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Assessment of Total Productive Maintenance Implementation through Downtime and Mean Downtime Analysis (Case study: a Semi-automated Manufacturing Company of Bangladesh)

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Abstract :- 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. One of the main objectives of TPM is to increase the overall equipment effectiveness of plant equipment with a modest investment in maintenance. Companies around the world spend a lot of money on buying new machinery to increase the production, however a little is done to get hundred percent output from the machines. Nevertheless, because of increased competition 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 particular, implementing an appropriate maintenance strategy has become increasingly important for manufacturing industries to fulfill these requirements. In this regard, this paper has focused on a case-study work with the aim of evaluating the effects of total productive maintenance implementation onto the existing production scenario of a selected semi-automated manufacturing company of Bangladesh by measuring downtime and mean downtime reduction and performing mean downtime analysis (MDT). Pareto analysis and statistical analysis of downtime data have been conducted to identify the most affecting downtime factors hierarchically. Based on the results summarized, modern maintenance management and production improvement techniques have been suggested to improve the maintenance procedure and at the same time to enhance the volume of production as well.

Keywords: - *Autonomous maintenance, Mean downtime, Pareto chart, T-test, Total productive maintenance.*

I. INTRODUCTION

Total Productive Maintenance (TPM) is a maintenance philosophy designed to integrate equipment maintenance into the manufacturing process. It is a system of maintaining and improving the integrity of production and quality systems through the machines, equipments, and processes that add business value to the organization.TPM focuses on keeping all equipment in perfect working condition to avoid breakdowns and delays in the manufacturing process. In addition, it strives to achieve no small stops or slow running and no defects during production as well as it values a safe working environment.

Total productive maintenance is considered as the key operational activities of the quality management system. It 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 Implementation

The steps involved in the implementation of TPM in an organization are initial evaluation of TPM level, introductory education and propaganda (IEP) for TPM, formation of TPM committee, development of master plan for TPM implementation, stage by stage training to the employees and stakeholders on all eight pillars of TPM, implementation preparation process, establishing the TPM policies and goals and development of a road map for TPM implementation. The implementation of a TPM program creates a shared responsibility for equipment that encourages greater involvement by production floor workers. In the right environment this can be very effective in improving the productivity of plant.

Total productive maintenance has eight pillars as shown in Fig. 1 below.

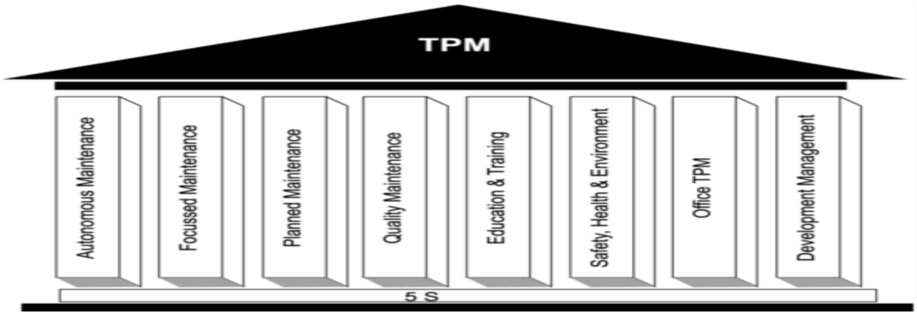

Fig. 1 Eight pillars approach for TPM implementation

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/support groups to outside suppliers.

1.1.1 Autonomous maintenance

Autonomous maintenance is "independent" maintenance carried out by the operators of the machines rather than by dedicated maintenance technicians. This is the core concept of TPM that gives more responsibility and authority to the operators and releases the technical personnel to do more preventative maintenance works. It means that operators perform the simpler maintenance routine works and certain equipment maintenance activities. This enables them to feel greater ownership for their work and become more in control of how things are done and what improvements are made. There are two types of F-tags used, namely - red tag and yellow tag. Red tag is used to represent the scenario which requires highly technical knowledge while yellow tag is used for simple indication which does not require highly technical knowledge.

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 [2].

