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Evaluation of Total Productive Maintenance Implementation in a Selected Semi-Automated Manufacturing Industry

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ABSTRACT: *Manufacturing industries around the world spend a lot of money on buying new equipment to increase production but a little is done to get hundred percent output from the machine. However, because of increased competency levels and demand of quality products at lower costs, buying latest equipment is not a solution unless it is fully utilized. Therefore machine maintenance and in general, implementing an appropriate maintenance strategy has become increasingly important for manufacturing companies to accomplish these requirements. Total productive maintenance (TPM) has become one of the most popular maintenance strategies to ensure high machine reliability since it is regarded as an integral part of Lean Manufacturing. Performance evaluation is the most important aspects in the field of continuous improving of the production process and overall equipment effectiveness (OEE) is one of the justified performance evaluation methods that is popular in the manufacturing industries to assess the machine's effectiveness and performance. In this concern, this research work has been conducted in a selected semi-automated manufacturing industry to study and evaluate the implementation of autonomous maintenance and planned maintenance pillars of TPM. After the OEE measurement, it has been benchmarked with the world class OEE. Pareto and statistical analysis of downtimes were performed to show the most affecting downtime factors hierarchically. Based on the obtained results, maintenance management and production planning have been suggested to improve their maintenance procedures and the productivity as well.*

Keywords: *Maintenance management, Maintenance strategy, Overall Equipment Effectiveness, Pareto analysis, Total Productive Maintenance.*

I. Introduction

Total productive maintenance (TPM) is a holistic approach to equipment maintenance that strives to achieve perfect production:

- No breakdowns
- No small stops or slow running
- No defects

In addition it values a safe working environment:

- No accidents

TPM emphasizes proactive and preventative maintenance to maximize the operational efficiency of equipment. It blurs the distinction between the roles of production and maintenance by placing a strong emphasis on empowering operators to help maintain their equipment. The TPM system addresses production operation with a solid, team-based program, i.e. - proactive instead of reactive. It helps to eliminate losses, whether from breakdowns, defects or accidents [1].

1.1 TPM Pillars

The implementation of a TPM program creates a shared responsibility for equipment that encourages greater involvement by plant floor workers. In the right environment this can be very effective in improving productivity.

Total productive maintenance (TPM) which is one of the key concepts of lean manufacturing provides a comprehensive, life cycle approach, to equipment management that minimizes equipment failures, production defects, and accidents. It involves everyone in the organization, from top level management to production mechanics, and production support groups to outside suppliers. TPM developed as a spin-off that focused more on equipment efficiency. Total Productive Maintenance has eight pillars.

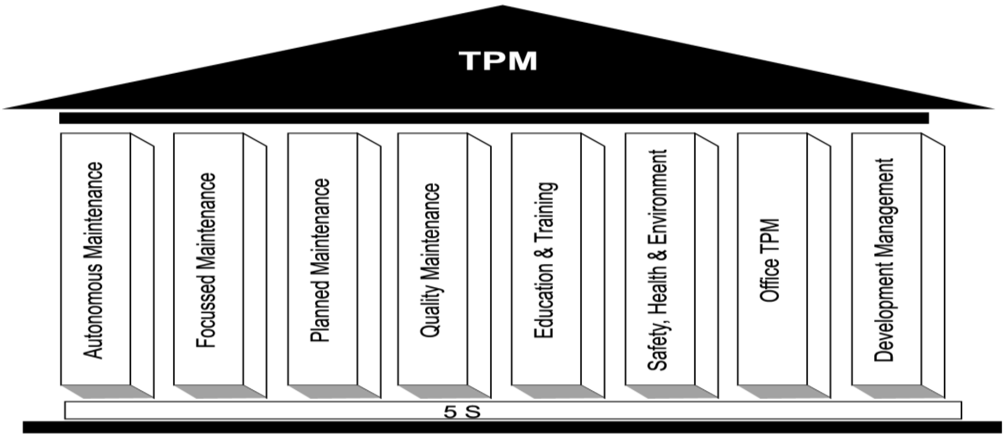

Figure 1: Eight pillars approach for TPM implementation

1.1.1 Autonomous Maintenance

The term autonomous doesn't mean performing maintenance in a vacuum or solely by the traditional maintenance department. Rather, it means that operators perform certain equipment maintenance activities and that maintenance crafts get closely involved in the daily operation of equipment. There are two types of tags used, namely- red tag and yellow tag. Red tag is used to represent the scenario that requires highly technical knowledge while yellow tag is used for simple condition which does not require highly technical knowledge.
Patra et.al. stated that employees have the ability to “detect abnormality” with regard to services and equipment, based on a feeling that “there is something wrong” on work [2]. This pillar is geared towards developing operators to be able to take care of small maintenance tasks, thus freeing up the skilled maintenance people to spend time on more value added activity and technical repairs. The operators are responsible for upkeep of their equipment to prevent it from deteriorating.

1.1.2 Planned Maintenance

Planned preventive maintenance (PPM) or more usual just planned maintenance (PM) or scheduled maintenance is any variety of scheduled maintenance to an object or item of equipment. Specifically, planned maintenance is a scheduled service visit carried out by a competent and suitable agent, to ensure that an item of equipment is operating correctly and to therefore avoid any unscheduled breakdown and downtime. It is aimed to have trouble free machines and equipment producing defect free products for total customer satisfaction. This breaks maintenance down into four families or groups which are noted below.

