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# Optimization of Production System: An Application of Total Productive Maintenance (TPM)

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***Authors' contributions***

*This work was carried out in collaboration between author CCI and EPS. Author EPS designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author CCI managed the analyses of the study. Author EPS managed the literature searches. Both authors read and approved the final manuscript.*

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## ABSTRACT

In today's trends of market competition, Production Company is moving towards improving and optimizing of their products in order to remain competitive. Total productive maintenance (TPM) is one the most ideal maintenance management program to ensure high system availability, since (TPM) is consider as a sub-part of Lean Manufacturing. In this work, research has been conducted to study the impact of equipment effectiveness, availability and performance through the use of total productive maintenance in Apex Automated Manufacturing Industry, with the objectives of producing goods without reducing product quality, increasing product cost and to produce a low batch quantity of products at the earliest possible time with non defective products. The equipment parameters, such as the availability rate, the performance and the quality rates of the goods produced are consider while optimizing the Equipment Effectiveness (EE) of a production system. Pareto principle and statistical models of downtimes were used to depict the most downtime factors. This study reported OEE of 22.4% and 23.5% for 2012 and 2013 years respectively as regards to the world class recommended OEE is 85%. Pareto analysis showed that planned

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maintenance and machine failure / breakdown caused about 80% of total downtime. And the management and maintenance group should always target total implementation of the eight pillars of TPM to bring the value of OEE to world class standard of 85%.

*Keywords: Production system; TPM; overall equipment effectiveness; equipment availability; performance rate; quality rate; Pareto principle.*

## 1. INTRODUCTION

Total productive maintenance (TPM) is a systematic method for equipment maintenance to achieve a perfect production: No breakdowns, non stopping or slow running and no defects. Total Productive Maintenance employed quick and preventative maintenance method to optimize the production efficiency of the production systems by stating clear the roles of operation activities and maintenance operators,' through education and training. In order to reduce or eliminate losses, total productive maintenance addresses the production activities from the grass root, whether from down-times defects or accidents [1,2]. TPM is fundamentally a maintenance schedule used for a newly defined propose for sustaining production systems and equipment. The aim of TPM program is to maximize the production line and equally employ standards models and rules to achieve job satisfaction [3]. It brings maintenance into an essential and competitive nature of the products, since it is regarded as a profit making activity/process [1]. The goal is to bring the emergency of down-times factors and the unscheduled maintenance of the systems to minimum rate.

The introduction of (TPM) program, give share responsibility for systems and equipment that undergo greater involvement by operator's and production floor. In this process it can be very useful and effective in maximizing productivity. TPM program is also an important key concept of lean manufacturing, providing a comprehensive and life cycle methods for equipment management that can reduce equipment failures and production defects [4,5,6].

It includes those in the organization, starting from the top level of management to the production, operational mechanics, to outside suppliers. TPM establishes an organized procedure that focused more on equipment efficiency at any point in time [4]. Total Productive Maintenance has major targets as shown below: [7].

- ***Motives of TPM***

  1. Ensuring consistence approach in maximize the overall system of manufacturing systems.
  2. Encourage and motivates operators through job education and training [7].

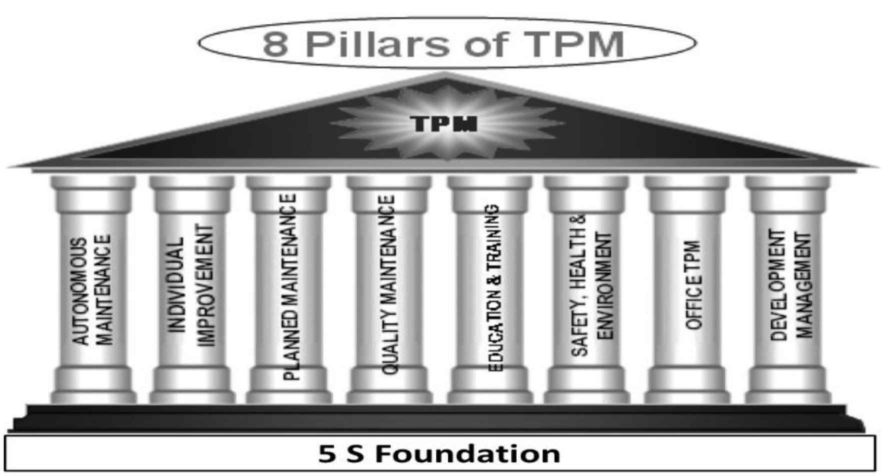


**Fig. 1. Eight Pillars of TPM [4]**

- ***Uniqueness of TPM***

  1. TPM and other concepts is clearly distinguished, that is all production team are inclusive in the organizational process [2].

