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Implementing Total Productive Maintenance in a Manufacturing Small or Medium-Sized Enterprise

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Abstract:

Purpose: This paper develops a 'light' total productive maintenance (TPM) model suitable for small and medium-sized enterprises (SMEs). By design, the system is rudimentary, using a relatively small sum of capital investment and resources. The model recommends TPM implementation in three stages, namely plan, improve and sustain.

Design/methodology/approach: Literature review provides the inputs to the model development. Action research is used to demonstrate and verify the effectiveness and practicability of the framework, in a SME manufacturing hydraulic parts in China. Overall Equipment Effectiveness (OEE) and awareness of employees were studied before and after the implementation.

Findings: The case study shows a significantly improved production efficiency of equipment. The framework structuralizes TPM deployment and binding different levels of organization into the program, from planning, implementation to sustaining the practices. To break the barrier of shop floor resistance, leader must drive many activities unassisted, it therefore necessitates an open endorsement of authority by the steering committee composed of top management. Prudent pilot run of TPM helped to accelerate the implementation at critical equipment, in addition to cultivating experience and hence confidence among staff.

Research limitations/implications: This study provides a pragmatic reference to other researches and practitioners to promote a light TPM model in SMEs, without losing the essences of TPM. Being an action research with the case study in a specific manufacturing industry, the resultant evidence therefore is anecdotal.

Originality/value: The model adopts a phased method to implement TPM, without aggravating the financial and human resource burden of the enterprise. It promotes the cultivation of employees' TPM awareness and active involvement, which can lay a solid foundation for the wide implementation of TPM in SMEs.

Keywords: Total Productive Maintenance (TPM), Small and Medium-sized Enterprises (SMEs), Overall Equipment Effectiveness (OEE)

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1. Introduction

In the context of economic globalization, SMEs face multiple challenges (Nallusamy, 2016), such as global economic downturn, low production efficiency, insufficient management capacity and financial resources and pressure from peer competitors. In order to meet these challenges, effective equipment management is essential, especially in SMEs (Dhillon, 2006). With the development of technology, the degree of automation and precision of production equipment has gradually improved, and of course the technological cost has become more significant. The production equipment represents most invested capital in SMEs, and the deterioration of these equipment leads to increased production costs, lower product quality, and longer delivery cycles (Baglee, Gorostegui, Jantunen, Sharma & Campos, 2017; Renna, 2016; Nallusamy & Majumdar, 2017; Singh, Singh & Sharma, 2018). Introducing advanced maintenance strategies can effectively alleviate this situation, Total Productive Maintenance (TPM) is one of them (Mukhedkar, 2020). TPM is a widely used equipment maintenance plan in the manufacturing industry to reduce losses in production activities, increase equipment life, and ensure effective utilization of equipment (Nallusamy & Majumdar, 2017), reduce the number of accidents and increase morale of the employees (Sharma, Singh & Rastogi, 2018). TPM is defined as a tool to maintain equipment efficiency, reduce failures and increase the initiative of workers. it showcases a new equipment maintenance culture, philosophy and attitude (Candra, Susilawati, Herisiswanto & Setiady, 2017). The implementation of TPM has a high success rate among many large enterprises (Joshi & Bhatt, 2018). Nevertheless, SMEs have size weakness to acquire mass production technologies (Yang, Hong & Modi, 2011), such TPM to reduce production cost. They largely adopt a conservative capital investment which prioritizes short-term benefits (Jain, Bhatti & Singh, 2014; Baker, Kumar & Singh, 2019). For many SMEs, TPM is difficult to implement and maintain (Elwardi, Meddaoui, Mouchtachi & En-nhaili, 2018). These enterprises gave preference to breakdown maintenance system instead of developing a preventive and productive maintenance system. Baglee and Knowles (2010) interviewed the managers of some SMEs, and 87% of the enterprises still adopted reactive maintenance strategy. The main reasons for this situation are that these enterprises are rather comfortable with the strategy and doubt the benefits of introducing advanced maintenance strategy to the enterprise. Meanwhile, study by Graisa and Al-Habaibeh (2011) show lack of TPM model for SMEs.

The motivation of research is to propose a light TPM model aimed for SME and to validate usability of the model in a SME through a case study. The model utilizes limited resources of the enterprise, focusing to key pillars of TPM. To fit the common constraints of SMEs, the system is rudimentary, using a relatively small sum of capital investment and resources. The model recommends TPM implementation in three stages, namely plan, improve and sustain. As research contribution, the research also intends to fill several research gaps in literature, as explained in the next section. This model would serve as a practical reference to other researchers who want to implement TPM in SMEs. This research was carried out in two stages. The first stage involves model development. Literature review provides the necessary inputs, where literatures are obtained primarily from peer-reviewed scientific publications for the past ten years, with more attention given to the recent publications. The main sources of publications include Scopus, ScienceDirect and ResearchGate. These literatures were organized into two categories: general TPM and TPM in SMEs. The first category examines the current development of concept, and the second category explores the implementation methods and their key features proposed for SME. These key features were adopted into framework, in conjunction to several new ideas. The second stage involves case study implementation to verify the usability of the model by measuring the changes in OEE and other aspects. The first stage and second stage overlapped in some degrees to revise inductively the model during the case study; this enables realignment of theme, incorporating changes suggested by the case study enterprise and removing nonessential elements.

As the main researcher participates directly in both stages, this makes the work an action research methodology, a subbranch of case study. The methodology is effective when the goal is to explore the connection between theory and practice (Eden & Ackermann, 2018). This improves practitioners' reasoning skills and help to develop self-monitoring measures to improve performance efficiency (McNiff & Whitehead, 2011). The research base of practitioner augments with the participation. All these elements were crucial to this case study where the success relied on a blend of leadership, exercise of authority and staff rapport. To mitigate the risk of bias, case study was assessed through hard data, e.g. overall equipment efficiency (OEE) and the researcher assumed the role of mediator in key decision making. The interim and final reports were verified by the company and the researcher. The model was only verified in a manufacturing SME, which according to Stake (2013), is enough when the aim is not for comparison. Nevertheless, the evidence by nature would be circumstantial. Whether the model can achieve the same effect as in other types of enterprises needs verification in future research.

The paper is outlined as follow. Section 2 is a systematic discussion of TPM, including the definition of TPM, the eight pillars and OEE. In addition, this section also focuses on the review of other research works implementing TPM in SME. Section 3 presents the developed model and describes the flow of information on each stage of the model. In Section 4, the model is verified by explaining the specific steps of the TPM model deployment in the referred enterprise. In the final section, the result of the current research and future research direction are discussed.

2. Literature Review

2.1. Total Productive Maintenance (TPM)

The TPM is based on the principles of 5S and is defined by Nakajima (1986). Under TPM, device maintenance is changed from passive to active (Mileham, Culley, Mclntosh, Gest & Owen, 1997). The tenets are to ultimately achieve zero defects, zero faults and zero accidents in all processes of the enterprise, involving the top management to the front-line operators; reduce the incidence of defects and equipment maintenance by establishing different teams and activities running as a system (Venkatesh, 2007). Therefore, TPM is not a temporary activity, but a continuous implementation and improvement program (Díaz-Reza, García-Alcaraz, Avelar-Sosa, Mendoza-Fong, Diez-Muro & Blanco-Fernández, 2018). The concept is later expanded to the maintenance and improvement of the production quality system, through the equipment, process and operator, and increases the commercial value of the product (Sharma & Singh, 2015; Parikh & Mahamuni, 2015). TPM implementation, which brings short and long-term improvements to the enterprise, including overall equipment efficiency (OEE) (Méndez & Rodríguez, 2017; Amorim, Hatakeyama & Rojas-Lema, 2018; Bataineh, Al-Hawari, Alshraideh & Dalalah, 2019). TPM minimizes the probability of equipment failure, manufacturing a non-conforming product and the occurrence of a safety accident (Patil & Raut, 2019). Other benefits include employee output and efficiency (Ali, 2019), absenteeism and overtime reduction (Li, 2013), reduced changeover time (Bon & Lim, 2015), boost in confidence (Maran, Thiagarajan, Manikandan & Sarukesi, 2016), harnessed maintenance ability (Singh & Ahuja, 2015). TPM is widely applied in large enterprises, such as spinning plant (Paropate & Sambhe, 2013), automotive (Li, 2013; Bon & Lim, 2015; Pacaiova & Izarlkova, 2019), semi-automated manufacturing (Rahman, Hoque & Uddin, 2014), auto-part machining (Méndez & Rodríguez, 2017; Sutoni, Setyawan & Munandar, 2019), service organization (Ali, 2019).