- preventive maintenance
- breakdown maintenance
- corrective maintenance
- maintenance prevention

1.2 Pareto Chart

In 1906, Italian economist V. Pareto created a mathematical formula to describe the unequal distribution of wealth in his country, observing that twenty percent of the people owned eighty percent of the wealth. In the late 1940s, Dr. Joseph M. Juran inaccurately attributed the 80/20 Rule to Pareto, calling it Pareto's Principle [3]. This technique helps identify the top portion of causes that need to be addressed to resolve the majority of problems. While this neither is common to refer to Pareto as "80/20" rule, under the assumption that, in all situations, 20% of causes determine 80% of problems, this ratio is merely a convenient rule of thumb and is not nor should it be considered immutable law of nature.

1.3 Paired Samples t-test

The paired samples *t-test* compares the means of two variables. It computes the difference between the two variables for each case, and tests to see if the average difference is significantly different from zero.

Assumption

- Both variables should be normally distributed.

Hypothesis

Null: There is no significant difference between the means of the two variables.
Alternate: There is a significant difference between the means of the two variables.

If the significance value is less than .05, there is a significant difference. If the significance value is greater than .05, there is no significant difference [4]. The paired sample *t-test*, Pearson correlation, partial correlation and other analysis can be performed by different computer programs. These programs are Microsoft Excel, SPSS, Stata, SAS and R.

1.4 Review of the Past Works

A paper was published on "Implementation of Total Productive Maintenance and Overall Equipment Effectiveness Evaluation" by - Islam H. Afefy, Industrial Engineering Department, Faculty of Engineering, Fayoum University, Al Fayoum, Egypt, in the year January 2013. This paper focused on a study of total productive maintenance and evaluating overall equipment effectiveness. A study was conducteded on "Total Productive Maintenance Review and Overall Equipment Effectiveness Measurement" by - Osama Taisir R.Almeanazel, Department Of Industrial Engineering, Hashemite University, Zarqa, 13115 Jordan, in September 2010. This paper emphasized the goals and benefits of implementing Total Productive Maintenance and also focused on calculating the overall equipment effectiveness in one of Steel Company in Jordan. Another paper was published on "Implementation of Total Productive Maintenance on Haldex Assembly Line" by - Zahid Habib and Kang Wang, Department of Production Engineering, Royal Institute of Technology, Sweden, in March, 2008. The core of this thesis was doing a study on assembly line of automatic brake adjusters at Haldex Brake Products and autonomous maintenance were described with a list of daily and weekly checks of the equipment's and whole assembly line to implement total productive maintenance. A research work was accomplished on "The initiation of Total Productive Maintenance to a pilot production line in the German Automobile industry" by – Daniel Ottoson, Luleå University of Technology, Sweden, in October 2009. In this research, a task force had been introduced called TPM-commando, specialized in eliminating the major losses and rendered a continuous improvement process to be applied.

II. Methodology

2.1 Overall Equipment Effectiveness

OEE is an abbreviation for the manufacturing metric overall equipment effectiveness (OEE). OEE takes into account the various sub components of the manufacturing process – availability, performance and quality. This percentage can be viewed as a snapshot of the current production efficiency for a machine, line or cell.

OEE= Availability x Performance Rate x Quality Rate

2.1.1 Availability

Availability takes into account down time loss, and is calculated as: Availability = $\frac{\text{Operating time}}{\text{Planned run time}}$*100%.

Here, planned production time is defined as the total time that equipment is expected to produce [5].
So, planned production time or run time = Available time – (Breakdown + Set up).

During the available time, equipment may be not operating for a number of reasons: planned breaks in production schedule, planned maintenance, precautionary resting time, lack of work and others. So, if there is any planned downtime, this should be subtracted from the available time and what is left is the active time.

Active time is the time during which an equipment is actually scheduled to operate and available for production.
So, active time = available time – planned downtime
During the Active time, however:

- Equipment may be subject to Break-downs and/or
- Equipment may need to be Set-up

If breakdown and/or set-up occur, their corresponding duration in time must be subtracted from the active time, and what is left is the operating time.

Operating time is the time during which equipment actually operates [6].
Operating time = active time – (breakdown + Set up)
= available time – (planned downtime + breakdown + set up)
= actual Capacity time – total Downtime
Now, considering the above mentioned formula for planned run time and operating time:
Operating time = available time – (breakdown + set up) –planned downtime
= planned run time – planned Downtime
So, Availability is calculated using the given formula below.

Availability = $\frac{\text{Planned run time} - \text{Planned Down time}}{\text{Planned run time}}$ *100 %

When downtime losses are zero, the availability is 1 or 100%, the gross operating time equals the available time for production. In other words, the installation throughput equals zero at no point of time, during the available time for production [7].

2.1.2 Performance Rate

The performance only concerns the gross operating time. A property of the gross operating time is that the speed exceeds zero at any time. There are no down time losses in the gross operational time. The performance factor is a measure for the speed losses.