- ***TPM Objectives***

  1. TPM objectives are to minimize and to achieve a zero product defects, zero machine breakdowns in order to limiting accidents in all functional areas of the organization [3].
  2. And it Involves people in all levels of organizational processes.

- ***Direct benefits of TPM***

  1. It increases productivity and Overall equipment efficiency of the systems by 50% when properly implemented and followed.
  2. It rectifies the customers' complaints properly.
  3. Reduce the production cost by 30% [2]
  4. Satisfy the customers' needs by 99 % (Delivering the right quantity at the right time).

- ***Indirect benefits of TPM***

  1. It creates higher confidence level among the employees.
  2. It keeps the work place clean, neat, orderly and attractive all time.
  3. It promotes good behavior with favorable mind-set of the workers.
  4. Knowledge and experience is shared among workers [7].

## 2. REVIEW OF RELATED LITERATURE

TPM is an innovative Japanese concept that began in early 1951, when autonomous and preventive maintenance started in Japan [4]. This system of maintenance was taken from United State of America [USA], when Nippondenso was the first company to introduce equipment wide autonomous and preventive maintenance in 1960 [4]. Preventive maintenance is the concept where operators produced items using machines and the maintenance team was dedicated with the work of maintaining the systems. However with the high technology of Nippondenso, maintenance was demanding as more maintenance personnel were required [4]. Hence the management engages the routine maintenance of systems which would be handling by the production personnel and it is called autonomous maintenance, the first features of TPM. Also Nippondenso, being the earliest industry, that stared preventive maintenance, had included Autonomous maintenance by production operators. The maintenance team went in the equipment/systems maintenance for optimizing their systems reliability. The modifications were made in new equipment leading to maintenance prevention. The objective of productive maintenance was to increase the total equipment effectiveness to achieve better and higher life cycle cost of production equipment [4].

A study performed on total productive maintenance review and overall equipment effectiveness by [8]. The study targeted the aims and importance of implementing TPM and is focused on evaluating the total equipment effectiveness in Steel firm in Jordan. In the same vein, another article was published on Implementation of Total Productive Maintenance on Haldex Assembly Line by [9], and the core of that article was on the analysis of assembly line of automatic brake adjusters at Haldex Brake Products [10,3]. In 1906, an Italian economist Pareto formulated a mathematical method to analyze the differences in distribution of his country's wealth by observing that only twenty percent (20%) of the people acquires eighty percent (80%) of the country's wealth [10]. Then in late 1940s, Joseph M. Juran termed the 80/20 ratio to Pareto, formulating it as Pareto analysis [4,10]. This methodology aids to find the major factors that need to be consider while fixing the major causes and down-times of any production organization. And the method is termed Pareto ratio $\frac{20}{80}$ rule, stating that, in every systems down-times, only 20% of down-times factors almost results to 80% of the total down-times factors, and this rule should not be considered immutable law of nature [4,10].

## 3. RESEARCH METHODOLOGY

### 3.1 Overall Equipment Effectiveness (OEE)

OEE account for different equipment and systems of any production processes including availability, performance and [11,10,5] and can be expressed as;

$$\text{OEE} = \text{Availability rate x Performance Rate x Quality Rate} \quad (1)$$

#### 3.1.1 Availability rate

Availability is defined as the percentage ratio of time the machine is available at work, with respect to the time it should be available for planned work [12,10] is expressed as;

$$\text{Availability} = \frac{(Operating\ time)}{Planned\ run\ time} x100\% \quad (2)$$

The planned production time is the actual time the equipment or machine is running at work for production [10]. Then, in case of any planned downtime, it should be taken off from the available time to get the active or actual time. While the actual time is the time the machine is available and is actively planned tso operate or work (working time). Therefore, the actual time of the system/equivalent is the system available time minus the system planned downtime. [10, 13,12].

