Int. J. Res. Ind. Eng. Vol. 8, No. 2 (2019) 140–157

International Journal of Research in Industrial Engineering

www.riejournal.com

Development of a Maintenance Schedule Plan to Improve the Equipment Efficiency of an Industry: A Case Study

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A B S T R A C T

The aim of this study is to implement Total Productive Maintenance (TPM) in a continuous injection molding industry. By implementing TPM, the industry can increase their Overall Equipment Effectiveness (OEE) and productivity. Before implementing TPM, overall equipment efficiency, availability rate, performance rate, and quality rate of the injection molding machine were 74.9%, 88.54%, 88.5%, and 95.6%, respectively. It needs to be improved for good operating condition of machines. In this paper, some tools are suggested to improve their productivity and maintenance procedure. These tools are cause and effect diagram, Pareto chart, WWBLA, and preventive maintenance schedule. TPM program is to change the culture of the company maintenance policy with involvement of all employees toward the maintenance system of the company. Through the proper planning of maintenance schedule, productivity can be improved. This schedule helps to maintain machines in good operating conditions as well as a good OEE value, and a world class standard OEE is achieved.

Keywords: TPM, Cause and effect diagram, Pareto chart.

Article history: *Received: 12 March 2018* *Revised: 11 June 2019* *Accepted: 20 June 2019*

1. Introduction

TPM involves a newly defined approach for maintaining plants and equipment in good working condition. All sections in regard to a manufacturing process is kept under consideration to reduce equipment losses to maximize OEE by using the tools and techniques of TPM. After finding all the causes of rejections, the most significant losses are identified and the causes for occurring such rejection are eliminated and the OEE improves [1]. It is necessary to implement some manufacturing excellences to produce good product without defects, minimize cost, good quality in order to maximize profits without increasing sales price. As the complexity and competition increase, the efficiency and effectiveness can be increased mainly by improving existing

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DOI: 10.22105/riej.2019.174907.1082

maintenance policy and operation effectiveness. The purpose of the maintenance management system is not to increase production or make system lean but also at the same time to bust up the employee morale and job satisfaction [2]. By involvement of all employees and by all departments, this system does not only give healthy environment but also makes system lean [3].

The thesis data is upon the Injection Molding Machine (IMM) which produces various plastics product. The product quality made by the injection molding machine is not consistent and reliable [4]. Today's global competition, demands the highest product quality and performance to be delivered at the shortest cycle time and the lowest unit cost [5]. An injection molding machine, also known as an injection press, is a machine which manufactures plastic products by process of injection molding. It consists of two main parts, one named injection unit and the other is clamping unit. Material granules for the part is fed via a hopper into a heated barrel, melted using heater bands, and the frictional action of a reciprocating screw barrel. The plastic is then injection through a nozzle into a mold cavity where it cools and hardens to the configuration of the cavity [6]. This injection molding machine has two ancillary machines names, compound machine and autoloader. Compound machine is used for proper mixture of raw materials according to their percentage which results raw materials in granular shape [7]. Autoloader is a machine which is used for loading the raw materials in the hopper of injection molding machine [8]. But the output do not cope with the approximated value. Some defects continuously affect the productivity which causes loss to company. Air bubbles, black spot, color change due to over-heat, shrinkage, extra-flash, etc. are the main problems. This paper therefore provides a method to identify the root cause of defects and maintenance policy to overcome this problems in an injection molding industry (RFL Plastics Ltd.) in Bangladesh.

TPM integrates production and quality systems through the machines, equipment, and processes that add business value to the organization. It focuses on keeping all equipment in perfect working condition to avoid breakdowns and delays in the manufacturing process. In addition, it do not tolerate any small stops or slow running and no defects during production; as well as a safe working condition for manufacturing process is also established by a TPM policy [8]. TPM stands on 8 pillars. Among these, the third pillar, Kaizen, fourth pillar, planned maintenance, and sixth pillar, education and training are used in this study. All these pillar aimed at reducing losses in the workplace that affect the efficiencies [9].

