

Short-Term TPM Implementation in SME : A Case Study

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Abstract

Total productive maintenance (TPM) is one of the lean manufacturing approaches that help to improve equipment performance by increasing production rate and equipment availability and enhancing the overall productivity of manufacturing. Implementing the eight pillars of TPM involves many challenges and difficulties, and it is difficult for small to medium enterprises (SMEs) in Canada to successfully implement TPM. The main objective of this study is to determine whether the Short-Term TPM (STTPM), based on Autonomous Maintenance and Planned Maintenance pillars and 5S technique can minimize losses in a production process and have a positive impact on manufacturing performance (MP). Furthermore, this study is to facilitate successful TPM implementation using the Short-Term TPM (STTPM) approach. Daily data was collected from a real manufacturing environment. A paired t-test was conducted to compare production rate (P_rR) and equipment availability (EV) before and after STTPM implementation for a production line considered in this case study. The results show that P_rR , and EV had significant differences before and after the implementation of STTPM in the production line. The paired t-test analysis was performed to identify the effect of STTPM on manufacturing performance.

Keywords

Total productive maintenance (TPM), Small to Medium Enterprises (SMEs), Equipment Availability (EV), Production Rate (P_rR).

1. Introduction

In an industrial environment, it is essential to apply lean manufacturing approaches to improve processes and eliminate losses. Manufacturing operations often operate at much less than full capacity, with low throughput, and with high cost. Therefore, equipment maintenance is a necessary function in manufacturing companies. The role of maintenance functions in modern manufacturing is becoming ever more critical in improving the equipment availability, productivity, quality and considering maintenance as a profit-generating business element (Singh et al., 2012). In industry, Total Productive Maintenance (TPM) is a system of maintaining and improving the integrity of production and quality systems through the machines, equipment, processes, and employees that add business value to an organization. According to Nakajima (1988), vice-chairman of the Japan Institute of Plant Maintenance (JIPM), TPM is a combination of American preventive maintenance and Japanese concepts of total quality management and total employee involvement. There are eight essential parts, each with distinct responsibilities, known as the eight pillars of TPM. These pillars are autonomous maintenance, focused maintenance, planned maintenance, quality maintenance, education and training, safety, health and environment, office TPM, and development management (Nakajima, 1988; Ahuja & Khamba, 2008). Implementing these eight pillars of TPM comes with many challenges and difficulties. Mora (2002) states that less than ten percent of companies established TPM programs within their organizations. Furthermore, a minimal number of North American companies obtained the TPM Award for Excellence from JIPM. It appears that North American organizations struggle significantly when trying to implement the eight pillars of TPM strategy. Prabowo et al. (2018) highlighted that TPM cannot be implemented in the same way across all organizations, because

of the differences in their culture, environment, and structure. The short-term TPM approach includes 5S, Autonomous Maintenance (AM) and Planned Maintenance (PM), and the remaining pillars are considered as long-term elements that support the TPM program and promote manufacturing performances (Lazim et al., 2013; Ahuja and Khamba, 2007; Bernstein, 2005; Cooke, 2000; and Ljungberg, 1998).

2. Literature Review

Over the last two decades, manufacturing plants have used different approaches to improve manufacturing performance. One approach to improving the performance of manufacturing activities is to implement and develop TPM pillars. Pradeep et al., (2014); Teonas et al., (2014); Banagar et al., (2013); and Ahuja & Khamba (2008), all agree that the goal of TPM implementation is to improve productivity, reduce quality costs and the final cost of products, improve the delivery of products, and increase the safety of operations. These researches also agree that TPM is to strive for the three ultimate goals of zero defects, zero accidents, and zero breakdowns. Autonomous maintenance, focused maintenance, planned maintenance, and quality maintenance pillars are TPM essentials that focus on maximizing production effectiveness and efficiencies, which have a direct influence on manufacturing performance, while the other pillars support the TPM program and promote manufacturing performances (Lazim et al., 2013; Ahuja and Khamba, 2007; Bernstein, 2005; Cooke, 2000; and Ljungberg, 1998).