Performance Rate = $\frac{\text{Planned run time} - \text{Planned Down time}}{\text{Planned run time}}$ *100% = ideal cycle time / (operating time / total pieces)

Ideal cycle time is the minimum cycle time that the process can be expected to achieve in optimal circumstances.

Design cycle time = $\frac{\text{Daily average planned run time}}{\text{Daily average target of production}}$.

It is sometimes called design cycle time, theoretical cycle time or nameplate capacity [8].

2.1.3 Quality Rate

During the net operational time, no down time or speed losses occur. It is not certain that the total produced output is conform quality specifications. To gain insight into this, the quality factor is defined:

Quality Rate = $\frac{\text{Total output} - \text{Average reject}}{\text{Total output}}$ *100%

= $\frac{\text{Good pieces}}{\text{Total pieces}}$*100%

The individual value of the three effectiveness factors lies between 0 and 1. Measuring these effectiveness factors independently, a satisfactory value would be 0.9 or 90%. The value of the OEE is in this specific case = 0.9 x 0.9 x 0.9 = 0.73.

Rate of expected OEE=availability (100 %)*performance rate*quality rate

The practice of maximizing Overall equipment effectiveness (OEE) involves taking a structured approach to minimizing the six major losses that impact upon these three factors [9].

2.2 World Class OEE

OEE is essentially the ratio of fully productive time to planned production time (refer to the OEE factors section for a graphic representation). In practice, however, OEE is calculated as the product of its three contributing factors:

OEE = availability*performance*quality

This type of calculation makes OEE a severe test. For example, if all three contributing factors are 90.0%, the OEE would be 72.9%. In practice, the generally accepted world-class goals for each factor are quite different from each other, as is shown in the Table 1 below.

Table 1: World class OEE rate

OEE Factor	***World Class Rate***
Availability rate	>90.0%
Performance rate	>95.0%
Quality rate	>99%
OEE	85.0%

Every manufacturing plant is different. Worldwide studies indicate that the average OEE rate in manufacturing plants is 60%. From the above TABLE 1, a world class OEE is considered to be 85% or better.

Table 2: Comparative world class OEE rate for various industries

Industry	***OEE set from top-level***	***Total OEE***
Manufacturing	85%	60%
Process	> 90%	> 68%
Metallurgy	75%	55%
Paper	95%	> 70%
Cement	> 80%	60%

The above Table 2 shows top-level OEE and total OEE values for different types of industries [10].

III. Analysis and Discussion

Avery Dennison Bangladesh Ltd. is a printing and packaging industry. From the very beginning of 2012, this company had started the practicing of autonomous maintenance and planned maintenance in the Offset sections' machines. Necessary data were collected from questionnaire, production data and factory complaint sheet to evaluate the impact of TPM practising.

3.1 Overall Equipment Effectiveness Calculation

Here OEE has been used to determine the effectiveness of the offset section machines.

3.1.1 Daily Availability Calculation

Firstly, daily average availability has been calculated for the existing machines in the floor. As for example, for a particular machine (Name: L-1) of type GTO, the following information regarding operations of the machine on day Jan 6th, 2013 have been collected.

Actual capacity time = 600 min.

Total downtime (sum of loss time) = 130 min. In this offset printing section set up time is zero.

Planned downtime = Total downtime – (breakdown time + set up) = 130-60 = 70 min.

Planned run time = 540 min.

Operating time = Planned run time – Planned downtime = 470-200 = 270 min.

Therefore- Availability = $\frac{\text{Operating time}}{\text{Planned run time}}$*100% = $\frac{470}{540}$ *100% = 87.037%

= 87.04% (approx.) of machine L-1 on day Jan 6th, 2013.

Calculating operating time and planned run time, daily average availability for every machines existing on that floor has been measured. Daily availability has been calculated by taking the average of equipment availability for 6th Jan, 2013.After calculating the equipment daily availability average daily availability for that month has been calculated similarly. Availability for every month, in the years 2012 and 2013, has also been measured in this way.

3.1.2 Daily Target of Production

As for example, for a particular machine (Name: L-3) of type GTO, the following information regarding operations of the machine on day Jan 6th, 2013 have been collected.

Number of impression sheet produced (per hour), according to machine type = 3000.

Number of label produced (per sheet) = 20

Quantity of label produced = No. of impression sheet produced (per hour)* Label quantity (per sheet)

=3000*20 = 60000 units

Operating time (hour) = $\frac{480}{60}$ = 8 hours

Daily target of production = Operating time (hour)* Label quantity produced

= 8*60000 = 480000

3.1.3 Daily Performance Rate Calculation

For a particular machine (Name: L-3) of type GTO, the following information regarding operations of the machine on day Jan 6th, 2013 have been collected.

Design cycle time = $\frac{\text{Daily average planned run time}}{\text{Daily average target of production}}$ = $\frac{480}{480000}$ = 0.001

Actual run time = Operating time = 480 minutes

So performance rate = $\frac{\text{Design cycle time} * \text{Quantity produced}}{\text{Actual run time}}$ *100%.

= $\frac{0.001 * 60000}{480}$ *100% = 19.016% (approx.) for L-3 machine in Jan 6th, 2013.

3.1.4 Monthly Quality Rate Calculation

Quality rate is defined as the ratio of accepted output over total output.