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 Review of Past Research Works

A research 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 [3]. This paper focused on a study of total productive maintenance and evaluating overall equipment effectiveness (OEE). A study was conducted on "Total Productive Maintenance Review and Overall Equipment Effectiveness Measurement" by - Osama Taisir R. Almeanazel, Department Of Industrial Engineering, Hashemite University, Zarqa, Jordan, in September 2010 [4]. This paper emphasized the goals and benefits of implementing Total Productive Maintenance and also focused on measuring the overall equipment effectiveness in one of Steel Companies 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 [5]. The core idea of this thesis work was to have conducted 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 the year October 2009 [6]. In this research paper, 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. THEORITICAL STUDY

2.1 Pareto Chart

In 1906, Italian economist Vilfredo 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 [7]. This technique helps identify the predominant causes of problems that need to be addressed first to resolve the majority of problems. While it is common to refer to Pareto chart 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.

2.2 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 [8]. The paired sample *t-test*, Pearson correlation, partial correlation and other analysis can be performed by different computer programs, such as Microsoft Excel, SPSS, and SAS etc.

2.3 Mean Downtime

During the available time, equipment may not be operating for a number of reasons - planned breaks in production schedule, planned maintenance, precautionary resting time, lack of work and others. Mean downtime (MDT) is the average of total downtime required to restore an asset to its full operational capabilities. Mean downtime includes the time from the reporting of an asset being down to the time the asset is put back into operations/production to operate. MDT includes active corrective maintenance time, administrative time of reporting, logistics, materials procurement and lock-out/tag-out of equipment, etc. for repair or preventive maintenance [9].

III. ANALYSIS AND DISCUSSION

The studied semi-automated manufacturing company is a leading printing and packaging factory of Bangladesh. From the very beginning of 2012, this company had started the practicing of two significant pillars of TPM, autonomous maintenance and planned maintenance in the Offset sections' machines. Necessary data had been collected through questionnaire as well as from production data and factory complaint sheet.

3.1 Downtime Analysis with Pareto Chart

Pareto chart has been used in downtime analysis. According to Pareto analysis, around 20% of the downtime factors causes 80% of total downtime. A Pareto chart was drawn to identify the predominant downtimes that caused around 80% of total downtime.

From the analysis of average monthly availability for year 2012, it has been revealed that comparative lower availability rate was particularly in April, July and November of 2012. Availability is reversely proportional to downtime. Therefore, Pareto analysis has been performed on the downtimes data of those corresponding months in which comparatively lower availability figures have been identified. Cumulative percentage of downtimes of April 2012 has been calculated and shown in Table 1 below.

Table 1 Cumulative percentage calculation of downtime (April, 2012)

Downtime name	Downtime (Minutes)	Cumulative Percentage of DT (%)
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 plotted and shown in Fig 2 below.