Arguably, TPM is multi-faceted and best represented as a House of TPM (Nakajima, 1988), as shown in Figure 1. The key constructs include a 5S foundation and eight pillars of maintenance-relevant activities, namely autonomous maintenance (AM), focused maintenance, planned maintenance (PM), quality maintenance, education and training, early management, office kaizen, safety and environment. Not all pillars can be implemented in an enterprise (Chong, Chin & Hamzah, 2012; Madanhire, Mugwindiri, Ndlovu & Mbohwa, 2018). Some cases only involve a single or selective pillars, e.g. AM (Ferreira & Leite, 2016; Guariente, Antoniolli, Ferreira, Pereira & Silva, 2017; Sukanta, Maulana & Sari, 2018), PM (Kar, 2016), AM and focused maintenance (Joochim & Meekaew, 2016) among others.

Fundamental to TPM (Sharma & Yadav, 2016), 5S is a system of organizing workplace to achieve stable performance, involving with the employees (Singh, 2017). It revolves around five basic tasks: Sort, Set in Order, Shine, Standardize, and Sustain (Harun Habidin & Latip, 2019). Sort means removing unneeded items from the work area and clean up the work area (Rizkya, Syahputri, Sari & Siregar, 2019). Set in order is to determine the location and quantity of needed items (Filip & Marascu-Klein, 2015). Shine involves cleaning and improving the workplace, identifying irregularities (Veres, Marian, Moica & Al-Akel, 2018). Standardize documents and standardizes the work method, using standard tools and procedures (Patel & Thakkar, 2014). Sustain is to maintain improvement, enabling employees to develop good work habits, and finally integrating 5S into the corporate culture (Gupta & Chandna, 2020).

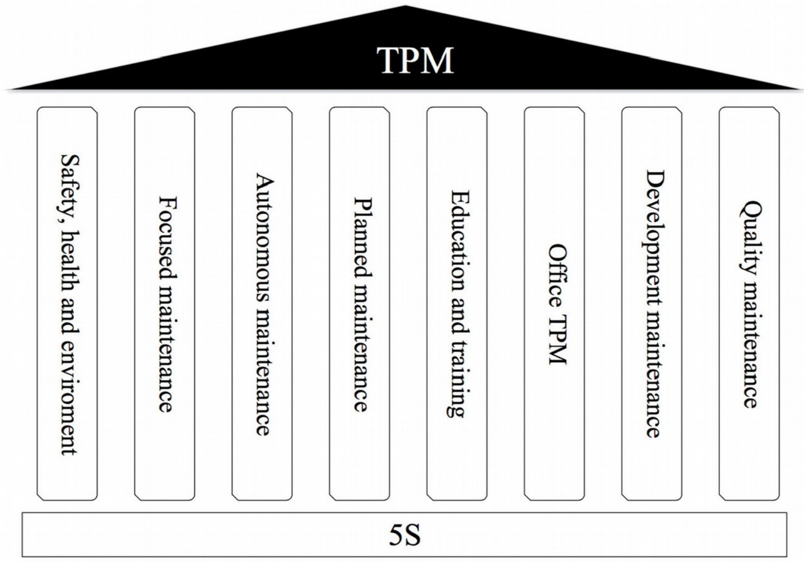


Figure 1. House of TPM (Pacaiova & Izarlkova, 2019)

In Autonomous maintenance (AM), equipment operators are given the responsibilities and powers in daily equipment maintenance, including 5S (Ferreira & Leite, 2016). This directly improves the skill of these operators to manage and improve the equipment (Wakjira & Iyengar, 2014). AM demands a cultural change to the way maintenance is done (Mugwindiri & Mbohwa, 2013). It can be divided into two themes (Farnsworth, Bell, Khan & Tomiyama, 2015). The first theme is the concept of 'self', focusing on incorporating 'self-healing', 'self-monitoring', 'self-aware', 'self-configure' and 'self-protect' technologies or characteristics; The second theme focuses on automating maintenance practices within enterprises, through autonomous robotics to assist or guide maintenance tasks. Guariente et al. (2017) implemented AM in air-conditioning tubes manufacturing line, which positively increased machine availability. When Sukanta, Maulana & Sari (2018) introduced AM to a sachet production line, the frequency of minor stoppages drops as much as 79.52%.

Focus maintenance or Kobetsu Kaizen underlines kaizen projects to identify and eliminate the major losses (Shinde & Prasad, 2017). Dave and Sohani (2015) reduced electronic breakdown frequency of hobbing machine through focused maintenance. Joochim and Meekaew (2016) introduced AM and focused maintenance in producing aluminium stranded conductors, and reduced equipment downtime and increased OEE.

Planned maintenance (PM) is to measure the failure rate of the equipment and then formulate a corresponding maintenance plan (Agustiady & Cudney, 2018). The method of PM includes preventive maintenance, breakdown maintenance, corrective maintenance and maintenace prevention (Kigsirisin, Pussawiro & Noohawm, 2016). Briefly explained, preventive maintenance maintains the equipment before failure and abnormal occurrence in the process (Yang, Ye, Lee, Yang & Peng, 2019). Breakdown maintenance involves equipment repair and restoration to operational state after the equipment failure (Poor, Zenisek & Basl, 2019). Corrective maintenance aims to improve the reliability and maintainability of equipment by improving equipment and components (Venkatesh, 2007). Maintenance prevention is to give equipment higher maintenance and reliability during the design phase of the equipment, to radically prevents the occurrence of equipment failure (Kodali & Chandra, 2001). Kar (2016) successfully increased the availability of the equipment in a bicycle tyre manufacturing company through planned maintenance.

Quality maintenance (QM) aims towards delighting customers by providing defect-free products (Vardhan, Gupta & Gangwar, 2015), achieving and sustaining customer complaints at zero (Ngadiman, Hussin & Majid, 2012). Quality maintenance specifically focuses on quality issues and cultivate such mentality, with improvement to eliminate defects from the beginning (Agustiady & Cudney, 2018). QM can be implemented through seven major practices (Asif & Vries, 2014): 1. Customer satisfaction management. 2. Process management. 3. Supplier management. 4. Data and information analysis. 5. Employee training and development. 6. Employee empowerment.

7. Quality circles. Kharub and Sharma (2015) consider strategic quality planning, supplier quality, process monitoring and control and strategic QM as key activities to implement QM. Vardhan et al. (2015) introduced QM in a food enterprise manufacturing potato chips, reduced the customer complaints to zero, the manufacturing defects by 83% and production costs by 46%.

Education and training is critical to TPM (Méndez & Rodríguez, 2017), with the aim to improve employee morale and experience by skills and technical training, bridge of the skills and knowledge gap (Adesta, Prabowo & Agusman, 2018). Through the pillar, employees transcend through the different phases of skills to be competent (Venkatesh, 2007). The training system needs to check status of education and training, in order to decide a suitable training module and schedule (Jain et al., 2014). Training could be varying, for example equipment operators learn how to identify abnormalities during their daily and periodic inspection activities, while equipment maintenance personnel learn maintenance principles and techniques, and develop specialized maintenance skills (Alsubaie & Yang, 2017).

Safety, health and environment pillar is to identify and eliminate corresponding incidents, to achieve ideal working place (Méndez & Rodríguez, 2017; Adesta et al., 2018). This pillar requires a safety committee, composed of business leaders and worker representatives, to regularly organize safety related activities such as safety slogan, safety competition and safety poster to raise the safety awareness of employees (Jain et al., 2014). In addition, regularly held security promoting activities such as security month, celebration of the week, poetry competition would improve safety in the workplace (Ahuja, 2009).