Innovation, Science and Economic Development Canada (2016) stated that 97.9 percent of businesses were small businesses, 1.8 percent were medium-sized businesses and 0.3 percent were large enterprises; therefore, almost 99.7 percent of all Canadian manufacturers are small and medium-sized enterprises (SMEs). These data highlight the important role SMEs play in the national economy; their survival and success are essential. Industry Canada (2019) defined SME based on workforce size or number of employees in a firm, which vary according to the industry. For example, firms with 99 or less employees are considered small, while firms with 100 to 499 employees are considered medium enterprises.

Several researchers and practitioners have assessed the contributions of TPM implementation philosophy towards improving manufacturing performance. A quantitative method was used by McKone et al., (2001) who study the relationship between TPM and manufacturing performance through Structural Equation Modeling (SEM) using Analysis of Moment Structures (AMOS) software. SEM is a multivariate statistical analysis technique that is used to analyze structural relationships. This technique is the combination of factor analysis and multiple regression analysis, and it is used to analyze the structural relationship between measured variables and latent constructs. Wickramasinghe and Perera (2016) conduct a study to examine the effect of total productive maintenance (TPM) pillars on the manufacturing performance of textile and apparel manufacturing firms. Consistent in their findings, Sharma and Bhaerdwaj (2012) propose that achieving the objectives of TPM leads to improving manufacturing performance. Additionally, Brah and Chong (2004) find the TPM program to be a strong predictor of manufacturing strengths. They also, concluded that TPM leads to improving business performance in several aspects such as operations performance, safety and cleanliness, employee morale and customer satisfaction. Furthermore, several researchers used quantitative methods to study the impact of the TPM approach on manufacturing performance. For instance, Aziz et al., (2013) conduct a study about a proper planning system for implementing TPM at the early stage in the organization. The study discusses the important key performance indicators (KPIs) of TPM, which are machine breakdown time, mean time between failure (MTBF), mean time to repair (MTTR) and setup time. The case study of TPM implementation was taken from a manufacturing company that had recently started implementing TPM. Since then, the KPIs have been significantly improved. Also, the study explains how TPM transforms an industry's overall maintenance system to increase productivity. Moreover, measuring the situations before and after the implementation of TPM is very important to see improvement opportunities (Hartmann, 1992). Similarly, Rodrigues and Hatakeyama (2006) stated that the success of TPM implementation is closely linked to the management of people and it is necessary to develop key indicators for the assessment of the performance of the program. These key performance indicators are used to validate the progress of TPM activities and productivity, quality, cost, safety, and moral issues (Rodrigues and Hatakeyama, 2006).

3. STTPM methodology

This study is intended to benefit SMEs to better understand TPM practice and to facilitate its adoption and impact on their performance. Implementing the eight pillars TPM model in SMEs is still considered a major challenge due to several non-conducive environments and factors in the adoption and implementation process. The proposed STTPM methodology is based on a set of stages that form an integrated system of several elements to achieve the strategy and objectives of the STTPM. The elements of the framework have been developed based on TPM literature. Each stage consists of some elements that must be executed to ensure successful implementation. All these elements improve the

efficiency of the overall maintenance application by improving and developing the maintenance plan for small and medium enterprises in Canada. With cultural differences between Japanese and North American workers, it is not easy to implement the TPM approach using the same method and behaviours.

This STTPM approach is a process to help companies smoothly and quickly implement TPM to achieve a desired future state for the maintenance function. It is vital to have top management support because they can effectively remove barriers to STTPM implementation. During the initial stages, upper-level management should coordinate with the production and the maintenance departments to choose the appropriate team for STTPM implementation. The method is made up of a five-stage model: TPM initial Preparation, Training and Motivation, 5S, AM and PM elements and STTPM Auditing, as shown in Figure1.