Quality Rate = $\frac{\text{Total output} - \text{Rejected quantity}}{\text{Total output}}$ *100%.

As for example, for every machine in the selected Offset printing section, the following information regarding operations of the machines on month January, 2013 have been collected.

Total output = 37620606 units.

Rejected quantity = 74491 units

Quality rate = $\frac{37620606 - 74491}{37620606}$*100 = 99.80199

= 99.80% (approximate)

Similarly quality rate of these years 2012 and 2013 has been measured.

3.1.5 OEE Measurement for Two Years

Calculating the three factors of OEE such as availability, performance rate and quality rate monthly, OEE for two years have been measured. As for example, availability, performance rate and quality rate of the machines in offset printing section have been measured for January, 2013.

Availability rate = 79.7%

Performance rate = 32.1% and

Quality rate = 99.8%

So OEE = availability*performance rate*quality rate = (79.7*32.1*99.8) % = 25.5%

Taking the availability as one hundred percent, rate of expected OEE has been measured. As for example, expected OEE rate of the selected Offset printing section have been measured on month January, 2013. Availability rate = 100%. So rate of expected OEE = (100*32.1*99.8) % = 29.6%

Expected OEE rate was 29.6% in January, 2013. Here, monthly OEE measurement for 2012 is shown in Table 3.

Table 3: OEE measurement in 2013

Months' Name	***Availability (%)***	***Performance rate (%)***	***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	82.0	24.1	99.9	19.7
December	75.7	25.6	99.9	19.3

In 2013, average OEE was 23.5% and expected OEE could be 29.5% if the equipment were cent percent available.

Plotting the avg. monthly availability in 2012, following graph is drawn below.

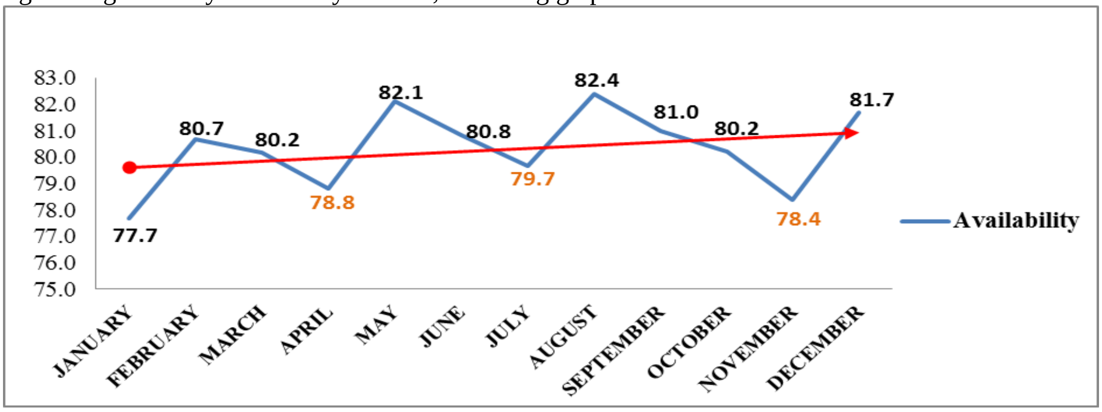

Figure 2: Average monthly availability in 2012

It has been identified from the Figure 2 that the availability in January was the lowest as the TPM program has just been launched. Afterwards, availability was increasing which implied the effect of TPM launching but comparatively lower availability rate have been found in April, July and November which required detailed analysis of downtimes for corresponding months. Plotting the avg. monthly availability in 2013, following graph is drawn.

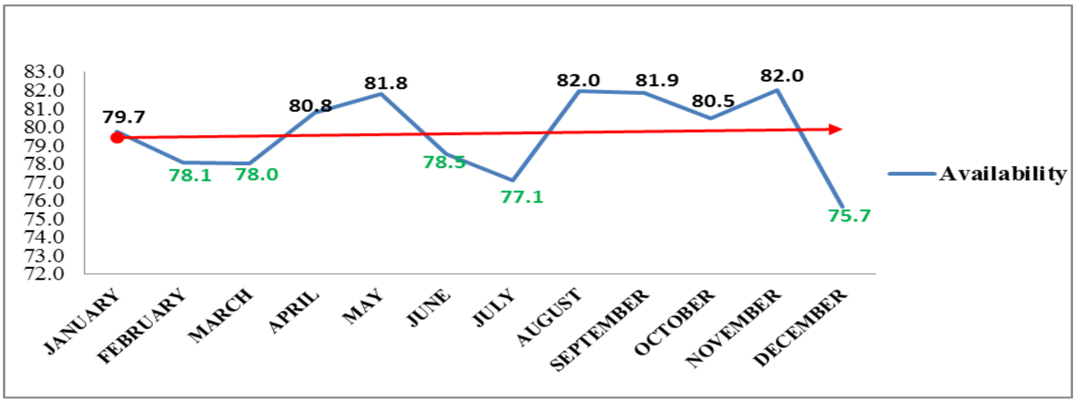

Figure 3: Average monthly availability in 2013

The following facts have been revealed from Fig. 3 regarding the monthly availability values. The availability figures in February, March, June and July have been found comparatively lower than the average availability. In order to identify the causes behind these findings it is required detailed downtime analysis of those months. The lowest availability in December showed the TPM program was not maintained properly. The trend line of 2012 was just reaching 80% whereas trend line of 2013 had exceeded 81%. Trend lines of two years reflect the inadequate practice of autonomous maintenance and planned maintenance.