The use of injection molding machine is increasing significantly in producing plastic products [10]. If the defected product is produced, many problems are induced, and at last, productivity decreases. After identified rejection reasons and eliminating them, OEE can be increased. The objective of this paper is as follows:

- Identification of major losses.
- Identification of significant losses by Pareto analysis.
- Calculation of Overall Equipment Efficiency (OEE).
- Reduction of losses with analytical techniques like planned maintenance, counter-measures, etc.

- Further OEE calculation and comparing it with international standard [1].

Rest of the paper is arranged in six section. The first Section covers literature review. The second Section describes research gap of this type of study. The third one provides methodology which describes some steps of this work. The fourth Section consists of data analysis and calculation of OEE. Finally, remained sections discuss the discussion and conclusion of this study.

2. Literature Review

TPM is a philosophy of continuous improvement and team work that focuses on how an equipment's basic condition can be sustain in order to enhance its life span [11]. The fast and foremost goal of TPM is to bring competitive, prestigious advantages to organizations, to promote quality products, and to reduce the cost of production line tremendously. Overall Equipment Efficiency (OEE) can be easily obtained which can be used to monitor the maintenance progress after implementing TPM successfully [12]. Productivity can be increased by reducing defects that results in minimizing the wastage of raw materials [13]. Researchers have given emphasis in increasing equipment effectiveness. Following works have been done so far in regard to TPM and OEE.

It is possible to eliminate losses in systematic method using various tools such as: PM analysis, Why-Why analysis, cause effect diagram, Pareto chart, and Kaizen maintenance schedule. These tools eliminate major losses in methodology [1]. Planned Maintenance (PM) reduces unplanned stoppage, Why-Why analysis finds out the inherent causes of a problem and gives a counter-measure of a problem. Pareto analysis helps to identify different defects and classifies them according to their significance. These defects often lead to the rejection of raw materials. To determine possible root causes of rejection, Cause-and-Effect Diagram (CED) is also a very useful tool. It helps to identify, sort, and display causes of a specific problem or quality characteristic. It graphically illustrates the relationship between a given outcome and all the factors that influence the outcome, hence identifies the possible root causes i.e. basic reasons for a specific effect, problem, or condition [11]. The paper of Chandna and Chandra [9] discussed about the defects in forging and injection molding [10]. Mustafa Graisa and Amin Al-Habaibeh investigated maintenance and production problems in the cement industry in Libya, with particular emphasis on future implementation of Total Productive Maintenance (TPM) [9].

Table. References as reported in the literature.

SL. No	References	Details
01	[14]	They analyzed the root cause for reducing breakdowns. First of all, they collected data and identified probable cause, then applied Pareto analysis and CED. They found out the major problem. They made a recommendation for using motor of better specification and showed a profit of Rs. 2, 10,000/- per month.
02	[15]	They implemented TPM for evaluating OEE. Firstly, they found out the big losses sites of the company. Then they calculated the OEE and compared it with world class OEE. As company OEE is much less than world class OEE, They recommended a TPM implementation plan.
03	[13]	They firstly identified the major losses occurring in two shifts (morning and afternoon). Then, they applied Pareto analysis and calculated the initial OEE. They made a WWBLA worksheet for minimizing the losses. Finally, they calculated the OEE again and had an improvement of about 50%.
04	[12]	They applied Pareto analysis and CED for minimizing rejection of raw materials. They applied it in three major processes of lamp production. They also calculated the total number of defects in that processes. Finally, they recommended corrective action against defects.
05	[1]	Initially, they investigated the major losses in a RMG factory. Then they applied Pareto analysis and calculated the OEE. Initial OEE was 59%. Then they developed a WWBLA worksheet for countermeasures against losses. Then they calculated OEE again and had a better result of 65%.