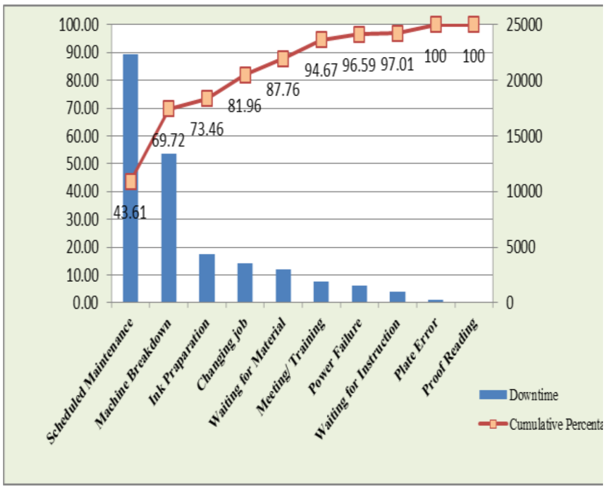

Fig. 2 Pareto Chart of April, 2012

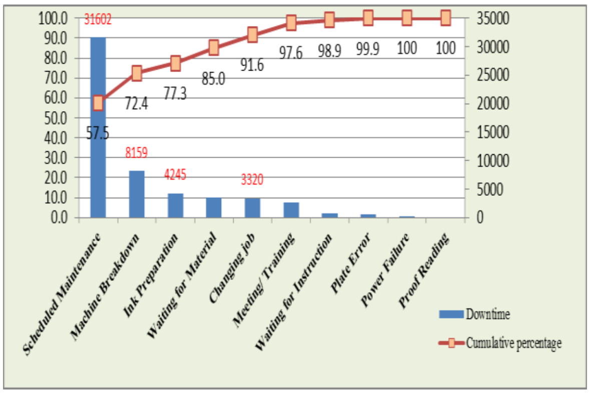

Fig. 3 Pareto Chart of March, 2013

From the above Pareto chart, it has been found that scheduled maintenance and machine breakdown in particular have caused around 70% of the total downtime. Whereas scheduled maintenance was unavoidable and machine breakdown could be reduced.

Similarly from the analysis of average monthly availability for year 2013, it has been revealed that comparatively lower availability rate was figured in February, March, June and July of 2013. A Pareto chart has been drawn on the downtimes and cumulative percentage calculation of downtime data of March 2013 in particular has been done and shown in Fig. 3 above.

From the Pareto analysis, it has been identified that like the Pareto chart of April 2012, scheduled maintenance and machine breakdowns have caused more than 72% of the total downtime measurement, whereas individual percentage contribution of machine breakdown was around 20%. It has been mentioned earlier that scheduled maintenance was unavoidable and machine breakdown could be reduced.

3.1.1 Discussion on Pareto analysis

It has been revealed from the Pareto analysis of downtimes of the critical months of year 2012 and 2013 that scheduled maintenance and machine breakdown have caused around 70% to 75% of total downtime calculations. As scheduled maintenance is the part of planned maintenance, it is not avoidable to large extent. Machine breakdown, ink preparation and waiting for material were next prioritized downtime factors those should be addressed for further reduction of total downtime.

3.2 Comparative Downtime Analysis for Two Years

The total 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 downtimes, comparative downtime analysis has been performed for two consecutive years and detailed as below.

3.2.1 Comparative Downtime Analysis of July 2012 and 2013

The various downtimes of the month July for two consecutive years has been measured, tabulated in Table 2 and plotted in Fig. 4 below.

Table 2 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

Percentages of every downtime in total downtime measurement has also been calculated and shown in the Fig. 4 accordingly.

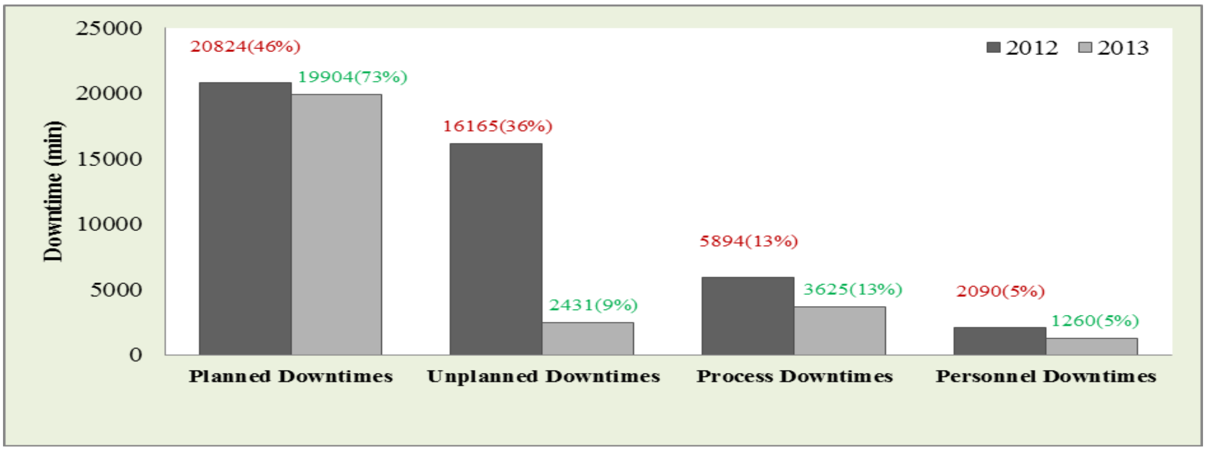

Fig. 4 Downtime comparison of July 2012 Vs 2013

From the above graph, 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, so as maintenance checklist was maintained effectively and unplanned downtimes had been reduced by significant amount.