The comparative scenario of monthly OEE values for the years of 2012 and 2013 is exhibited in Figure 4.

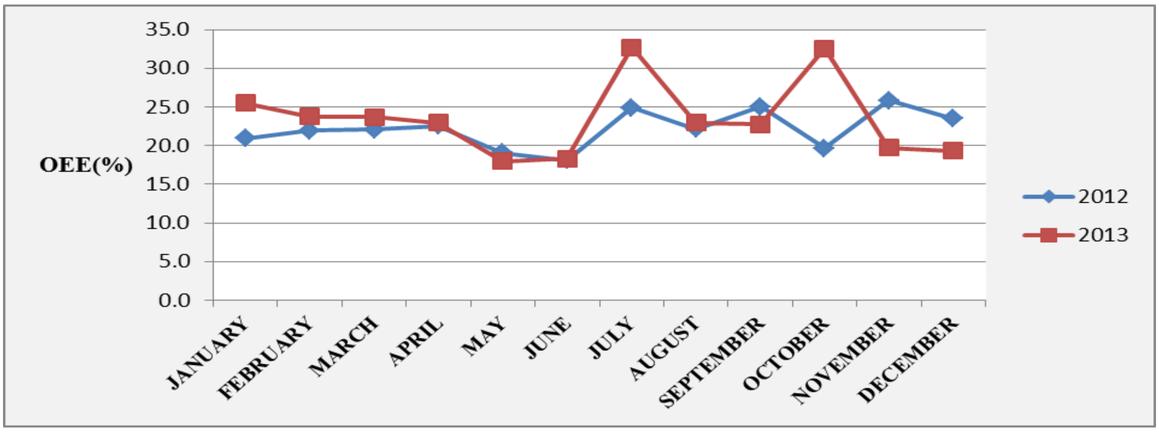

Figure 4: Comparison between monthly OEE values for 2012 and 2013

3.1.6 Discussion on OEE analysis

It has been found that from the OEE measurement and comparative analyses of OEE monthly OEE of 2013 was slightly upper than of 2012 because it was the impact of TPM's implementation of two pillars, autonomous maintenance and planned maintenance implementation. Consistent OEE has been achieved for both years at first quartile which showed the co-ordination of planning and production. Significant lower OEE rate for May, June months for both years because of lacking in the coordination among planning, production and maintenance which resulted in lower performance rate though the availability rate was higher. Downward direction of OEE rate, at the end of year 2013 (November and December), shows that irregular AM and PM practicing.

3.2 Downtime Analysis with Pareto Chart

Pareto Analysis has been used in downtime analysis. According to Pareto analysis, around 20% of the downtime factors cause 80% of total downtime. To identify the downtimes that have caused around 80% of total downtime, Pareto chart was drawn. It has been found that comparative lower availability rate was in April, July and November which was shown in Fig. 1. Availability is reversely proportional to downtime. Therefore, Pareto analysis has been performed on the downtimes data for those corresponding months.

Cumulative percentage of downtime has been measured and shown in TABLE 4 below.

Table 4: Cumulative percentage calculation (April, 2012)

Downtime name	Downtime (min.)	Cumulative Percentage
Scheduled maintenance	22331	43.61
Machine Breakdown	13370	69.72
Ink preparation	4354	73.46
Changing job	3539	81.96
Waiting for Material	2970	87.76
Meeting/ Training	1915	94.67
Power failure	1531	96.59
Waiting for instruction	981	97.01
Plate error	215	100.00
Proof reading (quality checking)	0	100.00

Using the data from the above table, a Pareto chart has been drawn and shown in Figure 5 below.