Machine operating time is defined as the period during which the machine is actively in operation [13].

Machine operating time = actual period – [down-time + Set uptime] (3)

Operating time = available time minus [breakdown plus set uptime minus scheduled downtime]

Operating time = scheduled time – schedule Downtime (4)

Here, the availability is evaluated using the given formula as in equation (5) below.

Availability =

$$\frac{(Planned\ run\ time - Planned\ Down\ time)}{Planned\ run\ time} x100\% \quad (5)$$

But at zero downtimes, the system availability is always hundred percentages, and the total operating time is the same as the machine available time for production. [14,12].

#### 3.1.2 Performance Rate

The equipment performance rate takes into account the gross operating time. During machine performance, there are no issues of down time factors, like failure of any kinds, in short, no losses in the production time. According to [10,13], the performance factor is expressed as the percentage of scheduled/planned run-times minus scheduled/ planned down-times with respect to the scheduled/planned run-times as in equation (6).

Performance Rate =

$$\frac{(Planned\ run\ time - Planned\ Down\ time)}{Planned\ run\ time} x100\% \quad (6)$$

Design cycle time =

$$\frac{(Daily\ avarage\ Planned\ run\ time)}{(Daily\ avarage\ target\ of\ production)} \quad (7)$$

#### 3.1.3 Quality Rate

Quality rate is defined as the percentage of total output of the production minus average rejection of the total output of the production during the net production time, since no machine failure occur in the cause of production. Hence it can be expressed as in equation 8a and 8b [10,13]

Quality Rate =

$$\frac{(Total\ output - Average\ reject)}{Total\ output} x100\% \quad (8a)$$

$$= \frac{(Good\ pieces)}{Total\ pieces} x100\% \quad (8b)$$

Since each of the three value factors of effectiveness lies between 0 and 1, measuring these factors independently should be ninety percentages. While the Overall Equipment efficiency, is calculated as shown in equation (9) [13,5,6].

OEE = availability (100 %) x performance rate x quality rate. (9)

### 3.2 World Class OEE

The world base classification for Overall Equipment efficiency (OEE) is a bench mark used to test the OEE of any manufacturing industry practicing TPM. The range of percentages is classified as given in Table 1.

**Table 1. World-class rate factor for OEE [11,10,6]**

| OEE parameters | World classification (%) |
|---|---|
| Availability | >90.0 |
| Performance | >95.0 |
| Quality | >97.0 |
| OEE RATES | 80.0 |

Since every manufacturing plant has different system of operation, the world classification rate depicts that the Overall Equipment efficiency

(OEE) rate in any manufacturing equipment should be at most ninety percent (90%) and not less than sixty percent (60) [7,10].

## 4. DATA ANALYSIS AND DISCUSSION

Apex Automated Manufacturing Industry is a paper printing and packaging manufacturing industry. In 2012, the industry begins the use of planned maintenance in the production section machines. Data were collected through questionnaire, and the production data were captured from the production records book and factory complaint sheet for the optimization of TPM application and Overall Equipment Effectiveness. Relevant models were used to calculate the OEE factors as shown in Table 2.

Using Table 2, 2013, the average OEE was 23.5%, if the equipment were 100 percent available.

By plotting the average monthly availability in 2012, the following graph was obtained as shown in Fig. 3.

The following facts have been revealed that Fig. 2 depicts the machine availability values in all the

**Table 2. Monthly OEE measurement for 2013 (%) using factory production records book**

| Month | Availability | Performance | Quality | OEE |
|---|---|---|---|---|
| January | 79.7 | 32.1 | 99.8 | 25.5 |
| February | 78.1 | 30.5 | 100 | 23.8 |
| March | 78.0 | 30.4 | 99.9 | 23.7 |
| April | 80.8 | 28.6 | 99.4 | 22.9 |
| May | 81.8 | 22.0 | 99.9 | 18.0 |
| June | 78.5 | 23.3 | 99.8 | 18.3 |
| July | 77.1 | 42.4 | 99.9 | 32.7 |
| August | 82.0 | 28.0 | 99.9 | 23.0 |
| September | 81.9 | 27.8 | 99.9 | 22.8 |
| October | 80,5 | 40.5 | 99.9 | 32.6 |
| November | 92.0 | 24.1 | 99.9 | 19.7 |
| December | 75.5 | 25.6 | 99.9 | 19.3 |

