management commitment, involvement of employees, trainings, organizational structure, manufacturing strategy, responsibility and teamwork.

To summarize, there are various models and approaches to implement TPM. However, most of the researches reviewed integrate TPM with continuous improvement models because the risks involved are minimal compared to other models that require long or costly overhauls.

3.2. TPM implementation barriers

TPM implementation involves drastic changes within an organization. Cooke (2000) has discussed on his research that implementations of TPM are affected by politics, finance, department, and inter-occupations barriers. Cooke's research was further argued by Baglee et al. (2007) that four main barriers should be represented by financial, management involvement, employee skills, and time. Attri et al. (2013), Panneerselvam (2012), and Poduval and Pramod (2015) has adopted Interpretive Structural Modelling (ISM) approaches to identify various implementation barriers which includes behavior, technical, operational, strategic, and human & cultural barriers. Attri et al. (2014) further introduced a graph theoretical approach to identify the intensity between these identified barriers. The outcome of the research was that the intensity of these barriers decreases from behavior, operational, human & cultural, strategic, and lastly technical barriers. Therefore, human behavior is the main barrier to TPM implementation.

3.3. Success factors in implementing TPM

The foremost action that is required to overcome TPM implementation barriers is to enroot lean philosophy into the company. Human behavior changes as they understand the real concept behind lean. Therefore, implementation of TPM becomes much easier as the employees are more willingly to provide contributions to establish a lean culture.

Based on the case study of Crute et al. (2003) in an aerospace industry, their research shows five success factors in lean implementation as follows:

1) Holistic and focused strategy: The implementation of lean is argued that the components of lean should be adopted as a whole and not individually. Therefore, it is important to understand the entire structure of lean before implementation of any lean tools. This is to ensure that the employees can understand and contribute to the lean system. Lean will not be sufficed only with the involvement of managerial level, total employees' involvement is also necessary to carry out lean activities.
2) Company culture: The company's culture is an important factor because if the type of culture does not encourage innovation and creativity, it will enhance the resistance to change among employees. Therefore, to encourage a proactive culture that encourages employees to contribute to the company requires supportive programs to reduce the resistance to change among employees. Besides that, proactive culture can also be developed by loosening management controls via empowering employees.
3) Product focus: Lean activities must be product related so that performance metrics can be observed.
4) Commitment of senior managers: Commitment from the management is important to initiate changes to an organization. If the management does not initiate or encourage changes, the employees will not be willing or motivated to change.
5) Risk taking in fast decision making: Companies need to understand there are certain risks involved during lean transformation due to uncertainties such as budgeting, manpower, skills and knowledge and etc. However, to initiate changes, the company must be able to make fast decisions during implementation of lean activities. The consequences of any lean activities should be resolved later by taking minor risks in advance.

Achanga et al. (2006) has performed a data analysis on the data collected from semi-structured personal interviews with the management and personnel at 3 large manufacturing industries and 10 small-medium enterprises to identify the four key factors in lean implementations. The four factors are as follows:

1) Finance: Finance is the primary key factor for implementing lean because financial resources are definitely required to perform lean activities which include trainings, rewards, losses in taking uncertain risks and etc.

2) Leadership: Lean activities carried out might not be successful all the time because they depend on how effective the team leader and members are. The role of the leader is to set certain standards and create communication medium for effective communication. Therefore, selection of an effective team leader is an important factor for implementing lean activities.
3) Organizational culture: The organizational culture must be proactive in order to be successful in lean implementation. High-performing companies usually encourage proactive employees.
4) Skills and employees' expertise: Employees that are highly skilled, creative and innovative can lead to successful implementation of lean.

In a multiple case study by Czabke et al. (2008), from their results for four case studies, they have outlined 3 main factors that are important in lean implementation. The 3 factors are:

1) New vision are communicated to all employees regardless of organization levels
2) Changes in organizational culture that are not proactive
3) Follow new principles and practices consequently

To summarize, most of the success factors described among the researches are similar. The changes in company's culture were the most-discussed factor which indicates lean implementation is mainly affected by the company's culture. Since TPM is the subset of lean, the success factors for implementing lean and TPM are similar. Two evidences are provided to prove the similarities between success factors of lean and TPM. First evidence, implementation of TPM requires the support of the whole organization especially from the top management (Nakajima, 1988). Second evidence, the critical success factor for implementing TPM requires top management commitment, good management of teams, and holistic approach (Brah and Chong, 2004).

4. Discussion and recommendations

4.1. TPM models and focus on cost-effectiveness

In Achanga et al. (2006) research, finance capabilities identified as one of the four key factors to bring success in lean implementation. It was further discussed that most managers are not willing to take risks for long payback period of investment for lean implementations. Therefore, the TPM model must be cost-effective because if not there is a possibility that the management will not buy-in on the TPM implementations. To put this simple, decisions made by the management are based on the current profitability of the company. Due to this nature, if the activities incur cost and the payback period is unpredictable, there will be a possibility that the management will not take that risk unless there is significant increase in key performance indicators that can be observed immediately after the activities.