3. Problem Statement

From previously mentioned paper, we can see that all of them found a way to increase productivity by using various tools of TPM. Researchers have used one or two tools of TPM. The higher accuracy that we get, depends on how many TPM tools are used. They did not use three or four tools of TPM together. Therefore we want four tools so that the analysis is easily understandable and the result will be accurate. No one still showed the preventive maintenance schedule to minimize the rejection reasons. When we use the preventive maintenance plan then the machine needs not to be a victim to frequent breakdown and the condition of machine can be easily understandable; it is a KAIZEN policy. Continuous improvement of the machines will result in higher productivity and it will reduce loss and breakdown of machines. A comprehensive plan has been made to identify root causes by using cause and effect diagram, Pareto chart, and made a maintenance policy by WWBLA and preventive maintenance schedule. No one still did the preventive maintenance schedule for an injection molding industry.

4. Methodology

Concept of TPM is applied to the plastic company by investigating the previous performance of the production line preliminarily with a view to improving the existing production techniques. The plant's past production data were analyzed and recorded [14]. Even after producing 24 hours a day and 7 days in a week, the company is unable to meet rapid growing market demand. So, the firm has to reduce the unwanted and unplanned stoppages of production in order to ensure a steady production level and to meet the market requirements. Production may be stopped due to many reasons like machine breakdown, maintenance work of machine or production floor, labor issues, insufficient material supply, machine trouble shooting problems, problems in manufacturing process, etc. [15]. Finally, the methodology of doing work is shown in Figure 1.

5. Data Analysis

5.1. Rejection Reasons

Various problems are associated with the rejection of products. We have found out twelve major problems behind the rejection of final products. These are such as:

Table 2. Rejection reasons.

Serial number	Rejection Reason
1	Operator activeness
2	Raw material proper preheating problem
3	Mold load-unload time takes more
4	Proper equipment lack during mold load unload
5	Machine parameter setting/machine trouble shooting time length
6	Power problem
7	Mold ejector pin broken problem
8	Recycle material over use
9	Not maintain material recipe
10	Machine heater damage or uncertain problem
11	Screw broken