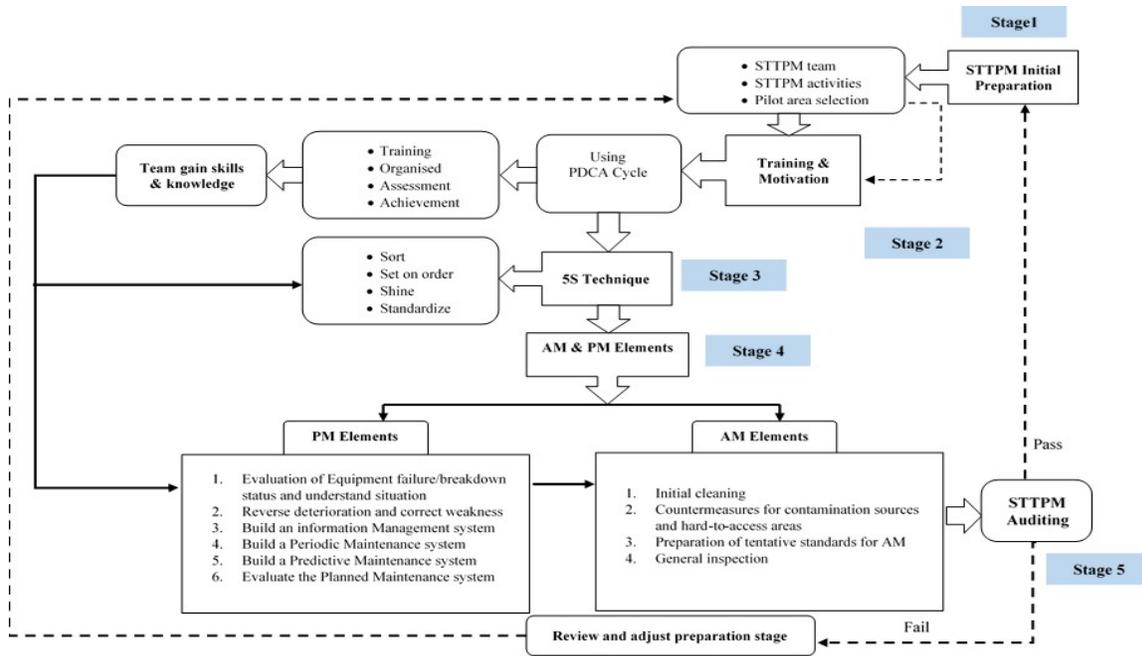


Figure1. The Implementation Process of STTPM

3.1 STTPM Initial Preparation

The first essential process of the STTPM approach is to form the STTPM team from among internal staff. The employees from the maintenance or production department with the most extensive knowledge and experience are appointed as the STTPM team leaders of each team. Each team has three members, one from the maintenance department and two from the production department. The plant manager can determine the responsibilities and roles of each STTPM member. A Gantt chart can be used to have the timeframe of STTPM implementation.

3.2 Training and Motivation

Proper training is necessary for the execution of STTPM implementation. Generally, training for STTPM implementation is carried out in a two-step method: classroom training to provide auditory and visual learning, and hands-on training to incorporate this with physical learning. As suggested by Digalwar and Nayagam (2014), training is the key to success for any lean manufacturing. Without proper training, the teams will not capture the STTPM implementation adequately and will not be able to standardize the STTPM activity. The team leaders must contribute by providing appropriate training for improving skills and knowledge towards implementing STTPM since its implementation is closely interlinked with the skill and knowledge base of team members.