The mission of Office TPM is to identify and eliminate losses in administrative functions (Bhawarkar & Dhamande, 2013). Twelve major losses are targeted (Nithiyanandhan & Kumar, 2016), such as processing loss, communication loss, idling, accuracy loss, office equipment breakdown, customer complaints, emergency expenses etc. Patra, Tripathy and Choudhary (2005) implemented office TPM in a library to improve services, filing systems and office automation.

Development management applies the knowledge and experience gained from maintaining existing equipment to the design of new equipment (Adesta et al., 2018). It helps to reduce the time it takes to receive, install, and set up newly purchased equipment (Kumar, Singh & Khan, 2016). Dogra, Sharma, Sachdeva and Dureja (2011) built a development management system for equipment/products that are easy to use in implementing TPM.

Only a handful of literatures place TPM implementation into the context of SMEs (Eugen, 2010; Sharma & Sharma, 2013; Jain et al., 2014; Jain, Bhatti & Singh, 2015; Raut & Raut, 2017; Chukwutoo & Nkemakonam, 2018; Nallusamy, Kumar, Yadav, Prasad & Suman, 2018; Amorim et al., 2018; Elwardi et al., 2018). Eugen (2010) divided TPM implementation into four phases: preparatory stage, introduction stage, implementation stage and institutionalizing stage. Kumar Sharma and Gopal Sharma (2013)'s model was based on DMAIC methodology. Jain et al. (2014) introduced a rather comprehensive TPM method extended from Nakajima (1988)'s twelve implementation steps. The steps start from proper announcement of TPM, education, support structure, policies and goals setting, deployment plan, implementation of different pillars and finally continuous improvement. A comparatively simpler model was proposed by them (Jain et al., 2015) a year later, consists of six steps: data collection, staff training through technical seminars, trial runs, fine-tuning and final implementation. On the other hand, Raut and Raut (2017)'s work directly focuses on critical equipment at the outset, with the implementation of 5S, AM, PM, focused improvement, then following by education and training as well as OEE monitoring. Chukwutoo and Nkemakonam (2018) differentiated three stages of TPM, first being the introductory stage involving top management; second being the preparatory stage for employees training and preparation of implementation plan, and finally the execution stage, to carry out the eight pillars of TPM. In Nallusamy et al. (2018), a five steps method to implement TPM starts with data collection, OEE calculation before root cause analysis, AM, PM, Kobetsu Kaizen and finally result verification on OEE. Amorim et al. (2018) also adapted to the classic 12-step TPM implementation by Nakajima (1988). Elwardi et al. (2018) proposed DDAIE model covering a series of stages to define, diagnose, analyze, implement and check for effectiveness. Another novelty of their work stemmed from a TPM maturity grading system to allow the enterprise understands their current standing in TPM program.

These literatures explore TPM in SMEs, focusing generally on development of steps. Not all however offer a case study for verification (Jain et al., 2014). Most researchers (Eugen, 2010; Jain et al., 2014; Amorim et al., 2018) have applied the classical 12 implementation steps of TPM in SMEs, which was introduced 30 years ago, without much alteration to suit the context. Some researchers (Jain et al., 2015; Raut & Raut, 2017; Nallusamy et al., 2018; Elwardi et al., 2018) do not discuss how to maintain improved results, hence overlook the issue of sustaining the relevant practice. Furthermore, most researchers did not make goal setting explicit, which plays an important role in organizational performance and success (Skinner, 2018). Kleingeld, Van Mierlo and Arends (2011) contended that goals help to motivate teams to succeed. Additionally, little information is revealed in literature on costing and resource utilization as both are considered critical constraints to SMEs. Finally, not much emphasis is being placed on human element in these TPM implementations, compared to general TPM literatures. For instances, human elements include cooperation and corporate culture (Park & Han, 2001), training employees to master the necessary knowledge and skills (Ramayah, Jantan & Hassan, 2002), changing the minds of operators (Sun, Yam & Wai-Keung, 2003) etc. Han and Yang (2006) promoted TPM in Polish iron and steel enterprises and believed that the independent management of employees was the key to the activity. The participation of operators in the daily maintenance of the equipment is conducive to the promotion of TPM (Lazim & Ramayah, 2010). Singh and Ahuja (2015) believe that the internal factors of the enterprise, such as the education level of workers and the service life of equipment, will affect the promotion of TPM. Jain, Bhatti and singh (2017) opinioned that effective top management leadership will improve TPM success. Prashanth Pai, Ramachandra, Srinivas and Raghavendra (2018) believed that reasonable plans and proper understanding positively affects implementation of TPM. Manihalla, Gopal, Rao and Javaraiah (2019) opinioned that appropriate rewards for employees are conducive to the implementation of TPM within the organization.

2.2. Overall Equipment Effectiveness (OEE)

Proposed by Nakajima (1988), OEE is an independent measuring tool to show the ratio of the actual production capacity of the equipment to the theoretical production capacity. It is an important performance and machine health indicators in manufacturing (Saleem, Nisar, Khan, Khan & Sheikh, 2017), and to determine the success of TPM (Logesh, Kuppuraj & Augustine, 2017). Rather than efficiency, OEE measures machine's effectiveness comprehensively (Wudhikarn, 2016) and intuitively reveals production problems (Singh, Clements & Sonwaney, 2018). OEE identifies six major losses of equipment (Muchiri & Pintelon, 2008), that consume resources within the enterprise (Garza-Reyes, Eldridge, Barber & Soriano-Meier, 2010) and include breakdowns, setup and adjustment, idling and minor stoppages, speed losses, defect and rework and startup losses.

OEE is obtained by the product of three factors: availability(A), performance(P), and quality(Q) (Tsarouhas, 2019). The relationship between OEE and these three factors (Hedman, Subramaniyan & Almström, 2016), are shown in follows:

$$\text{OEE} = \text{Availability(A)} \cdot \text{Performance(P)} \cdot \text{Quality(Q)} \tag{1}$$

Availability refers to the ratio of loading time minus downtime and loading time. Performance refers to the ratio of processed amount times theoretical cycle time and operating time. Quality refers to the ratio of processed amount minus defect amount and processed amount. The calculation of Availability, Performance and Quality is as follows:

$$\text{Availability(A)} = (\text{Loading time - Down time}) \;/\; \text{Loading time} \cdot 100\% \tag{2}$$

Loading time refers to the running time after the removal of planned activities that affect production (Garza-Reyes et al., 2010).

$$\text{Performance(P)} = (\text{Processed amount} \cdot \text{Theoretical cycle time}) \;/\; \text{Operating time} \cdot 100\% \tag{3}$$

Theoretical cycle time refers to the shortest cycle time that can be achieved under optimal conditions (Singh et al., 2018).

$$\text{Quality(Q)} = (\text{Processed amount - Defect amount}) \;/\; \text{Processed amount} \cdot 100\% \tag{4}$$

Khan and Quazi (2014) urged training employees to acquire ability for loss identification and prioritization, through practical session involving seven steps. The steps start with normal OEE data collection, followed by further investigation and narrowing of focus into the equipment with least OEE as well as the critically affected products. Finally, kaizen was performed to improve the situation.

3. Model Description

The TPM model is presented in Figure 2. The model aims to improve equipment performances through proactive maintenance plan in SME. At a higher level, the model underlines an organization learning in the SME adopting a new practice to implement TPM, eventually forms a part of the organization culture. Several principles underpin the model. First the model must improve the availability, performance, reliability and quality of the equipment, reduce production waste and ultimately increase the OEE of the equipment. Second is the emphasis of cost saving. Resources are saved through recycling of material available in the company or public domain (e.g. information). Simple analysis methods are added to the model, which does not require the enterprise to purchase complex analysis software. In addition, idle resources within the enterprise can be fully used during the improvement process.

Second, cascading planning is exercised so that there is a clear connection, role definition and distribution of task from top to bottom of the organization. There must be a logical and standardized deployment and flow of TPM. Focus and pilot run on critical equipment to conserve resources and to build experience and confidence among staff. A regulation system of AM and PM which involves schedule, leader standard walk and audit.