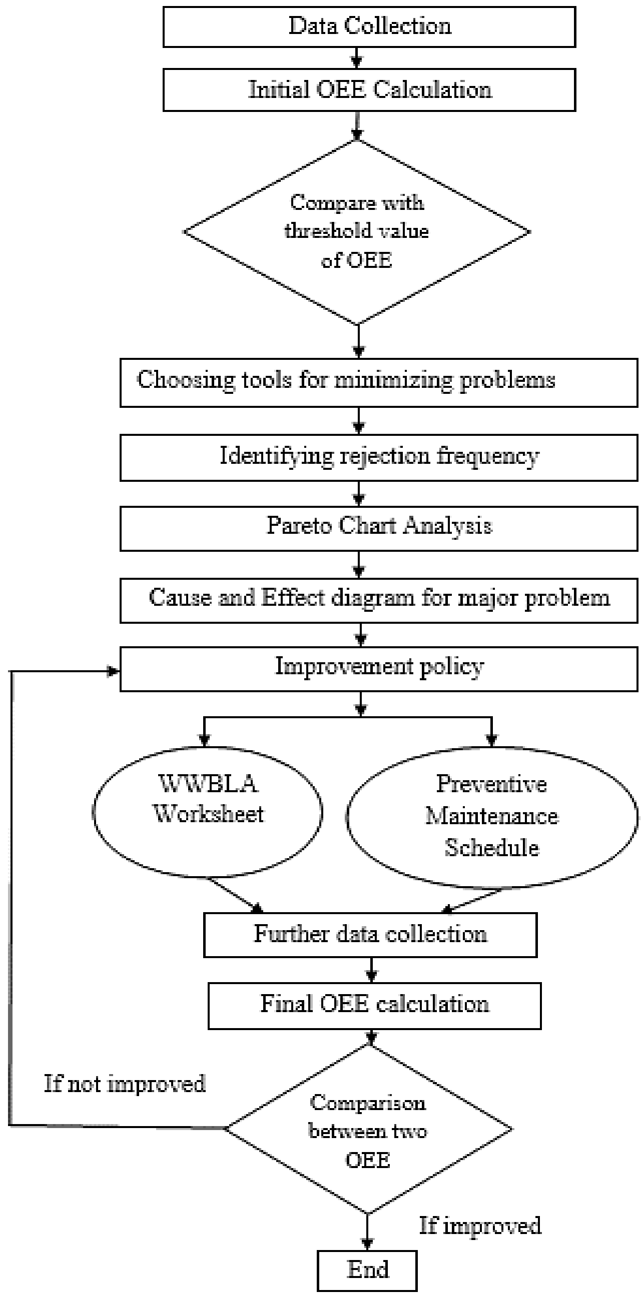

Figure 1. Process flow diagram of methodology.

It is also noticed that there is no preventive maintenance schedule in production floor of injection molding and lack of proper working condition for employees and workers.

5.2. Data Collection

Our paper work is done upon the data collected from one of the renowned factories in Bangladesh named RFL PLASTICS LTD, situated at Narsingdi, Bangladesh. They produces quality products and have high market demand. They always meet the market demand with in time. Injection molding machine is vastly used for their plastics production. For thesis purpose their factory have been visited twice. First time one of their factories is visited which have 66 injection molding machines in twelve lines and around 400 molds. Their production runs about 24 * 7 in a week. Our thesis data was collected from a production floor that produces sanitary fittings of about various sizes, shapes and quantity in the month of December. Our collected data was about 3 inch elbow fittings. Its cycle time is 55 seconds. Second time we visited there and noted down some rejection reasons and problems associated with IMM and other relevant machine i.e. Compound machine and Autoloader. The frequency of rejection is identified by the information based on Maintenance section. Then root causes of rejection is found out initially and finally make a solution of these problems. By this process initial OEE is calculated. After observing so much ins and outs, an effective and feasible maintenance plan is recommended which results in better OEE.

Initial data is collected from factory. For OEE calculation various data are needed. These are collected by visiting factory and inspecting production floor. It's a continuous production factory so machine runs almost 24*7. Data on scheduled production, unplanned stoppage, targeted production, actual production, rejected items and acceptable items are collected separately. These are given below in Table 3.

Table 3. Data on various criteria.

Week	Scheduled Production (hrs)	Unplanned Stoppage (hrs)	Targeted Production (pcs)	Actual Production (pcs)	Rejected Items (pcs)	Acceptable Items (pcs)
1	168	21	10990	9607	455	9152
2	168	19	10990	9739	430	9309
3	168	19	10990	9739	425	9314
4	168	18	10990	9803	410	9393

5.3. Initial OEE Calculation

The calculations for Overall Equipment Efficiency (OEE) of the machines follow the subsequent formula:

Overall Equipment Efficiency (OEE) = Availability * Performance Rate * Quality Rate

where,

$$\text{Availability (\%)} = \sum \frac{Effective running time}{Scheduled production} * 100$$

$$= \sum \frac{Scheduled production - Unplanned stoppage}{scheduled\ running\ time} * 100$$

$$\text{Performance Rate (\%)} = \sum \frac{Actual\ production}{Targetedproduction} * 100$$

$$\text{Quality Rate (\%)} = \frac{Acceptableitems}{Actualproduction} * 100$$

$$= \frac{Actualproduction - Rejecteditems}{Actualproduction} * 100.$$

Calculations are given in Table 4.

Table 4. Initial OEE calculation.