3.3 5S Technique

The 5S technique was considered as a first step towards the actual implementation of STTPM and adoption of lean manufacturing. 5S refers to five principles: Sort, Set in Order, Shine, Standardize, and Sustain. The actual implementation of 5S practice is initiated by preparing and maintaining records of the jobs to be performed. The team

leaders are responsible for implementing the 5S technique according to guidance designed for this purpose. According to the recommendations of each team, the leader of the production line should set up an action plan for 5S implementation. After a month and as a first stage, the official kick-off of 5S implementation in the first production area would take place with a small ceremony to emphasize its importance. It would be a model for the rest of the production lines/areas. Indeed, the implementation of each item of 5S principles is considered an important step in contributing to the STTPM's successful implementation. 5S assists in changing the operators' attitudes and reveals hidden faults that are usually unnoticed.

3.4 AM Elements

After the training stage and 5S implementation, operators will learn the basic maintenance skills they need through AM program as required by JIPM (2017) to achieve the TPM Excellence Award, Class B. In general, there are seven elements to accomplish to gain the other TPM Award Class. The implementation of autonomous maintenance takes place after conducting operator training to be able to perform some basic maintenance tasks for the equipment. The STTPM team must be provided with technical job skills training such as operating, maintaining equipment, preventive maintenance techniques, test equipment operation, and safety training.

- ***Initial cleaning.***

The first element of AM is cleaning equipment. This cleanliness helps with the early detection of defects such as the presence of leaks or cracks depending on the five senses of the operator. The focus of the initial cleaning is in the production line that is identified as the critical area. Also, this step is considered to determine hidden problems so that the equipment can be restored to its best condition. Abnormalities are recorded using a daily or weekly inspection sheet for each production line/area.

- ***Countermeasures for contamination sources and hard-to-access areas.***

This is the second element of AM. After the initial cleaning has been performed, this element tries to eliminate all possible contamination sources, and improve accessibility for cleaning and maintenance. At this point, the operators start looking for the root causes of contamination, especially if they supported activities in element one to correct the problems thoroughly by modifying either the equipment, the processes, the work areas or work practices aimed at reducing the time to clean, lubricate or inspect.

- ***Preparation of tentative standards for AM.***

From 5S element one and two practices, the operators would gain the experience to keep the level of cleanliness that was achieved, and the equipment improvement made to deal with contamination sources and hard-to-access areas. To do this, basic standards for cleaning, inspecting and lubricating must be formulated. Cleaning standards are established to include a description, method, cleaning tools, cleaning time and frequency. Lubrication standards include a lube diagram, type and amount, method, tools, and frequency. Equipment inspection includes daily startup and shutdown procedures. The main goal of these standards is to improve equipment reliability and maintainability.

- ***General inspection.***

This element aims to provide operators a wide understanding of the functions, principles, and structure of their equipment, and to develop their ability to perform basic maintenance including hydraulic systems, fasteners, leak prevention and seals, drives, gears, bearings, electrical devices, and lubrication (JIPM 2020).

3.4 PM Elements

AM is considered the first step toward PM implementation. In addition, planned maintenance is commonly referred to as planned preventive maintenance. The STTPM team through this stage (AM and PM), helps to keep equipment up and running to avoid any unplanned downtime during daily operations. PM includes the repair, replacement, and maintenance of equipment in order to avoid unexpected failures. The main objective of PM is to achieve high reliability of equipment and minimize maintenance costs such as inspection and repair, and equipment downtime. The best way to carry out PM elements is the following (JIPM 2020) implementation of the PM phase.

3.5 STTPM Auditing

The purpose of an STTPM audit is to ensure the stage requirements of the STTPM approach are being fulfilled. The requirements have been referenced in the JIPM excellence award criteria. To follow up and monitor the STTPM implementation, auditing the stages of the STTPM approach is required. The plant manager, quality inspector and team leader are selected as the STTPM committee. The STTPM audit is carried out based on the check sheets and feedback of observations. The results of the STTPM audit are used for further improvement to achieve the objectives of the STTPM approach.