Finally, the model can be easily emulated. In other words, after the selected equipment has been improved, the application can be extended to other equipment using the same format.The three interdependent stages are explained briefly. Plan indicates a general study on the current situation of the enterprise. Preliminary assessment indicates the causes underlying the current situation backed with quantitative and qualitative evidence, and goal-setting is the determination of improvement goals which are divided into long-term and short-term goal. Improve involves a systematic execution of steps to reach the goal. Sustain indicates institutionalizing of steps to maintain the improved effects. The detailed introduction of the model is as follows.

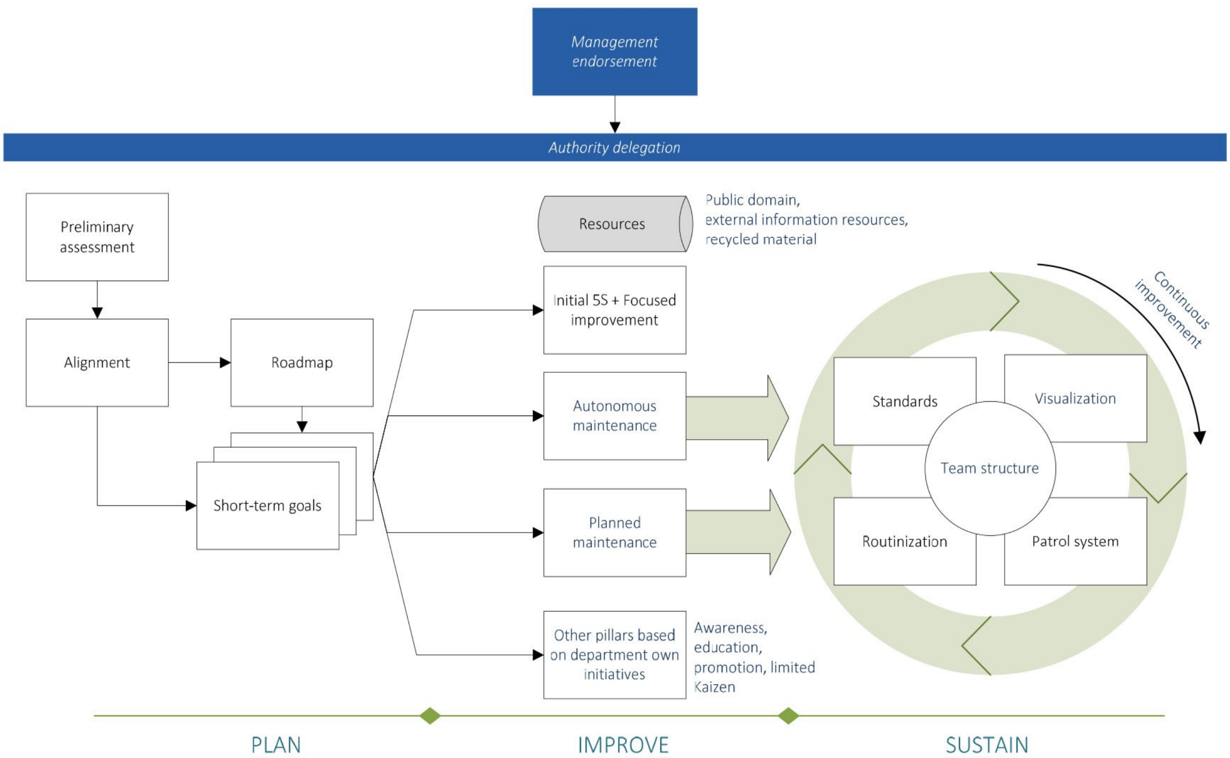


Figure 2. TPM implementation model in SMEs

3.1. Plan

In order to get the support of top management and facilitate the implementation of TPM, a steering committee made up of top management personnel is established and regularly meet to drive TPM. A suitable candidate from the middle management is appointed to lead the implementation. The leader should possess the enthusiasm and adequate knowledge in TPM and soft skills. Formal authority delegation to the leader aids to secure cross-departmental cooperation in implementation.

Preliminary assessment and alignment are the initial steps in the stage. Leader determines product families and their sales volumes. The value stream of the top runner is mapped, to trace the entire process flow and lean wastes (non-value-added activities) along the value stream. The undertaking should be the effort of a team, as the step aims to gradually set the mindset of the team members. OEE of equipment operates at this value stream is collected based on historical data, such as defect records and machine logs. In circumstance where reliable data is not available, estimate must be made prudently to best capture the reality. At this stage, equipment or a cluster of equipment with relatively low OEE (hence critical equipment) is determined to pilot run TPM. Other selection criteria would be the production criticality, team capacity and resource allocation. At this juncture, the steering committee meets to review the data and findings collected. Given enough justification, the choice of equipment would encounter little objection. Meanwhile, basic long-term goals are deliberated, potentially in the form of roadmap to outline organization strategy and commitment in the pursuit of TPM; as well as the expectation normally linked to OEE and competitive strengths of the enterprise. Equally forthcoming would be the consensus on the readiness to adopt TPM pillars and their preferred depths in time. Short-term goals are then cascaded from these long-term goals and roadmap to materialize TPM on the shop floor.

3.2. Improve

Establishing a kaizen team is the first step, which is composed of operators, maintenance personnel, managers and leader. Relevant training on TPM is necessary at the beginning of kaizen especially for team members fresh to the concept. AM and PM always start with an initial 5S jointly in the presence of operators and maintenance personnel. Potential defects of equipment are detected and rectified. A brainstorming session immediately after the initial 5S aims to identify parts of the equipment to be cleaned to facilitate the establishment of sustaining system discussed later.

Next, focused maintenance is a targeted improvement of the factors affecting the equipment OEE. A low OEE could stem from the six major losses. Study from value stream mapping would be valuable information. For example, operator actions, the equipment adjustment time is prolonged, thereby reducing the OEE of the equipment. When the reason for low OEE is not apparent, a more thorough study such as root cause analysis (e.g. pareto analysis, fishbone diagram or five why analysis) could be deployed. Pareto analysis identify the vital few causes that significantly contribute to low OEE. Fishbone diagram is a tool to identify the root cause of problems which represents the effect and the factors or causes influencing it (Shinde, Ahirrao & Prasad, 2018). In SMEs, focused maintenance is itself a kaizen project. Priority should be given to "low hanging fruits", impactful projects demanding little resources and executable in short cycle. For example, TPM heavily applies visual system to enhance personnel's grasp and hence swiftly response to the condition through visual sensory contact. This includes the installation of shadow board for tool and adequate labelling of essential components in AM and PM activities.

3.3. Sustain

The sustaining system prevents return to the state before improvement. It has four related constituents: standardization, routinization, visualization and patrol system. Standards underline desirable results benchmarked against and to develop desirable working habits. Generally, details to an AM standard should include precautions, required tools, cleaning positions, steps, frequency and the person in charge. It discerns abnormal condition to normal condition. Experience from equipment maintenance personnel and equipment operation manual would be the sources of information. As standard development is a continuous process, proper dating and documentation should be kept in mind. Applied to AM and PM, checkpoint table details inspection by equipment operators/maintenance personnel into equipment conditions and to detect early sign of equipment failures. Items to be displayed in a checkpoint table are location map, description, mode, related parts, tools, required standard and cycle. OEE monitoring runs at three facets and understandingly any unprepared SMEs would be drained to fulfill the onerous requirement. The task should be distributed to relevant parties. OEE baseline could be established and upon breaching the baseline, an alert system and corrective action should be set at full vigor. Patrol system appoint a superior as auditor to inspect the compliance of AM and PM on the shop floor, at specific interval. The auditor reports any noncompliance in through the identified channel such as shop floor meeting. Public disclosure of standards, checkpoints and patrol system through visual display on the shop floor helps information transparency and accessibility. Additionally, this cultivates trust between management and executive level staff. Continuous improvement ensures a closed loop and adaptive system that regularly revises TPM in accordance to the status of environment and the need of the organization. Continuous improvement is carried out by executive level staff, as a way to gradually decentralize responsibility and nurture new leaders. One way is to establish TPM circle (small regular group) among them to periodically meet and openly discuss TPM matters, such as suggestion for improvement, new knowledge etc. Minute to the circle meeting needs to be taken. Valid suggestion will be escalated to management and duly actualized.