**Table 3. Monthly OEE measurement for 2012 (%) using factory production records book**

| Months | Availability | Performance | Quality | OEE |
|---|---|---|---|---|
| January | 77.7 | 26.38 | 100 | 20.5 |
| February | 80.7 | 28.31 | 99.8 | 22.8 |
| March | 80.2 | 29.42 | 99.6 | 23.5 |
| April | 78.8 | 29.09 | 99.9 | 22.9 |
| May | 82.1 | 23.31 | 99.8 | 19.1 |
| June | 80.8 | 22.67 | 99.9 | 18.3 |
| July | 79.7 | 31.40 | 99.9 | 25.0 |
| August | 82.4 | 28.91 | 99.9 | 23.8 |
| September | 81.0 | 31.14 | 99.9 | 25.2 |
| October | 80.2 | 23.71 | 99.9 | 19.0 |
| November | 78.4 | 34.47 | 99.9 | 27.0 |
| December | 81.7 | 29.65 | 99.9 | 24.2 |

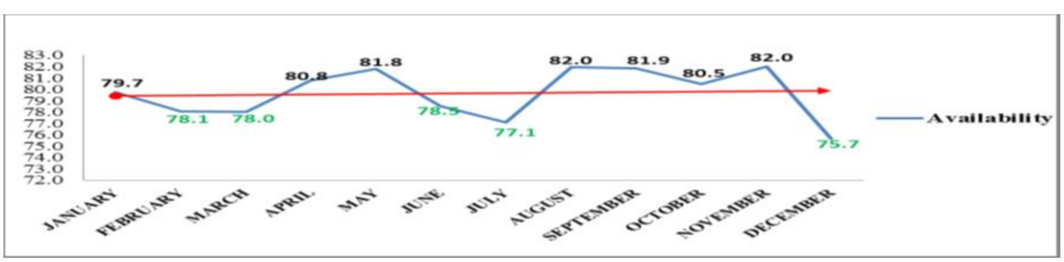


**Fig. 2. Average monthly availability in 2013 using Table 3**

months, with the months of March, June and July showing the lower average availability [10]. To find the reason of these down-times, detailed downtime analysis of these months is required. From Fig. 3, the month of December depicts the lowest availability figure, which showed that the technique was not followed. Comparing the two years trends, the trend in 2012 is eighty percent and that of 2013 had exceeded eighty-one percentages. The two years trends signify improper management and poor strictly follow-up of the maintenance program.

Also the availability figure in Fig. 3 show that January has the lowest value because of the take-off of TPM program and later the value rises. The rise depicts the improvement of TPM program [10]. By plotting the average monthly availability in 2012, the following graph is obtained as shown in Fig. 4.

Using the comparison for monthly OEE values from the Overall Equipment Efficiency measurement in Fig. 4, the monthly OEE of 2013 was higher than of 2012 because of the consistence follow-up through the impact of TPM's implementation of two pillars, autonomous maintenance and scheduled maintenance implementation only.

To identify the downtimes factors from Fig. (1), by using Pareto's principle, the model depicts that twenty percentages (20%) of the down-time parameters actually resulted to about eighty percentages (80%) of the overall down-time parameters, which also resulted to lower availability rates in the months of April, July, and November as modeled in Fig. (5) respectively [10]. Data in Table (4) depicts the cumulative percentages of downtime analysis for the affecting months [10,5].

Using the data of Table 5, a Pareto's model is shown in Fig. 5.

Since the planned/scheduled maintenance has the unavoidable nature of the program and also the equipment breakdown loss can be minimized or reduced. The Pareto's model in Fig. 5, depicts that the two factors (planned/scheduled maintenance and equipment/machine breakdown losses) has the major causes of about seventy-five (75%) percentages of the total downtime losses of the equipment with lower availability values in February, March, June and July in Fig. 2 respectively, as model in Fig. 6 accordingly [10].