4. A Case Study

A case study assessing short-term TPM implementation in SMEs was conducted in a manufacturing company located in southern Ontario, Canada. A Production Line (PL) was selected on the shop floor, which is considered as a key production area to implement STTPM. The production line data was provided from the company daily records. The company's production line data was statistically analyzed. The data collected included production output, downtime, cycle time, and defects. The study was performed to compare production line performance (P_rR , and EV) before and after STTPM implementation using t-tests analysis to see how their means compare when implementing the STTPM approach and whether it is significant. The dataset from the daily production was measured by the following methods:

- Production Rate: the number of products manufactured in the production line for each shift.
- Equipment Availability: the percentage of time during which an equipment is available to run.

4.1 Data Analysis

The quantitative method was found to be more appropriate since it contains operational data from the production line. Implementation of STTPM as an integral part of the TPM approach can be measured by the results associated with performing a manufacturing performance assessment of the production line process. Since the sample data obtained from the same machines and the population standard deviation is unknown, the z-test was not considered. Even though the sample size is over 30, the t-distribution and z-distribution look very similar. Because of these factors, a paired t-test was used to test the hypotheses for the difference in the performance of the production line before and after implementing the STTPM approach; therefore, the null hypothesis is that the difference is zero, and the alternative hypothesis is less than zero. The level of significance $\alpha = 0.05$ is used. The paired t-tests were conducted on the production line data with the following hypotheses:

- **Production Rate**

H_0 : There is no significant difference in the production rate measured before and after the implementation of STTPM (STTPM implementation has no positive effect).

H_A : There is a significant difference in the production rate measured before and after the implementation of STTPM (STTPM implementation has a positive effect). The mathematical representation of the null and alternative hypotheses is defined below:

$$H_0 : \mu d = 0$$

$$H_A : \mu d < 0$$

- **Equipment Availability**

H_0 : There is no significant difference in the equipment availability before and after the implementation of STTPM (STTPM implementation has no positive effect).

H_A : There is a significant difference in the equipment availability before and after the implementation of STTPM (STTPM implementation has a positive effect). The mathematical representation of the null and alternative hypotheses is defined below:

$$H_0 : \mu d = 0$$

$$H_A : \mu d < 0$$

5. Results and Analysis

The data set collected from daily operations for six months was used to test these hypotheses. For P_rR , daily operation data were produced from the same machines, in this case, the PL1 do produce continuous data so it has met that assumption. It also needs independent observations, so for each time it needs to have two values and the values are paired; so, it has met that assumption. The differences between the dependent variables should be approximately normally distributed and should not contain any outliers. From Figure 2, the histogram is not a perfect Normal distribution; but generally, the bell-shaped curve can be noticed in this histogram. Figure 3 presents the Probability plot of differences where the points are close or on a straight line. Thus, we would suggest that these data are normally distributed, and the assumption of normality is satisfied. Figure 4 shows the boxplots of differences. It is noticed that there are no points plotted above the top whisker or below the bottom whisker, so there are no outliers in this distribution. For the other manufacturing performance variable EV, see Figures 5, 6, and 7.

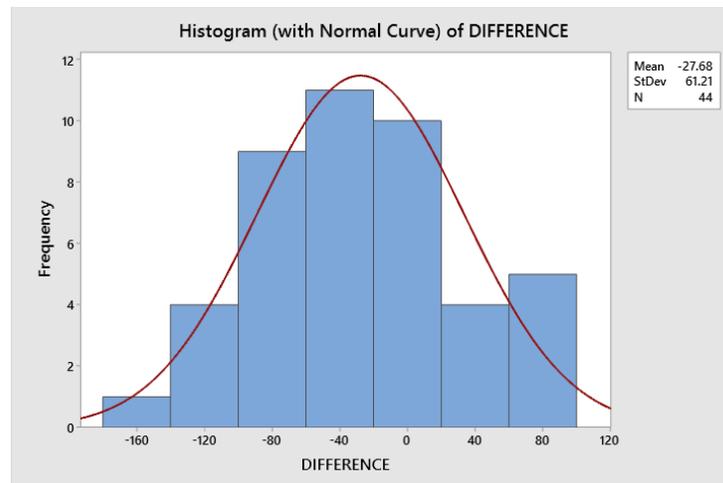


Figure 2. Plot histogram (P_rR).