4. Case Study

Founded in 2008, BSL is a hydraulic parts manufacturer located in Tancheng County, Linyi City, Shandong Province, China. The company has 72 employees of different levels, 19 CNC machining centers, 28 CNC lathes and 14 ordinary lathes. The company divides into four departments: production, quality inspection, testing and logistics. The annual sales volume of the enterprise is more than 20 million RMB. According to SME promotion law of China, 2011, the enterprise belongs to SME. The company has won the title of top 50 key parts and mechanical basic parts of machinery industry in Shandong Province and national high-tech enterprises and received ISO 9001 quality management system certification. Although BSL has obtained many honors and is reputable in the industry, the enterprise still adopts a relatively backward breakdown maintenance.

4.1. Plan

In this research, researcher has employed this model in BSL. First established steering committee (Table 1) and appointed the researcher as the leader, due to knowledge in TPM and strong family tie with the major shareholder. The next step identified the focus equipment, which refers to the following points:

1. Current value stream of product family A (Figure 3), on account of it is the highest sales volume in previous year (Figure 4). The product family consists of valve body and valve stem, which produced separately through a series of processes and combined only during assembly. After assembly, products went through testing, gas testing, packaging and stored in warehouse as finished goods before delivery to customers by schedule. The mapping revealed the significances of WIP and wastes of action in most processes, attributed by poor production arrangements. WIP buildup was heaviest at Quenching and Forming. This provides strong justification for equipment selection at the later stage.
2. The equipment failure record in previous year. due to the failure of CNC machining center are intermittent, largely cyclical and predictable, with relatively long MTBF. Therefore, the focus equipment of this research were focused on Lathe department.

The five focus equipment were selected, respectively LP20, CXK400-62-450, CF_Mill, Quench_A and Quench_B. There is another reason for choosing these five equipments: CXK400-62-450, LP20 and CF_Mill constitute a U-shaped production unit required by most valve stems and all valve stems can only be quenched at Quench_A and Quench_B. Through measurement, the OEE of LP20 was 60.46%, CXK400-62-450 was 57.32%, CF_Mill was 54.94%, Quench_A was 43.72%, Quench_B was 54.72%. As aforementioned, significant inventories presented between these machines and the upstream production, primarily due to low equipment efficiency.

Name	Corporate position	Role
Liu Linxin	Chairman	Champion
Zhang Lianggang	General manager	Co-champion
Chen Yupei	Workshop supervisor	Member
Yang Xiucheng	Maintenance supervisor	Member
Zhang Tianxiang	/	Execution leader

Table 1. The steering committee of BSL

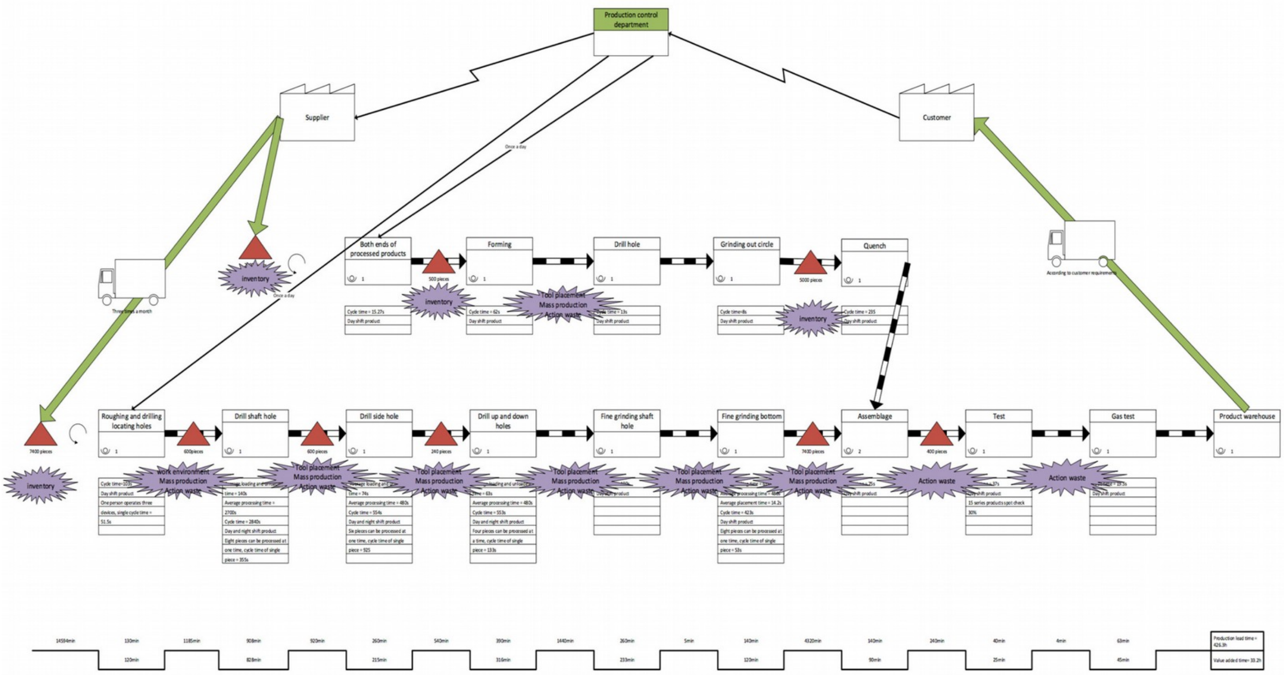


Figure 3. Current value stream of product family A

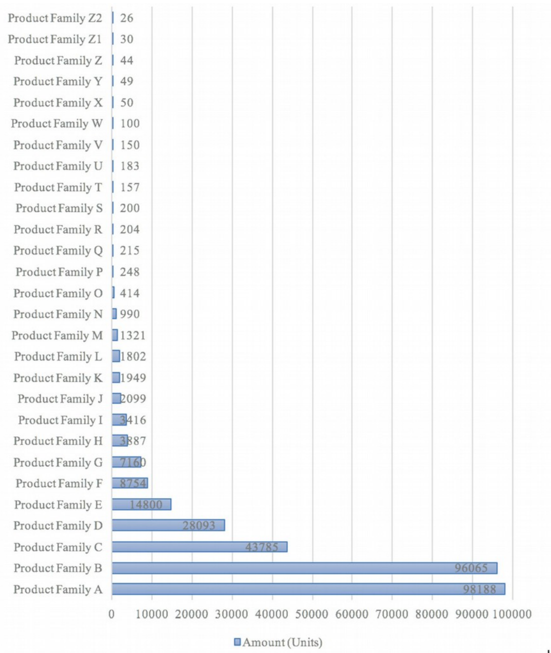


Figure 4. Product family selection table

Backing with evidence and results obtained, steering committee recognized the need to continuously improve and adopt world-class maintenance policy, such as TPM by stages. Long term goal would be important to establish a common understanding and to drive all levels of organization, especially the executive level.

After the discussions of steering committee, the enterprise's long-term goals (2019 to 2021) were formulated. By the end of 2021, all equipment will be involved in TPM and the average OEE of the equipment will be higher than 75%. The enterprise intended to develop new markets and become top tier automotive vendor in the next three years. This requires the enterprise to respond quickly to customer needs and reduce production lead time. Under the customer's automotive vendor development framework introduced to top tier vendor, high machine reliability is the prerequisite to Lean concepts such as pull production and production. In order to guide BSL to turn long-term goals into reality, researcher has drawn a long-term roadmap for the implementing TPM (Figure 5).

The short-term goals of this research are cascaded from the long-term goals, which are as follow: increasing the OEE of critical equipment to above 65%, develop AM and checkpoint table.