3.3 Overall Comparative Analysis of Downtimes in Year 2013

Scheduled Maintenance of planned downtimes, machine breakdown of unplanned downtimes, ink preparation of process downtimes and changing job of personnel downtimes in the month February, March, June, July and November of 2013 together with the position in the corresponding Pareto charts have been tabulated in Table 3.

Table 3 Overall analysis of Pareto charts of 2013

Down time (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	2nd	2nd	2nd	3rd	2nd
Ink preparation	3015	4245	1475	2160	4080
Position in Pareto chart	3rd	3rd	4th	2nd	3rd
Changing job	2660	3320	1445	1110	2585
Position in Pareto chart	6th	5th	6th	6th	5th

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

To identify the most affecting and contributing downtimes 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, the following formula has been 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 evaluated by measuring the following times for the year 2012 where meeting/training = 32633 minutes and total downtime = 580957 minutes.

So, percentage contribution of Meeting/training = $\frac{32633}{580957}$*100% = 5.6% of total downtime.

Similarly percentage contribution of every downtime for two consecutive years has been measured and given in Table 4 for the year of 2012 in particular.

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 downtimes was performed for the year 2012 and has been put in Table 4 below. As Scheduled maintenance contributed the most, this was ranked as First.

Table 4 Ranking based on % of contribution (Year: 2012)

Downtime types	**Downtime (min.)**	**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 of Year 2012

Comparing all variables (downtimes) with each other using SPSS software, a two-tailed alternative hypothesis test has been performed and result has been plotted in Table 5 below. 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.

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. Considering the existing pair below the standard level of significance (<0.05), the most affecting factors (downtimes) have been identified. Thus, paired t-test analysis has been performed for the downtimes data of two consecutive years and plotted in Table 5 for the year 2012.

Table 5 *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

Comparing the mean values of every pair, the t-value has been obtained. This value shows the dependence factor of all variables. A comparative scenario of the downtime ranking between t-test and percentage of contribution has been drawn for the year 2012 and presented in Table 6.

Table 6 Comparison between T-test ranking and percentage contribution ranking (2012)

According to percentage of contribution		**According to *t-test***	
Downtime types	Rank	Downtime types	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

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 done and presented in Table 7 below.

Table 7 Comparison between t-test ranking and percentage contribution ranking (2012)

According to percentage of contribution		**According to *t-test***	
Downtime types	Rank	Downtime types	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 7, it has been identified that scheduled maintenance was the most affecting factor among all the downtime factors, which was unavoidable. Machine breakdown was ranked the second factor which requires rigorous maintenance practices to reduce this. Waiting for materials and ink preparation were the next prioritized factors to be taken into consideration according to t-test analysis.

3.4.4 Discussion on paired t-test

From the analysis of Table 6, it has been identified that ink preparation, meeting/training and changing job have been ranked as fourth jointly according to t-test that refers to these downtimes have similar dependence over other downtimes. So, continuous focused improvement technique can be utilized to reduce these downtimes simultaneously. Similar interpretation can be drawn from Table 7 as well. In Table 6 and 7, percentage of contribution showed the effect of every downtime over total downtime whereas paired t-test interpretation indicated the downtimes to focus with certain priority.

3.5 Mean Downtime (MDT) Analysis

To find the effect of TPM implementation over every downtime, comparative mean downtime (MDT) analysis for two consecutive years has been performed. Mean down time for every downtime has been calculated by using the following formula and the results are shown in Table 8 for the year 2012.

Mean down time = $\frac{1}{n}\sum_{i=1}^{n} D_i$; Here, D_i = Downtime for a month and n = Total number of months.