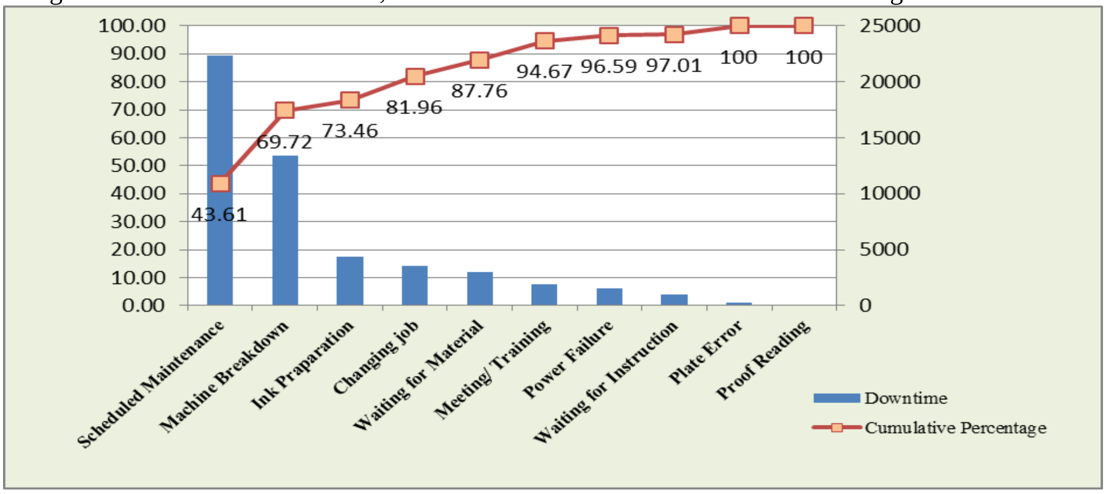

Figure 5: Pareto Chart of April, 2012

From the Pareto chart it has been obtained that scheduled maintenance and machine breakdown have caused around 75% of the total downtime. Whereas scheduled maintenance was unavoidable and machine breakdown could be reduced.

It has been found that comparative lower availability rate was in February, March, June and July which was shown in Fig. 2. Pareto chart on downtime in March, 2013 is drawn among these months.

Using the data from the above table, a Pareto chart has been drawn and shown in Figure 6 accordingly.

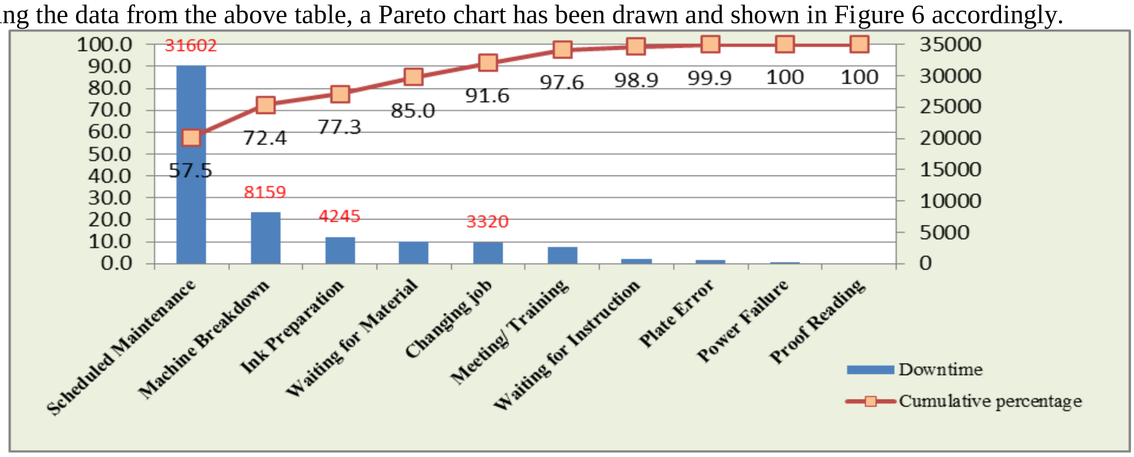

Figure 6: Pareto Chart of March, 2013

From the Pareto chart, it has been obtained that scheduled maintenance and machine breakdown have caused more than 70% of the total downtime. Whereas scheduled maintenance was unavoidable and machine breakdown could be reduced. Individual percentage contribution of machine breakdown was around 20%.

3.2.1 Discussion on Pareto Analysis

It has been found from the Pareto chart analysis of downtimes that scheduled maintenance and machine breakdown have caused around 75% to 80% of total downtime. As scheduled maintenance is part of planned maintenance, it is not avoidable in large extent. Machine breakdown, ink preparation and waiting for material were next prioritizing downtime factors those should be focused for further reduction of total downtime. Machine breakdown was comparative lower for particular months and other downtime factors should be analyzed for downtime reduction.

3.3 Comparative Downtime Analysis for Two Years

The downtimes can be classified into four types considering the causes of downtimes. These types are noted below including relevant downtimes.

1. Planned downtimes that contain scheduled maintenance, meeting/training and proof reading (quality checking).
2. Unplanned downtimes that contain machine breakdown, plate error and power failure.
3. Process downtimes – downtimes due to process deficiencies that include ink preparation and waiting for materials.
4. Personnel downtimes – downtimes due to operator or maintenance personnel deficiencies that include changing job and waiting for instructions.

Considering these four types of downtime for two years, comparative downtime analysis has been performed and given here.

3.3.1 Comparative Downtime Analysis in July

The various downtimes for the month of July for two consecutive years has been calculated and tabulated in Table 6 below and is shown in Figure 7 accordingly.

Table 6: Comparative downtime calculation in July

Downtime type	*Downtime in 2012 (min.)*	*Downtime in 2013 (min.)*
Planned downtimes	20824	19904
Unplanned downtimes	16165	2431
Process downtimes	5894	3625
Personnel downtimes	2090	1260

Percentage of every downtime in total downtime is plotted in the graph below.