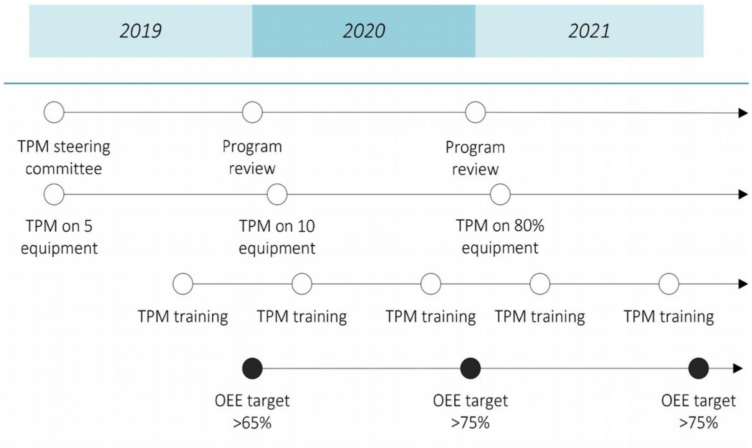


Figure 5. Implementing TPM roadmap

4.2. Improve

The kaizen team includes the leader, production director, maintenance personnel and two equipment operators taking care of the five equipment. The leader conducted several sessions of training to team members on the concept and practices of TPM, as shown in Table 2. A photo of a training session is shown in Figure 6. The leader discussed the specific details of the improvement steps, including initial 5S, focused improvement and other TPM pillars.

Date	Content	Duration (hours)	No of attendees	Source of information
19/2/2019	Team forming	2.5	10	Online lecture notes, video compiled from public internet sources.
	Introduction to equipment maintenance concept			
	TPM			
20/2/2019	OEE	3.0	11	
	Six major losses			
20/2/2019	Individual pillars of TPM	1.5	10	
21/2/2019	Sharing and brainstorming	2.0	10	

Table 2. TPM Training

Figure 6. TPM Training was carried out to the first batch of employees

For illustration, Quench_A shows how to implement TPM pillar activities. The equipment was more than 10 years old. Some historical data on the equipment can be obtained from various production sources. Also, a proper data correction was carried out for a week on the process to best estimate availability, performance and qualified product rate before any improvement. The estimated availability of Quench_A is 88.5%, the estimated performance is 49.18%, the estimated qualified product rate of Quench_A is 100%, and the OEE is 43.72%.

Initial 5S was carried out during production offline. Any detection of broken parts, e.g. cooling pipe were immediately rectified. Buildup of dust and dirt (including previously missing valve stems, amounted to RMB1000) were cleared under the board. Any corroded area, including equipment surface, processing section and landing gear, were polished and covered with anticorrosive paint. Hardened waterproof rubber and leaking pipes at the rear of the oil immersed transformer were replaced to prevent further water leakage. Splashes from quenching or from the rinse tank cause high humidity in the surrounding. Quenching involves constant heating and cooling (with water) in a poorly ventilated work area, entailing a rather humid operating environment. A simple decision suggested by the team is to implement an operator routine to open the window in good weather to promote natural circulation of air. To make it into a good habit, a reminder is placed. Any problems were recorded.

A lower OEE of the equipment is attributed by the equipment performance. Two focused improvements on equipment performance were performed after Gemba to the workplace. After quenching, workpieces would be gathered to a quantity for tempering and oxidation takes effect during this time. Removing oxidation from the workpiece is time-consuming, taking up about 31% of the production time. Two solutions were implemented as part of focused improvement. After finding a relevant anti-rust advice from a reliable expert website, top management gives endorsement to the team to place the tempering container in the antirust liquid, soon after the workpiece was quenched. Splashes were reduced by installing a plastic waterproof cover at landing gear, which also functions as a screen to prevent workpiece drops into the water pool. After improvement, oxidation removal is no longer required.

Second, during previous practice of product changeover, the height of the worktable and fixture need frequent manual adjustment to the requirement of workpiece type. Additionally, the tool sets and fixtures were not kept properly, wasting even more times when the operator rummages for them. As solutions, a tool shelf was introduced to place the fixtures and tool sets, now being arranged based on usage frequency and convenience to operator. Fixtures were labelled and the position of landing gear at worktable were marked, all according to the common types of workpiece. This eliminates the need for multiple adjustments.

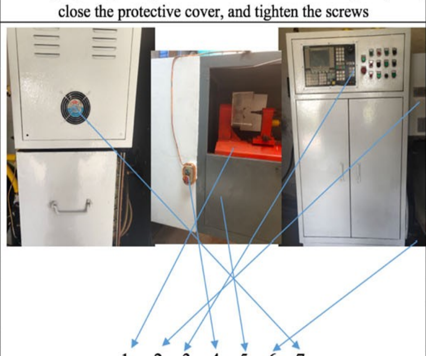
Other TPM pillars were taken in less vigor, focusing on high impact low cost initiatives. Enterprise participates in the production safety awareness workshop organized monthly by the government. Any good practice learned from the workshop was brought into the enterprise. For example, maintenance personnel were tasked to clean and inspect the power distribution box of the equipment by schedule to prevent electrical accidents. Briefing on safety was made compulsory in weekly shop floor meeting. Quality maintenance involves monthly quality meeting, and graph plotting and display of defect based on product family. Visibility of quality issue in the enterprise was used as passive instrument to drive the improvement. In Office TPM, preliminary study and awareness effort were implemented to improve the work efficiency of corporate administrative departments, including procurement approval of spare parts.

4.3. Sustain

With the authorization of the steering committee, the kaizen team decided to establish a system to sustain the results of the improvement. The maintenance system consists of four parts, which are standards, routinization, visualization and patrol system. Each part will be introduced next.

Standards: AM/PM standards and checkpoint tables were established as shown in Figure 7 and Figure 8 respectively, after communicating with equipment operators, equipment maintenance personnel and referring to the equipment manual. Pictorial information is included to guide the process. Checkpoint table indicates early sign of abnormality in equipment.

Cleaning Standards of Quench_A

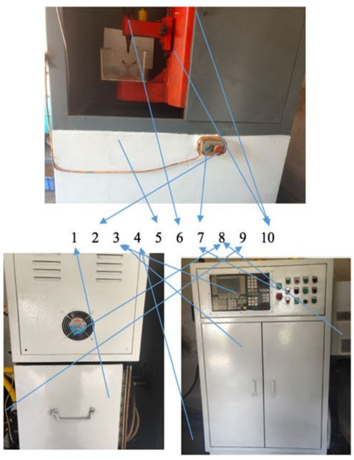
Design person: Zhang Tianxiang	Establishment date: 5.10.2019	Endorsed person: Cao Yanmei
1Cleaning of landing gare(Everyday)	2Cleaning of air conditioner filter(Every six months)	3. Cleaning of the operation panel (Everyday)
Dissolve the cleaning agent in a water-filled bucket and moisten the rag	Remove the fixed screws with a screwdriver Open the guarding of the air conditioning filter	Dissolve the cleaning agent in a water-filled bucket and moisten a rag
Wipe the surface of landing gare with a wet rag	Take out the conditioner filer	Wipe the surface of the panel with a wet rag
Wipe the surface with a dry rag	Rinse it under faucet and clean it with a brush	Wipe the surface of the panel with a dry rag
	After drying completely, install the filter back to its original place, close the protective cover, and tighten the screws	
4Cleaning of equipment emergency stop switch and starting switch(Every week)		5Cleaning of the equipment surface (Every three months)
Clean the emergency stop stwich and starting stwich with a brush		Dissolve the cleaning agent in a water-filled bucket and moisten the rag
Dissolve the cleaning agent in a water-filled work basket and moisten the rag, wipe it with wet rag		Wipe the surface with a rag Wipe the surface with a dry rag
Wipe it with a dry rag		
6Cleaning of area between equipment (Every month)		7Cleaning of the cooling fan(Every six months)
Carry wooden board to outdoors		Take out the fixed screws with a screwdriver
Clean up the dust on the board		Disconnect the cooling fan data line
If a falling workpiece is found, pick it up and put it in the corresponding basket		Take out the cooling fan and clean it with a brush
Clean the floor with a besom, and then use mop		Connect the cooling fan data line and install the cooling fan back in place
When the ground is dry, put back the board	1 2 3 4 5 6 7	Tighten the fixed screws