Therefore, TPM models should be both effective and cost-effective. Scheduling of preventive maintenance should be optimized using cost-effective approaches such as by integrating Reliability-Centered Maintenance (RCM) into the model. RCM is a strategy that optimizes the

maintenance process by determining whether preventive maintenance is cost-effective to be performed on a particular machine or subsection. Thus, if it is not cost-effective to perform routine preventive maintenance, the equipment will be repaired upon failure. In another words, RCM is used to improve the reliability of equipment through cost-effective approach of maintenance processes. RCM requires predictive tools to predict possible failure modes of equipment so that it can prevent the occurrence of certain failure modes. Tools are ranged from complex vibration analysis techniques to simple risk analysis such as FMEA.

RCM is usually integrated with FMEA to prioritize risks. The advantages of integrating RCM with FMEA are that critical sections of equipment can be identified and possible failure modes of the sub critical section can be prevented through effective actions. This is to minimize the risk involved, obtain a short payback period on investment, and to enhance the cost-effectiveness of maintenance processes.

4.2. A master strategy to implement TPM effectively

Establishing TPM in an industry is a long process because preparations for resources such as finances, skills, knowledge, and data are required. A master management strategy supported by a series of strategies is required to change the existing culture into a proactive culture. Formulation of master strategies are from corporate levels where goal-setting should be specific, measureable, attainable, realistic, and timely as they are important for the middle management to translate these goals into specific tasks or strategies. Before data collection or providing trainings to employees, the first step is to formulate a maintenance strategy to establish the foundation of TPM. The strategy should include decision making processes in scheduling and monitoring preventive maintenances and to also obtain feedbacks for continuous improvements (Jain et al., 2016).

4.3. TPM tools

There are many TPM tools available to implement TPM. Studies shows there is a clear correlation between the numbers of tool used and the effectiveness of TPM implementation. However, not all small medium companies have the capabilities to implement that many tools as compared to larger companies. Therefore, smaller companies should focus on the effectiveness of tools being used rather than the number of tool used.

It is meaningless to use that many tools if they are not performed effectively. Thus, smaller companies should only focus on those tools that are well-known in effectively implementing TPM. From Digalwar and Nayagam (2014) literature-based metadata analysis on TPM implementations in manufacturing industries, 42 companies were analyzed regarding on TPM tools usage and concluded that education and training are the most commonly used tools followed by OEE, autonomous maintenance, planned maintenance, and Kaizen. Education and training are the most commonly used tools because they bring the most significant impact to TPM implementations. Without skills and knowledge regarding TPM and its tools, it is not possible that the employees can perform them effectively. For example, many industries had implemented 5S but because the operators did not understand the main purpose of 5S, 5S activities would only be carried out before audits or when the operators are being told to do so. This indicates that 5S cannot be implemented effectively if employees do not have the understanding on 5S even if they know how to perform 5S activities.

Besides education and training, tools such as OEE, autonomous maintenance, planned maintenance and Kaizen are best preferable by companies because they are much more easier to be implemented on large scale as compared to other tools available such as root cause and failure analysis, why-why analysis, and computerized maintenance management system which require much more experiences, knowledge and skills.

4.4. TPM and integration with continuous improvement models

Implementation of TPM should not be a one-time event but should be improved at a continuous basis. The implementation of TPM is best to be integrated with continuous improvement models such Six-Sigma to ensure the maintenance processes are continuously improving and replacing previous set standards. As discussed previously in this paper, Kumar and Gopal (2014) has integrated Six-Sigma in TPM implementation because TPM and Six-Sigma share similar success factors. This will ease any company that had implemented Six-Sigma to easily implement TPM due to the similarities or overlap of activities. The second reason is Kaizen; one of the TPM pillars concentrates in focused improvements. Through Six-Sigma model, Kaizen projects will be held frequently which will indirectly fulfill one of the TPM pillars.

5. Conclusion

Industries should pay close attention to lean maintenance as it was proven to boost business performance upon successful implementations. TPM is the key in lean maintenance so researchers have developed a few TPM models which are usually integrated with other lean tools. The models that are discussed in this paper are TPM integrated with Kanban, ISO 9001:2008 QMS and Six Sigma. Only one case study discussed was on a stand-alone model which emphasizes on Kaizen, one of the TPM pillars. These models are constructed based on the TPM barriers that were pre-identified by various researchers. They adopted various methods in

identifying these barriers such as statistical methods, survey and case study. To overcome these barriers, researches have been done on the success factors to TPM implementations. As per their claim, the most commonly identified success factor was to change the existing company's culture. Suggestions on the construction of TPM models are that the models should be cost-effective and integrated with continuous improvement elements. Furthermore, TPM implementation should be implemented effectively guided by a master strategy and effectively use of TPM tools. Based on several researches, up to 3 to 5 years are requited for complete implementation. Therefore, further research should be focused on formulating effective master strategy rather than solely on models so that the implementation period can be shortened. This will raise the interest of manufacturers into lean maintenance.

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