Similarly, since the planned maintenance and equipment breakdown losses are unavoidable factors, which has resulted over seventy-five to eighty percentages of the overall down-time factors of the equipment, while the other factors amount only twenty-five percentages of machine breakdown for the two years trends (2012 and 2013).Then the down-time factor for the month of July has been categorized using Table (4) and presented in Table (5) [10].

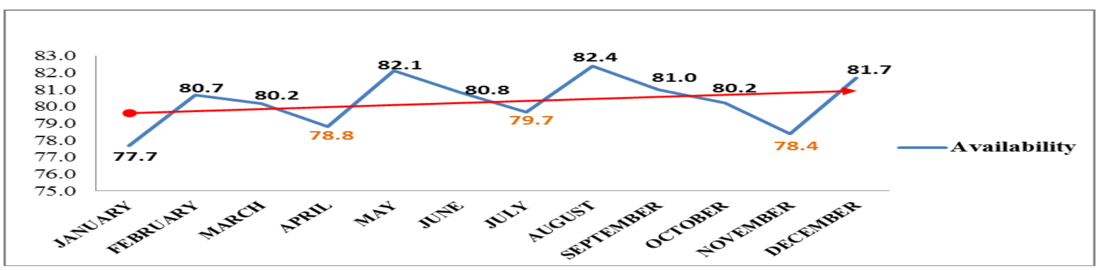


**Fig. 3. Average monthly availability in 2012 using table 4**

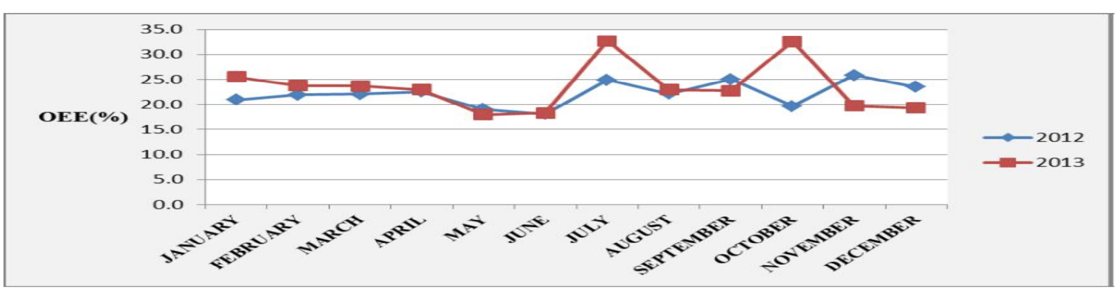


**Fig. 4. Comparison between monthly OEE values for 2012 and 2013**

**Table 4. Percentage analysis in April, 2012 for the production downtime in minutes**

| Downtime factors | Downtimelosses (Min) | Percentage of losses | Cumulative Percentage |
|---|---|---|---|
| Scheduled maintenance | 22331 | 43.61 | 43.61 |
| Machine Breakdown | 13370 | 26.11 | 69.72 |
| Ink Preparation | 4354 | 8.51 | 73.46 |
| Changing Job | 3539 | 6.91 | 81.96 |
| Waiting for material | 2970 | 5.80 | 87.76 |
| Meeting and Training | 1915 | 3.74 | 94.67 |
| Power failure | 1531 | 2.99 | 96.59 |
| Waitingfor instruction | 981 | 1.92 | 97.01 |
| Plate error | 215 | 0.42 | 100.00 |
| Poor reading (quality check) | 0 | 0 | 100.00 |

**Table 5. Downtime analysis of July 2012 and 2013 [10]**

| Downtime loss events | Downtimes loss in 2012(min) | Downtimes loss in 2013(min) |
|---|---|---|
| Planned downtimes losses | 20824 | 19904 |
| Unplanned downtimes losses | 16165 | 2431 |
| Process downtimes losses | 5894 | 3625 |
| Personnel downtimes losses | 2090 | 1260 |