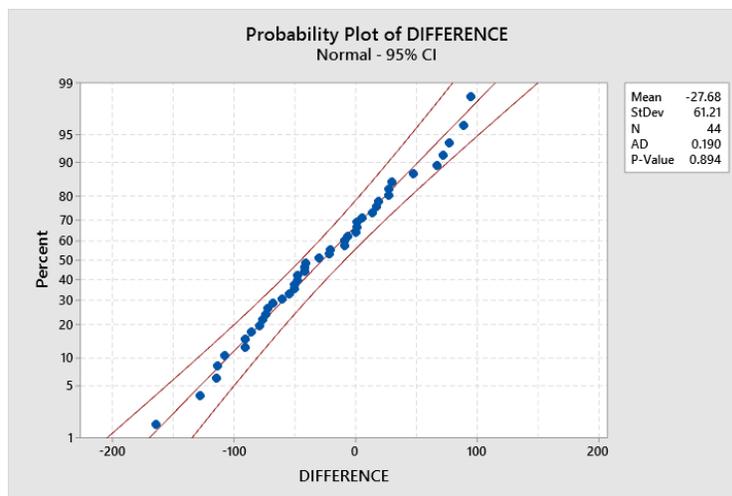


Figure 3. Probability plot of differences (P_rR).

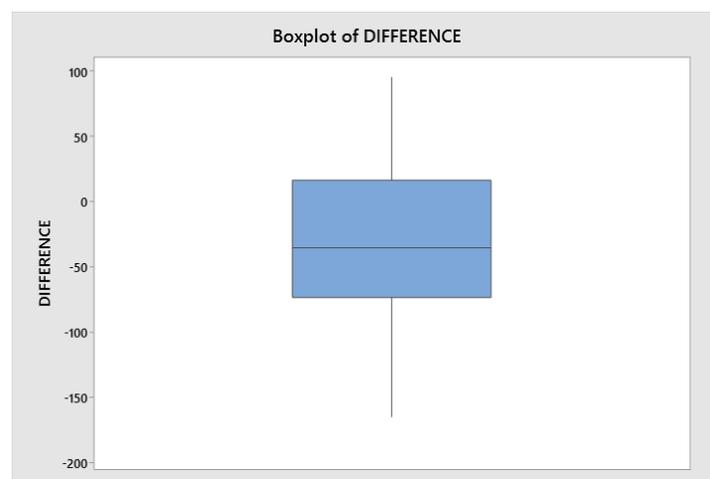


Figure 4. Plot boxplot (P_rR).

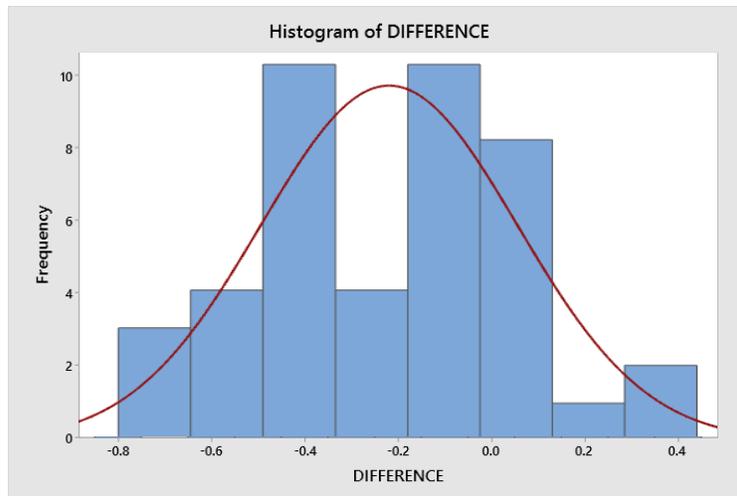


Figure 5. Plot histogram (EV).