Week	Scheduled production (hrs)	Unplanned stoppage (hrs)	Effective running time (hrs)	Availability %	Targeted production (pcs)	Actual production (pcs)	Performance Rare %	Rejected Items (pcs)	Acceptable items (pcs)	Quality Rate %	OEE
1	168	21	147	87.5	10990	9607	87.4	455	9152	95.3	72.9
2	168	19	149	88.7	10990	9739	88.6	430	9309	95.6	75.1
3	168	18	149	88.7	10990	9739	88.6	425	9314	95.6	75.1
4	168	18	150	89.3	10990	9803	89.2	410	9393	95.8	76.3

So OEE for one month (4 weeks) is 74.9%.

5.4. Comparison

A table showing comparison between world class OEE and RFL's OEE is developed below:

Table 5. Comparison between world OEE and RFL's OEE (4 weeks).

OEE Factors	World Class OEE	RFL Plastics Ltd. OEE
Availability	90.0%	88.6%
Performance Rate	95.0%	88.5%
Quality Rate	99.9%	95.6%
Overall OEE	85.0%	74.9%

From the above table, it is seen that RFL's all OEE factors are less than world class OEE factors. Moreover, overall OEE of RFL is 74.9%, which is much less than the world class OEE of 85%. So, remedial action and as well as corrective and preventive action should be patronized in order to improve the OEE value.

5.5. Problems Minimizing Tools

For improvement in TPM, some analytical techniques are basically used. These are:

- WWBLA (Why Why Because Logical Analysis).
- P-M analysis.
- Why-Why analysis.
- Fault tree analysis.
- Failure mode effect analysis cause and effect diagram.
- Pareto analysis.
- SPC, etc.

These tools are used for minimizing losses. We used WWBLA, Pareto chart, cause and effect diagram and P-M analysis/preventive maintenance schedule for our solution [1].

5.6. Frequency of Individual Reason with Consuming Time

After identifying the major eleven reasons for rejection of products regarding the production sectors of RFL plastics industries, a table is established for identifying the frequency of occurrence for each reason and time consuming for several reasons. A Pareto chart is then established according to frequency and time data. It's shown in Table 6.

Table 6. Reasons for Rejection of Products for Several Weeks (4 weeks).

Week	Rejection Reasons	Frequency	Time consuming (min)
1	Raw material proper preheating problem	5	10
	Mold load/unload problem	2	30
	Lack of proper mold loading/unloading equipment	1	0.5
	Machine parameter setting	1	1
	Auto loader jam	1	20
2	Raw material proper preheating problem	4	7.33
	Mold load/unload problem	2	30
	Machine parameter setting	1	0.5
	Heater damage	1	60
3	Raw material proper preheating problem	6	11
	Mold load/unload problem	1	15
	Machine parameter setting	1	1
	Auto loader jam	1	20
	Power problem	1	10
	Screw broken	1	350
4	Raw material proper preheating problem	2	4
	Mold load/unload problem	2	30
	Lack of proper mold loading/unloading equipment	1	1
	Machine parameter setting	3	2

5.7. Pareto Chart Analysis

Now, from Pareto analysis, it is seen that major reasons for rejection is in raw materials preheating problem which has the highest frequency of occurrence comprising of about 46% of cumulative occurrence. So, it is necessary to eliminate this major problem first to increase the OEE. The main causes of this problem is due to preheater's heater cut off and hopper problem. Now, WWBLA technique is used for identifying the countermeasures with a view to minimize the causes of problem [1].