Note	Required Tools	Rag	Bucket	Cleaning agent	Besom	Mop	Screwdriver	Brush
Note: Power off should be done before cleaning. Gloves are required during cleaning	Quantity	2	1	1	1	1	1	1

Figure 7. Cleaning standards for Quench_A (Actual display is in Mandarin)

Quench_A Checkpoint Table

Equipment state:	Checkpoint cycle:	Endorsed person:	Design person:	Establishment date:
○ Running mode ● Stop mode	D day W week M month Y year	Cao Yanmei	Zhang Tianxiang	18. 10. 2019



Position	Specific location	Serial number	Checkpoint content	Required standard	Checkpoint cycle: Operator	Checkpoint cycle: Equipment maintenance personnel	State: Operator	State: Equipment maintenance personnel
Electrical site	Transformer	1	Oil quantity	Above the lowest liquid level	1D	/	●	/
			Operation noise	No abnormal noise	/	3M	/	○
			Temperature	Normal operating temperature	/	3M	/	○
	Emergency stop switch	2	Appearance	Normal line connection	1D	/	●	/
			Physical movement	Normal rebound	1D	/	○	/
	Control cabinet	3	Appearance	No rust, no damage	1M	/	●	/
	Monitor		Contents	No alarm, normal display	/	1M	/	●
Equipment subject	Surrounding environment	4	Appearance	No dust, no sundries	1D	/	●	/
	Equipment main body	5	Appearance	No rust, no damage	1M	/	●	/
Operative site	Operation handle	6	Physical movement	Reliable positioning and flexible movement	1D	/	○	/
	Starting switch	7	Physical movement	Can be used normally	1D	/	○	/
Cooling site	Cooling device	8	Appearance and monitor contents	Normal operation, no dust filter, set the correct temperature	3M	6M	●	●
	Cooling fan		Heat dissipation effect	Normal operation, no dust accumulation	1M	/	○	/
	Waterpipe	9	Appearance	No water leakage	1D	/	●	/
Transmission site	Electric motor	10	Operation noise	No abnormal noise	/	3M	/	○
	Axis		Physical movement	No abnormal noise when moving	/	3M	/	○
	Landing gear		Appearance	No paint peeling off	1M	/	●	/

Figure 8. Checkpoint table for Quench_A (The actual display is in Mandarin)

A system was initiated within the enterprise to distribute the task of OEE data collection and monitoring. The operator would record the OEE information of the equipment and send the information to the manager at the end of workday. The enterprise manager sorts and compares the information with the OEE baseline every week. For example, the OEE baseline is 65%, in line to the target set in the TPM roadmap for year 2020. The manager would call a meeting with the relevant personnel such as equipment operator to dissect the cause and formulate corrective.

Visualization: Depicted in Figure 9, a visual information board was set up at the gathering area on the shop floor, displaying weekly OEE information, checkpoint table, checkpoint record table, cleaning process standard, key parts and cleaning standards table for the equipment and it is updated once a week.

Routinization: to enable the operator to check and clean the equipment according to the above standards, record table for cleaning schedule (Figure 10) and checkpoint record table (Figure 11) were established. These tables would be collected at the month end for analysis.

Figure 9. The whiteboard for five key equipment

<table>
<tr><td colspan="2" rowspan="3">Record table for Quench_A cleaning schedule</td><td colspan="6">Month</td><td colspan="2">Year</td><td>Design person:</td><td>Endorsed person:</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>2019</td><td>2020</td><td rowspan="2">Zhang Tianxiang</td><td rowspan="2">Cao Yanmei</td></tr>
<tr><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>2021</td><td>2022</td></tr>
</table>

<table>
<tr><td rowspan="2">Position</td><td rowspan="2">Frequency</td><td colspan="7">The first week</td><td colspan="7">The second week</td><td colspan="7">The third week</td><td colspan="7">The fourth week</td><td colspan="7">The fifth week</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Landing gare</td><td rowspan="2">Every day</td><td colspan="35"></td></tr>
<tr><td>Operation panel</td><td colspan="35"></td></tr>
<tr><td>Emergency stop switch and starting switch</td><td>Every week</td><td colspan="35"></td></tr>
<tr><td>Area between equipment</td><td>Every month</td><td colspan="35"></td></tr>
<tr><td>equipment surface</td><td>Every three months</td><td colspan="35"></td></tr>
<tr><td>Air conditioner filter</td><td rowspan="2">Every six months</td><td colspan="35"></td></tr>
<tr><td>Cooling fan</td><td colspan="35"></td></tr>
<tr><td colspan="2">Meaning of symbol</td><td colspan="35">√: Done, X: Not done, O: Rest day</td></tr>
</table>

Figure 10. The record for Quench_A cleaning schedule (The actual display is in Mandarin)

Quench_A checkpoint record table (Operator)	Date		Design person:	Endorsed person:
	Month	Year	Zhang Tianxiang	Cao Yanmei
	1 2 3 4 5 6	2019 2020		
	7 8 9 10 11 12	2021 2022		

Position	Checkpoint cycle	The first week							The second week							The third week							The fourth week							The fifth week						
		1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Transformer																																				
Emergency stop switch																																				
Operation handle	Every day																																			
Starting switch																																				
Waterpipe																																				
Control cabinet																																				
Equipment main body	Every month																																			
Landing gear																																				
Cooling device	Every three months																																			
Meaning of symbol	√: Meet the required standards X: Does not meet the required standards O: Rest day																																			

Figure 11. The checkpoint record for Quench_A (The actual display is in Mandarin)

Patrol system: To develop the patrol system, workshop supervisor was assigned to carry out random inspection on AM/PM, following the details in cleaning standards and checkpoint. A loose OEE monitoring system was installed where operator fills in breakdown incidents and units produced weekly whereby defects information would be fed by quality control department. The information would be compiled by manager.

Continuous improvement: A TPM circle of 4 members was formed with monthly review of the TPM program. The executive level staff chaired the circle meeting in rotation. The meeting was organized after normal shift and lasted not more than 1 hour. It is intended to be casual, rapport building and knowledge sharing. Several feedbacks were brought out, including improvement on checkpoints and facilities. For examples, a more durable PVC plastic was recommended by the operator of Quench_A and Quench_B. The equipment maintenance personnel proposed regular case sharing sessions.

5. Discussion and Conclusion

The first stage of the model, plan, is considered the foundation of the model, because the steps in the following stages were based on the data collected in this stage. Short-term and long-term goals would set pace and target for the future decision making and action. The second stage, improve, involved shop floor execution carrying out by the operators of equipment. Through leadership, the resistance of the operators was overcome, and the resulting impact to build a right TPM culture would be long-term. The final stage, sustain, involved the establishment of a new regulation system to maintain the results obtained, which includes standardization, routinization, visualization and patrol system.

To reduce the burden on human and financial resources of the enterprise, the model narrows down equipment selection as early as possible and builds a practical equipment maintenance program around the key equipment, moreover, the model makes full use of the wisdom of team members, and most of the improvement methods are the results of brainstorming of team members. Resources utilization and expenditure were kept to minimum and most ideas were derived through public free sources and internet. For example, the total expenditure for improving these equipment was 889.8 RMB, or 178 RMB per equipment. Many material and resources, such as sander and visual board were spare material to be reused. Summary of the TPM implementation in the case study is shown in Table 3. The OEE was 66.90%, improved from 54.23%, hence meeting the target for 2020. Nevertheless, further improvements were planned on Quench_A and Quench_B to lift their OEE to the baseline of 65%. Of the six major losses, equipment setup was tackled through focused improvement, contributing significant improvement to

OEE. The short-term goal was achieved. Moreover, a simple survey was performed to obtain employee feedback about TPM concepts, steps and benefits. Figure 12 shows that before the improvement, the proportion of employees in know nothing is 88.89%, and after the improvement, the proportion is reduced by 1.39%. Based on the feedback from the questionnaire, TPM helped top management and equipment operators to gain confidence in and enthusiasm for the project.