Similarly, mean downtime calculation for the year 2013 has been performed and compared with the mean downtime measurement of 2012.

Table 8 Mean downtime analysis of Year 2012

Downtime Type	Power failure	Meeting / Training	Changing job	Waiting for instruction	Scheduled maintenance	Waiting For material	Ink preparation	Plate error	Machine Breakdown	Proof reading	Total downtime
January	160	6520	2660	350	25655	3470	3967	205	12274	0	55261
February	482	2762	2375	420	18151	2050	1711	115	10319	0	38385
March	1584	2794	2450	477	20731	4228	4410	265	13522	0	29730
April	1531	1915	3539	981	22331	2970	4354	215	13370	0	51206
May	146	2342	2430	579	18996	2746	2051	175	18822	0	48287
June	55	2459	1200	245	16738	2772	1704	375	12940	0	38488
July	755	2275	1970	120	18549	3826	2068	250	15160	0	44973
August	254	1770	2270	506	18512	2425	1685	245	9839	0	37506
September	0	2469	3325	813	28444	4912	3539	1460	12175	0	57137
October	500	2918	3755	580	30313	4901	4088	305	7166	350	54876
November	30	2829	3210	680	26007	3048	4622	417	13272	0	54115
December	0	1580	1625	1505	28539	3777	5336	590	7310	0	50262
Mean downtime	458.08	2719.4	2567.4	604.67	22747.2	3427.08	3294.58	384.75	12180.75	29.17	48413.1

For example, from the data collected, the mean downtime calculation for machine breakdown is =

$$\frac{12274+10319+13522+13370+18822+12940+15160+9839+12175+7166+13272+7310}{12}$$

= 12180.75 minutes

3.5.1 Comparative Mean Downtime Analysis between Year 2012 and 2013

To understand the clear effect of TPM implementation from year 2012 to 2013, a comparative mean downtime analysis has been performed. It has been revealed from the analysis that mean down time for most of the downtime factors has been reduced in the year 2013 except a few has been increased. From the data collected, it has been found that in the year 2012, mean down time of total downtime was = 48413.1 minutes, whereas in 2013, mean down time of total downtime = 41391.75 min. So, percentage of mean downtime reduction = 14.5%. Mean down time comparison of every downtime factors have been evaluated and presented graphically in Fig. 5 below.