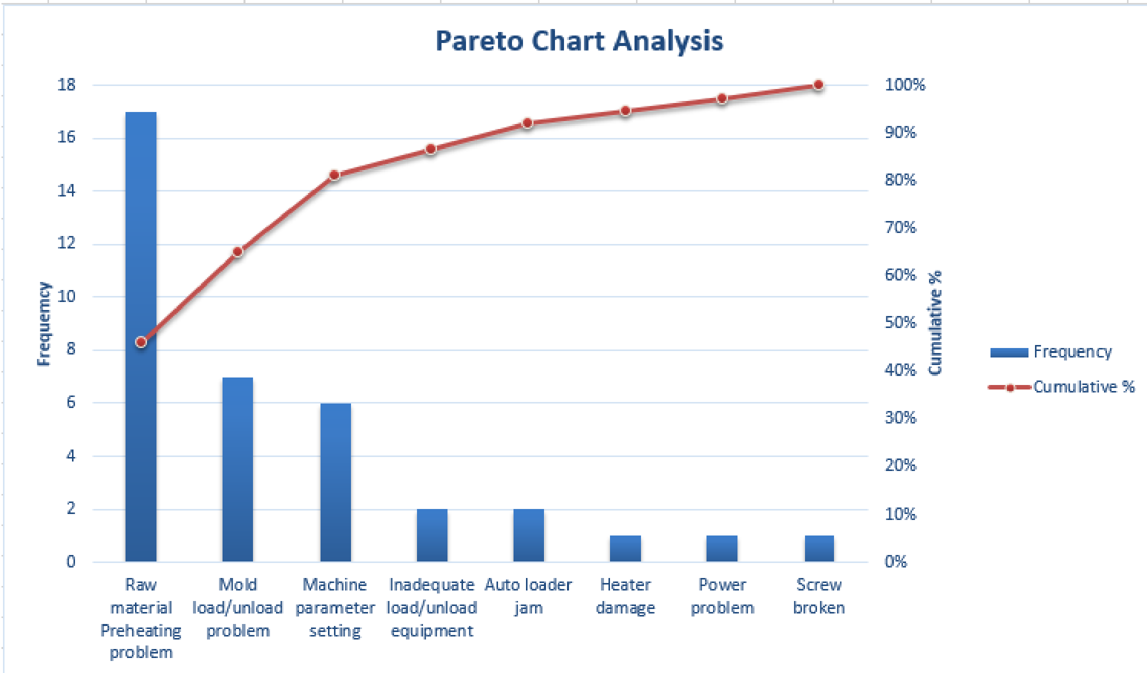

Figure 2. Pareto chart analysis.

5.8. Identifying Causes behind Most Frequent Problem

Cause and Effect Diagram is used to identify the major causes of most frequent problem. Here the most frequent problem is raw materials preheating problem. There are some issues against the occurrence of this problem i.e. preheater's heater cut off, Hooper problem, wet floor, etc. These are depicted in CED in Figure 4.