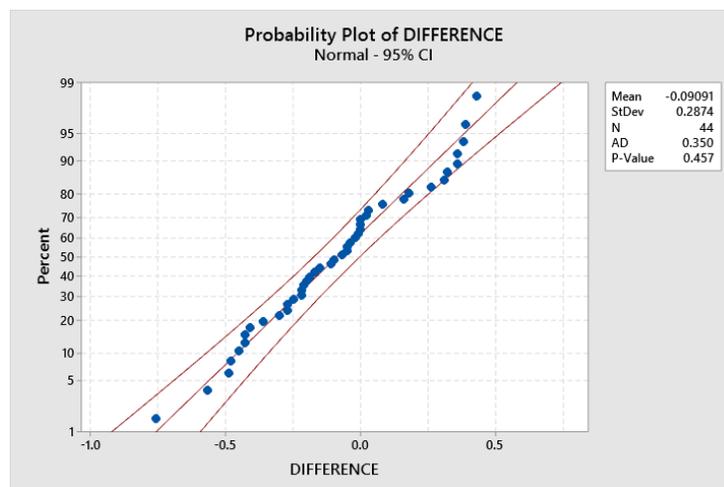


Figure 6. Probability plot of differences (EV).

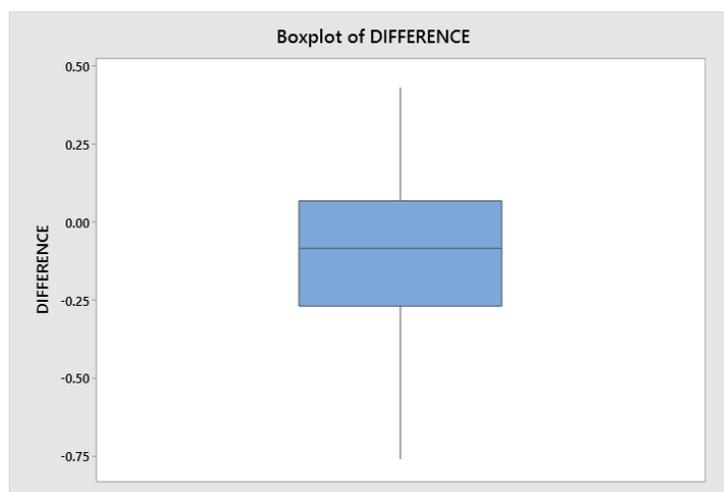


Figure 7. Plot Boxplot (EV).

5.1 Production Rate

In Table 1 and Table 2, the results show that production rate has increased by a large amount after STTPM implementation (mean= 150.7955, StDev = 56.688) compared to results before STTPM implementation (mean = 123.1136, StDev = 62.968). The critical value for *t* distribution, at the significance level $\alpha = 0.05$, and 43 degrees of freedom is: $t = -1.681$, and the computed value is: T-statistic = -3.00. The null hypothesis of no significant difference in the production rate produced before and after the implementation of STTPM can then be rejected. And the alternative hypothesis is that there is a significant difference in the production rate produced before and after the implementation of STTPM.

Table 1. Paired Statistics Results for Production Rate Before and After STTPM Implementation.

Sample	N	Mean	StDev	SE Mean
P _r R BEFORE STTPM	44	123.11	62.97	9.49
P _r R AFTER STTPM	44	150.80	56.69	8.55

Table 2. t-test Results Production Rate Before and After STTPM Implementation.