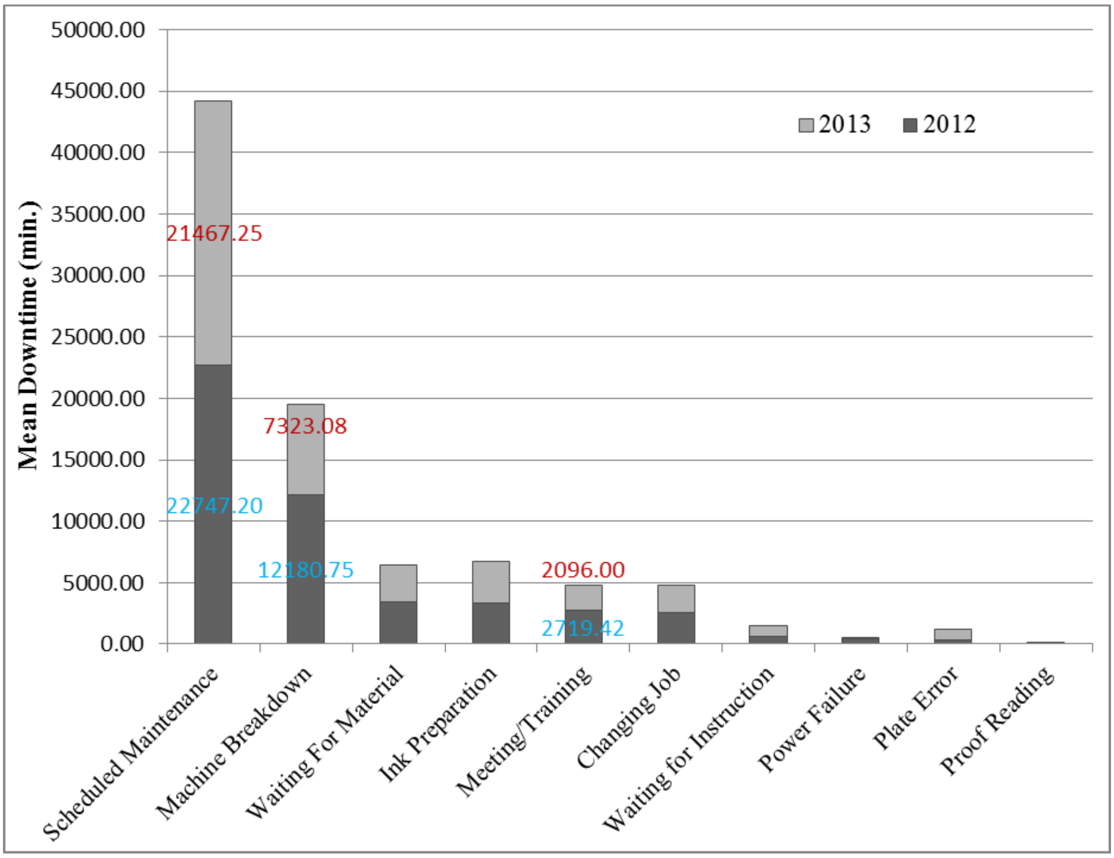

Fig. 5 Comparison of Mean downtimes between Year 2012 and 2013

3.5.2 Discussion on mean downtime (MDT) analysis

From the figure 5, it has been revealed that MDT of three downtime factors, namely - waiting for instruction, ink preparation and plate error have been increased in the year 2013 which means the lacking in production planning technique and less maintenance efficiency. MDT of all other downtime factors has been decreased in 2013. So, it can be said that autonomous maintenance and planned maintenance practices were maintained effectively. MDT of power failure has been reduced the most. Power failure was occurred due to breakdown of the power supply unit in the machines. Since it has been reduced, the preventive maintenance as part of the planned maintenance was performed consistently. MDT of meeting/training has been reduced around 22% which represents that planned maintenance practices were performed in the year 2013.

3.6 Results of Analysis

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

3.6.1 Results of Downtime Analysis

Pareto chart for the selective months' of studied year indicating comparatively lower availability rate have been drawn. The facts that have been identified from the analysis are detailed as follows-

- Scheduled maintenance and machine breakdown have caused around 75% of total downtimes.
- Ink preparation, meeting/training and waiting for material were the next level of affecting downtimes in most of the months.
- According to *t-test*, ink preparation, meeting/training and changing job have been ranked as fourth level of downtime factors in the year 2012.
- According to *t-test*, in the year 2013, fourth level of downtimes' was waiting for material, meeting/training and changing Job.
- Mean downtime of total downtime has been reduced 14.5% from 48413.1 minutes for year 2012 to 41391.75 minutes for year 2013.

IV. CONCLUSIONS

One of the main objectives of TPM is to increase the overall equipment effectiveness of plant equipment. Machine maintenance and in particular, implementing an appropriate maintenance strategy has become increasingly important for manufacturing industries to fulfill this requirement. In this regard, this paper has focused on a case-study work with the aim of evaluating the effects of total productive maintenance implementation onto the existing production scenario of a selected semi-automated manufacturing company of Bangladesh by measuring downtime and mean downtime reduction and performing mean downtime (MDT) analysis.

This case-study research work has extracted an overall scenario of equipment effectiveness, key downtime causes and various downtime factors during the total productive maintenance (TPM) practicing in the selected semi-automated factory. 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 be considered for reduction of total downtime. It has been revealed from data analysis that MDT of total downtime has been reduced 14.5% in the second year of total productive maintenance implementation. This shows the positive impact of TPM implementation. Modern maintenance practices and production improvement techniques could have been applied to reduce the downtimes of machines to large extent and at the same time to enhance the volume of production as well.

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