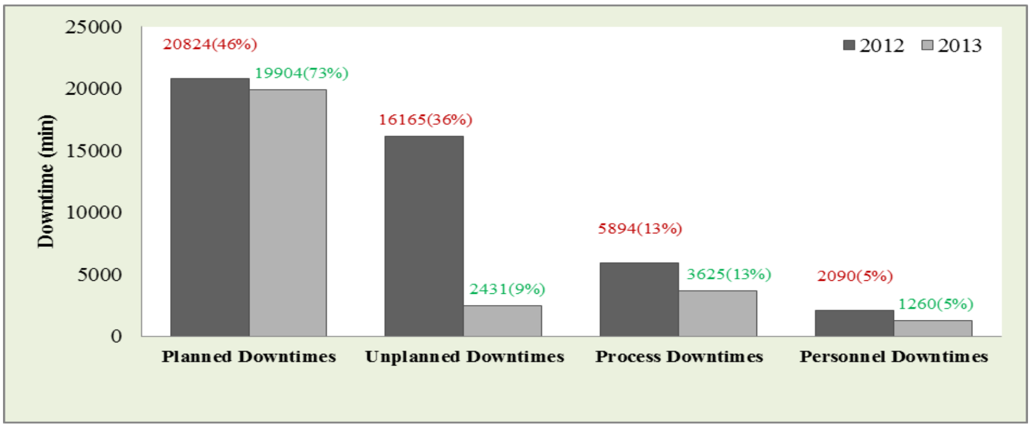

Figure 7: Downtime comparison in July (2012 versus 2013)

From the above Figure 6, the facts being identified are that every downtime has been reduced in 2013. Unplanned downtimes, process downtimes and personnel downtimes were reduced significantly. As scheduled maintenance was being practiced, maintenance checklist maintained effectively, unplanned downtimes were reduced significantly.

3.3.2 Overall Comparative Analysis of Downtimes in Year 2013

Scheduled Maintenance from planned downtimes, machine breakdown from unplanned downtimes, ink preparation from process downtimes and changing job from personnel downtimes in February, March, June, July and November with the position in corresponding Pareto chart has been tabulated in Table 7 below from the analysis of corresponding Pareto charts.

Table 7: Overall Analysis of Pareto Charts in 2013

Downtime (min.)	*February*	*March*	*June*	*July*	*November*
Scheduled Maintenance	24382	31602	21618	17835	19315
Machine Breakdown	6155	8159	5440	2151	7362
Position in the Pareto chart	Second	second	second	third	Second
Ink preparation	3015	4245	1475	2160	4080
Position in the Pareto chart	third	third	fourth	second	Third
Changing job	2660	3320	1445	1110	2585
Position in the Pareto chart	Sixth	fifth	sixth	Sixth	Fifth

3.4 Ranking of the different Downtimes based on Individual Percentage Contribution and Paired t- test Analysis

To identify the most affecting and contributing downtime in total downtime, ranking of the downtime has been done. Ranking has been performed in two ways- based on percentage contribution and *t-test* data interpretation.

3.4.1 Individual Percentage of Contribution Calculation

To measure the individual contribution of every downtime this formula is used. Individual percentage of contribution = $\frac{X_i}{\sum_i^n X_i}$ *100% = $\frac{\text{Individual Downtime}}{\text{Total Downtime}}$*100%.

As for example, percentage contribution of meeting/training in total downtime has been measured, by collecting the following in 2012. Meeting/training = 32633 min. Total downtime = 580957 min.

So, percentage contribution of meeting/training = $\frac{32633}{580957}$*100% = 5.6% of total downtime. Similarly percentage contribution for every downtime for both years has been measured.

3.4.2 Ranking of Downtimes Based on Percentage of Individual Contribution

According to hierarchical sequence of individual contribution, different downtimes have been ranked. To establish a chronological order of all downtimes according to their contribution and inter-dependability, ranking of all downtime was needed. As Scheduled maintenance contributed the most, this was ranked as First.

Table 8: Ranking on Contribution (Year: 2012)

Downtime type	**Downtime**	**Percentage**	**Rank**
Scheduled maintenance	272966	47.0	1
Breakdown	146169	25.2	2
Waiting for material	41125	7.1	3
Ink preparation	39535	6.8	4
Meeting/training	32633	5.6	5
Changing job	30809	5.3	6
Waiting for instruction	7256	1.2	7
Power failure	5497	0.9	8
Plate error	4617	0.8	9
Proof reading	350	0.1	10

3.4.3 Paired Comparison t-test Analysis of Downtimes (2012)

Comparing all variable (downtime) with each other using SPSS software, a two-tailed alternative hypothesis test has been performed.

Table 9: t-test Data Interpretation (Year: 2012)

Downtime type	**Highest value of "*t*"**	**Lowest value of "*t*"**	**Level of significance for highest "*t*" value**	**Valid value within confidence level (< .05)**	**Rank**
Scheduled Maintenance	17.614	5.189	.0000000021	9	1
Machine breakdown	12.776	7.876	.0000000609	8	2
Waiting for material	13.560	.395	.0000000328	5	3
Ink preparation	8.458	1.155	.0000038314	4	4
Meeting /training	7.327	.381	.0000149037	4	4
Changing Job	12.002	8.497	.0000001161	4	4
Waiting for Instruction	5.193	.728	.0002978488	1	5
Plate error	3.226	-.329	.0080738508	1	5
Power Failure	2.602		.0245870693	1	5

Different t-value with the level of significance for 2012 downtimes pair was calculated using SPSS. According to the null and alternate hypothesis, level of significance means the significant changes in mean values.