<table>
<tr><th>Machine</th><th>OEE (Before)</th><th>OEE (After)</th><th>Average OEE (After)</th><th>Estimated cost saving (RMB)</th><th>Number of checkpoint</th><th>Initial cleaning duration</th><th>Number of operator involved</th><th>Cleaning cost (RMB)</th><th>Recurring cost (RMB)</th></tr>
<tr><td rowspan="4">Quench_A</td><td>Availability: 88.5%</td><td>Availability: 96.2%</td><td rowspan="20">66.9%</td><td rowspan="8">1080 Per month</td><td rowspan="4">15</td><td rowspan="8">25days</td><td rowspan="8">1</td><td rowspan="8">408</td><td rowspan="8">39 Per month</td></tr>
<tr><td>Performance: 49.2%</td><td>Performance: 62.1%</td></tr>
<tr><td>Quality: 100%</td><td>Quality: 100%</td></tr>
<tr><td>OEE: 43.7%</td><td>OEE: 62.6%</td></tr>
<tr><td rowspan="4">Quench_B</td><td>Availability: 88.1%</td><td>Availability: 95.7%</td><td rowspan="4">15</td></tr>
<tr><td>Performance: 61.5%</td><td>Performance: 67.1%</td></tr>
<tr><td>Quality: 100%</td><td>Quality: 100%</td></tr>
<tr><td>OEE: 54.7%</td><td>OEE: 64.3%</td></tr>
<tr><td rowspan="4">CF_Mill</td><td>Availability: 80.2%</td><td>Availability: 95.3%</td><td rowspan="12">3540 Per month</td><td rowspan="4">9</td><td rowspan="12">34days</td><td rowspan="12">1</td><td rowspan="12">199</td><td rowspan="12">44 Per month</td></tr>
<tr><td>Performance: 69.1%</td><td>Performance: 71.0%</td></tr>
<tr><td>Quality: 100%</td><td>Quality: 100%</td></tr>
<tr><td>OEE: 54.9%</td><td>OEE: 67.7%</td></tr>
<tr><td rowspan="4">LP20</td><td>Availability: 86.4%</td><td>Availability: 95.3%</td><td rowspan="4">26</td></tr>
<tr><td>Performance: 70.8%</td><td>Performance: 74.1%</td></tr>
<tr><td>Quality: 100%</td><td>Quality: 100%</td></tr>
<tr><td>OEE: 60.5%</td><td>OEE: 70.6%</td></tr>
<tr><td rowspan="4">CXK400-62-450</td><td>Availability: 85.0%</td><td>Availability: 95.1%</td><td rowspan="4">26</td></tr>
<tr><td>Performance: 65.4%</td><td>Performance: 72.9%</td></tr>
<tr><td>Quality: 100%</td><td>Quality: 100%</td></tr>
<tr><td>OEE: 57.3%</td><td>OEE: 69.3%</td></tr>
</table>

Table 3. Summary of TPM implementation in the case study

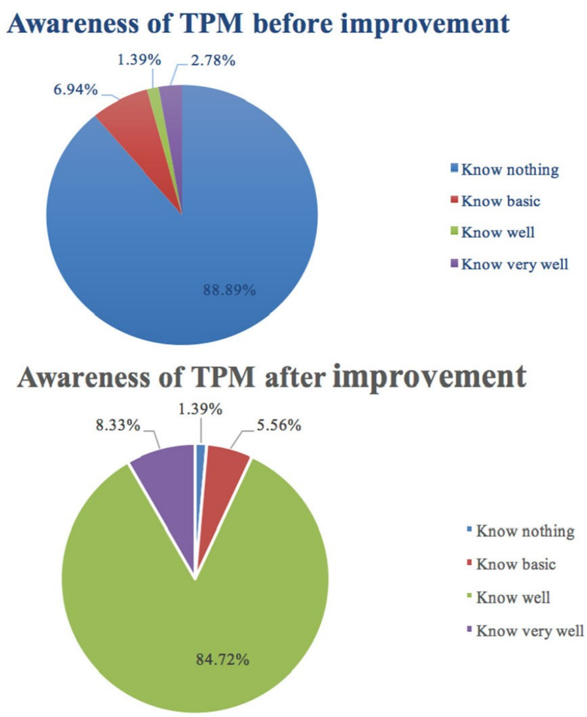


Figure 12. Comparison of TPM awareness before and after improvement

Comparing with other TPM models in existing studies (Eugen, 2010; Sharma & Sharma, 2013; Jain et al., 2014; Jain et al., 2015; Raut & Raut, 2017; Chukwutoo & Nkemakonam, 2018; Nallusamy et al., 2018; Amorim et al., 2018; Elwardi et al., 2018), the model has two advantages. First, the model minimizes implementation cost as the methods used are not complex and utilized spare resources in the improvement. Second, the model can be easily emulated. After key equipment has been improved, the application can be extended to other equipment using the format.

In this research, a 'light' TPM has been developed and described. The feasibility of the model was verified by implementation within a manufacturing SME in China. Compared with previously practiced breakdown maintenance, TPM has advantages in improving equipment manufacturing performance and preventing equipment degradation. This research reveals that employee awareness needs to be nurtured early on, through education, training and brainstorming sessions and pilot is a trial run of implementation to help employee to accumulate relevant experiences and refine strategy before system propagation, which are significantly improved their acceptance level. Initial cleaning is effective to introduce 5S and focus improvement to the equipment, as well as establish the groundwork for AM and PM. In addition, the implementation of TPM should be a continuous and incremental process to broaden the coverage of TPM as well as improve the OEE level at each round. The leader and the management of enterprise play a key role in process. It is necessary to have a sustained system to prevents the operator from returning to the state before improving. Research results show that implement TPM within SMEs in accordance with the model can effectively improve the OEE value, make them more competitive in the dynamic market.

In this research, a 'light' TPM has been developed and described. The feasibility of the model was verified by implementation within a manufacturing SME in China. Compared with previously practiced breakdown maintenance, TPM has advantages in improving equipment manufacturing performance and preventing equipment degradation. Roadmap and short-term goals set the tempo and shared focus in the organization to install and align TPM activities. This allowed smooth transition of one stage to the other. This research reveals that employee awareness needs to be nurtured early on, through education, training and brainstorming sessions and pilot is a trial run of implementation to help employee to accumulate relevant experiences and refine strategy before system propagation, which are significantly improved their acceptance level. Educational and technical information are aplenty, in various formats and easily accessible on public domain (e.g. internet), often at no cost. Through accessing these materials, the implementation was benefited considerably in training, preparation of templates and planning of activities. A case in point is the demonstration video of AM in actual workplace, captured from a social media portal, was found far more effective to impart the procedural knowledge to the staff in the training, as compared to slide presentation. Initial cleaning is effective to introduce 5S and focus improvement to the equipment, as well as establish the groundwork for AM and PM. In addition, the implementation of TPM should be a continuous and incremental process to broaden the coverage of TPM as well as improve the OEE level at each round. The leader and the management of enterprise play a key role in process. It is necessary to have a sustained system to prevents the operator from returning to the state before improving. The sustained system is holistic by emphasizing in establishing standards, visualization, routinization, patrol system and continuous improvement. Execution level staffs were given the opportunity to contribute ideas and improve the system. Research results show that implement TPM within SMEs in accordance with the model can effectively improve the OEE value, make them more competitive in the dynamic market.

Change is a constant. The business status, equipment structure, working environment and working methods of an enterprise will change with the progress of technology and time. To increase the competitiveness of an enterprise, the authors believe that future research should consider combining TPM with advanced manufacturing concepts, such as Lean production. Lean production focuses on the production process to reduce wastes related to production and establish a customer-demand-oriented pull production. On the other hand, TPM focuses on production equipment to reduce waste related to equipment. The combination of the two is not direct application of their tools and methods arbitrarily. Instead, a rigorous study is required to examine the appropriateness of these tools and methods, considering the contextual factors of the enterprise and to plan a suitable deployment strategy that helps to synergize the combined effect when they are integrated as a system.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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