Mean	StDev	SE Mean	95% Upper Bound for μ difference
-27.68	61.21	9.23	-12.17

μ difference: mean of (P_rR_BEFORE_STTPM - P_rR_AFTER_STTPM)

Null hypothesis
 Alternative hypothesis

T-Value
 -3.00

H₀: μ difference = 0
 H₁: μ difference < 0

P-Value
 0.002

5.2 Equipment Availability

The results show that equipment was more available after STTPM implementation (mean= 0.8411, StDev = 0.17263) than before (mean = 0.7502, StDev = 0.19355). The critical value for *t* distribution, at the significance level $\alpha = 0.05$ and 43 degrees of freedom is $t = -1.681$, and the computed value is T-statistic = -2.10. Paired t-test found this difference to be significant, ($T < t$) lower-tailed test. The null hypothesis can be rejected, since $p < 0.05$, (p -value = 0.021). There is a significant difference in the equipment availability before and after the implementation of STTPM as in Table 3 and Table 4.

Table 3. Paired Statistics Results for Equipment Availability Before and After STTPM Implementation.

Sample	N	Mean	StDev	SE Mean
EV BEFORE STTPM	44	0.7502	0.1936	0.0292
EV AFTER STTPM	44	0.8411	0.1726	0.0260

Table 4. t-test Results In Equipment Availability Before and After STTPM Implementation.

Mean	StDev	SE Mean	95% Upper Bound for μ difference
-0.0909	0.2874	0.0433	-0.0181

μ difference: mean of (EV_BEFORE_STTPM - EV_AFTER_STTPM)

Null hypothesis
 Alternative hypothesis

T-Value
 -2.10

H₀: μ difference = 0
 H₁: μ difference < 0

P-Value
 0.021

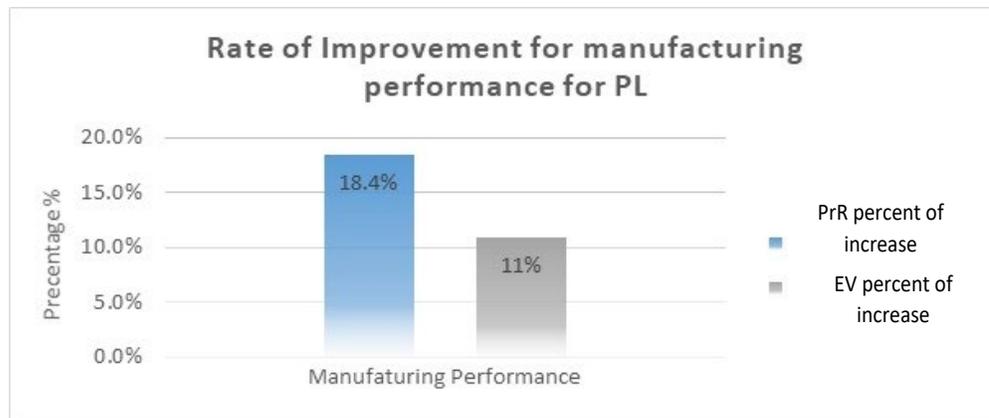


Figure 8. The rate of improvement for production line.

This study produced statistical evidence to support the theory that the STTPM minimizes losses in the production process and has a positive impact on MP. Figure 8 shows the percent of improvement for the production line after STTPM implementation. Furthermore, the STTPM approach is the first step to facilitate a more extensive TPM implementation and can help improving manufacturing performance.

6. Conclusions

The STTPM approach introduced in this study supports SME's in four ways. The framework is concise, simple and flexible for companies to implement. The framework does not require significant financial support, and any initial costs can be offset by the potential long-term profit increase and cost reduction. Manufacturing improvement can be achieved shortly after implementation. Finally, the framework does not require the expertise of an external TPM team and is better implemented utilizing the knowledge and experience of already present internal staff, another cost-saving measure. The STTPM approach helps SMEs improve the production rate, and equipment availability. This study concluded that there was a significant difference in the MP variables before and after the implementation of STTPM in the production line. The case study was intended to illustrate that the STTPM approach can be applied to other manufacturing industries. The STTPM approach can produce desirable results. The STTPM approach in this study should be used whenever applicable to impact on manufacturing equipment performance. The result shows that (PrR and EV) had a significant difference before and after the implementation of STTPM in the production line.

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