Table 10: Comparison between t-test ranking and Percentage Contribution ranking (2012)

According to percentage of contribution		According to *t-test*	
Downtime	**Rank**	**Downtime**	**Rank**
Scheduled maintenance	1	Scheduled maintenance	1
Machine breakdown	2	Machine breakdown	2
Waiting for material	3	Waiting for material	3
Ink preparation	4	Ink preparation	4
Meeting/training	5	Meeting/training	4
Changing job	6	Changing job	4
Waiting for instruction	7	Waiting for instruction	5
Power failure	8	Plate error	5
Plate error	9	Power failure	5

If the significance value is less than .05, there is a significant difference. If the significance value is greater than .05, there is no significant difference. Counting the existing pair below the standard level of significance (<.05), most affecting factor (downtime) has been found. Thus, paired t-test analysis has been accomplished for both year downtimes data. Comparing the mean values of every pair the t-value has been obtained, this value showed the dependence factor of all variables. Comparison of the downtime ranking from two ways has been presented in Table 10 below. Similarly performing the individual percentage of contribution calculation and paired *t-test* analysis of every downtime in 2013, ranking of the downtimes based on their comparative inter-dependence has been performed and presented in Table 11 below.

Table 11: Comparison between t-test Ranking and Percentage Contribution ranking (2013)

According to percentage of contribution		**According to *t-test***	
Downtime	**Rank**	**Downtime**	**Rank**
Scheduled maintenance	1	Scheduled maintenance	1
Machine breakdown	2	Machine breakdown	2
Waiting for material	3	Waiting for material	4
Ink preparation	4	Ink preparation	3
Meeting/Training	5	Meeting/Training	4
Changing job	6	Changing job	4
Waiting for instruction	7	Waiting for instruction	5
Power failure	8	Plate error	6
Plate error	9	Power failure	6

From Table 11, it has been identified that scheduled maintenance was the most affecting factor among the downtime factors, which was unavoidable. Machine breakdown was ranked as the second factor which requires rigorous maintenance practices to reduce this. Waiting for materials and ink preparation were the next prioritize factors to be marked according to t-test analysis.

3.4.4 Discussion on Paired t-test

From the Table 10, it has been revealed that ink preparation, meeting/training and changing job factors have been ranked as fourth combined according to t-test that refers to these downtimes have similar dependence over other downtimes. So, kobetsu kaizen (continuous focused improvement) can be used to reduce these downtimes simultaneously. Similar interpretation can be drawn from form Table 11. Percentage of contribution showed the effect of every downtime over total downtime whereas paired t-test interpretation indicated the downtimes to focus at certain priority.

IV. Results And Findings

In this research work different types of analyses have been performed to evaluate the impact of TPM implementation. Corresponding results of these analyses are given below.

4.1 Results of OEE Analysis

Monthly OEE rate for every month in 2012 and 2013 is measured. Following points have been found from the analysis-

- In 2012, Avg. OEE was 22.4% whereas it had changed to 23.5% in 2013.
- In 2012, Avg. of expected OEE was 27.6% whereas it had changed to 29.6% in 2013.
- Highest monthly OEE rate was in July, 2013.
- Lowest monthly OEE rate was in May, 2013.

4.2 Results of Downtime Analysis

Pareto chart for comparatively lower availability rate indicating months' are drawn. Following facts have been found from the analysis-

- Scheduled maintenance and machine breakdown have caused around 80% of total downtime.
- Ink preparation, meeting/training and waiting for material were the next level of affecting downtimes in most of the months.
- According to *t-test*, fourth level of downtimes' was ink preparation, meeting/training and changing job in 2012.
- According to *t-test*, fourth level of downtimes' was waiting for material, meeting/training and changing Job in 2013.

V. Conclusions

Performance evaluation is the most important aspects in the field of continuous improving of the production process and accordingly overall equipment effectiveness (OEE) is one of the justified performance evaluation methods that is popular in the manufacturing industries to assess the machine's effectiveness and performance. In this concern, this research work has been conducted in a selected semi-automated manufacturing industry to study and evaluate the implementation of autonomous maintenance and planned maintenance pillars of TPM. This case-study research has extracted an overall scenario of machine effectiveness, key downtime causes during the total productive maintenance (TPM) practice in the selected industry. In order to gain a reasonable market share as well as to sustain in the present competitive market, it is necessary to improve the productivity level of any manufacturing industry. Overall equipment effectiveness (OEE) has been measured because it helps to take subjective decision in strategic level of any manufacturing organization. It has been found from the study that OEE rate was 22.4% in 2012 and 23.5% in 2013 whereas world class OEE for similar type industry is 68%.

Availability was quite satisfactory comparing world class rate and quality rate resemble the world class rate. Average OEE rate increment was 4.6% from 2012 to 2013. But average availability was reduced in 2013 from 80.3% to 79.9% which shows the deterioration of maintenance practices.

Different downtimes of machines are non-value adding activity. This non-value added time is the scope of improvement for a company. Pareto chart of all downtimes has been analyzed monthly. Some downtimes were unavoidable, inter-dependent and partially avoidable. Statistical analysis of downtimes focuses on the prioritized downtime factors to consider for reduction of downtime. Applying modern maintenance practices and production improvement techniques the downtime of machines can be reduced to some extent.

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