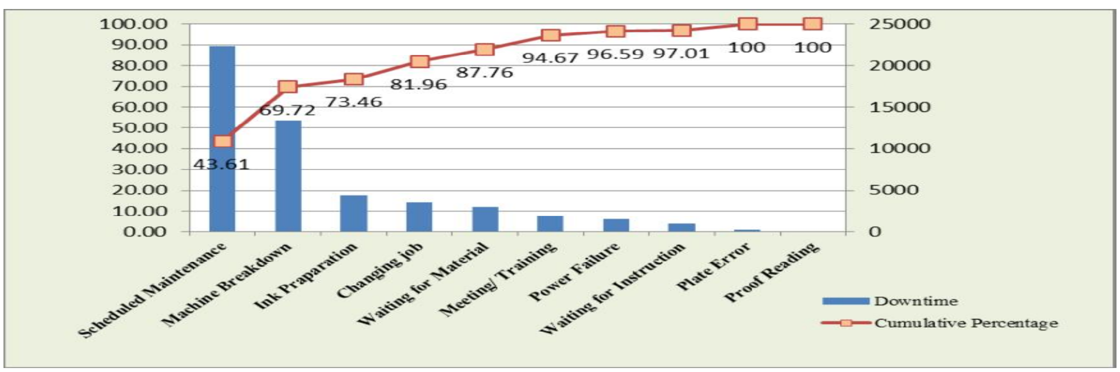


**Fig. 5. Pareto Chart of April, 2012 using table 5**

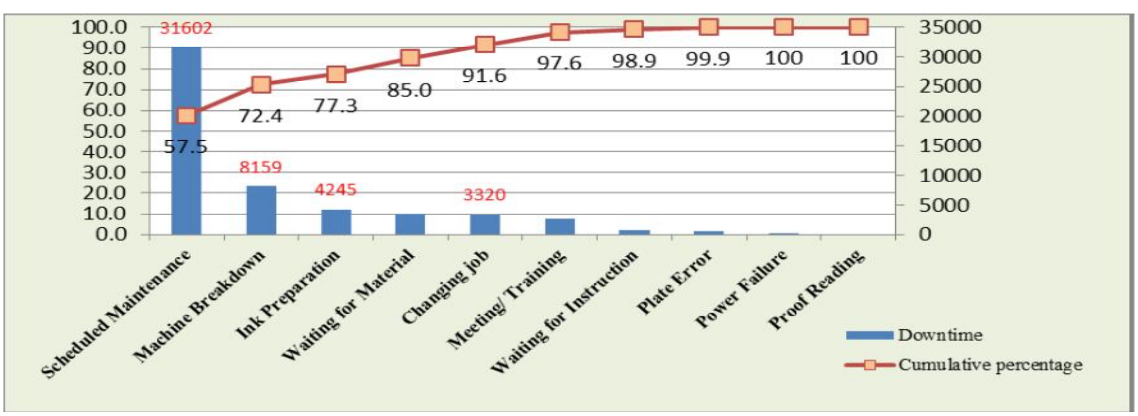


**Fig. 6. Pareto Chart of March, 2013 using table 5**

From July 2012 to 2013, comparative analysis of down-time in Table (5) depicts a sharp reduction of all the down-time factors. For instance, using Table (5), the planned maintenance down-times values of 2012 has reduced from 20824 to 19904 of 2013 down-times, for unplanned down-times values of 2012 has reduced from 16165 to 2431 of 2013 down-times, also for process down-times, values of 2012 has reduced from 5849 to 3625 of 2013 down-times and finally for personnel downtimes values of 2012 has reduced from 2090 to 1260 of 2013 down-times. The values show that all the downtime factors have reduced in 2013.

The analysis of the study signifies a significant improvement and a progressive impact of total productive maintenance of the system through the overall equipment efficiency.

## 5. CONCLUSIONS

This study concludes that:

- Evaluation of TPM should be consistently practice for optimizing the overall operational function and accordingly OEE is justified performance evaluation methods in the manufacturing industries systems effectiveness and performance.
- From the overall analysis, it depicts a sharp reduction of all the down-time factors from 2012 to 2013 and the OEE rate has silently appreciated from 2012 to 2013 respectively.
- The management and maintenance group should always target total implementation of the eight pillars of TPM to bring the value of OEE to world class standard of 85%.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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