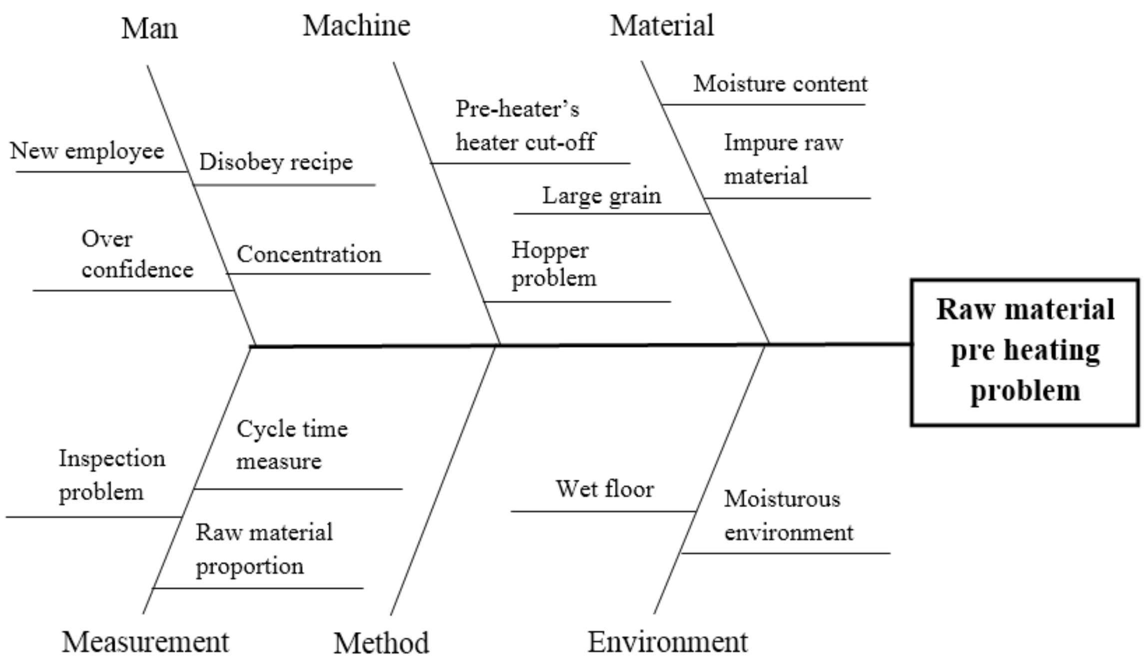

Figure 2. Cause and effect diagram.

5.9. Improvement Poly

After identifying the major reasons for rejection and major problems, now remedial actions should be accelerated. For directing remedial action, two solutions are proposed. One is WWBLA worksheet which comprises countermeasures for problems and other is preventive maintenance schedule for better maintenance of machines.

5.9.1. WWBLA (Why-Why because logical analysis) worksheet

Now, WWBLA technique is used for identifying the countermeasures with a view to minimize the causes of problem. By WWBLA technique, root causes of a problem is identified. In this technique, each major problem is considered separately and a worksheet is prepared. For each major problem, a cause is identified and referred as first factor for problem. It is then verified for further dividing into root causes. If it is possible, then it is marked as G, where G stands for Go. Then, second factor for problem is identified and verified. In this way, a third, fourth or even fifth problems are identified. If further verification is not possible then is marked as NG means No Go. Finally, countermeasures for each root causes of the problem are identified simultaneously [1].

Table 7. WWBLA Worksheet.

Problem	1st factor for problem	Verification	2nd factor for problem	Verification	3rd factor for problem	Verification	4th factor for problem	Verification	Countermeasures
Raw material proper preheating problem	Preheater's heater cut off	G	Excess power	G	Voltage up/down	G	Unavailability of stabilizer	NG	Use of stabilizer in each production floor
			Improper parameter setting	G	Operator activeness	NG	-	-	Training Shifting policy Motivation
	Not maintain material recipe	G	Recycle materials over use	G	Operator's over confidence	NG	-	-	Training
			Inadequate inspection	G	Lack of inspection schedule	NG	-	-	Inspection schedule

5.9.2. Preventive maintenance schedule

Before preparing maintenance schedule, it is needed to figure out the problems corresponding to each machine. It is shown in Table 8 below.

Table 8. Problems related to each machine.

Problems	Frequency	Related machine		How to prevent problem
Raw material proper preheating problem	17	Injection molding machine	Injection Molding Machine	Check parameter Check hopper Inspect circuit board Check ejector pin Check toolbox Do necessary clamping action vii. Inspect cranes
Mold load/ unload problem	7	Injection molding machine		
Lack of proper mold load/unload equipment	2	Injection molding machine		
Machine parameter setting	6	Injection molding machine compound machine		
Auto loader jam	2	Autoloader	Compound Machine	Check screw Check autoloader Inspect water line Check feeder Supervise heater Check cutter Inspect vacuum point
Power problem	1	Injection molding machine compound machine autoloader		
Screw broken	1	Injection molding machine		
Heater damage	1	Injection molding machine compound machine	Autoloader	Jamming Check power supply

A preventive maintenance schedule is proposed for better inspection and maintenance of production machines. It will help tremendously in reducing rejection related problems and unplanned stoppages of machines. It is depicted in Figure 5 below.

Preventive Maintenance Schedule of 2018 at RFL

Team: ……………………

Shift: Day

Area: RFL Industrial Park-4

		Machine Name															
		Compound Machine							Injection Molding Machine							Autoloader	
Day	Time	Check Screw	Check Auto Loader	Check Feeder	Check Cutter	Supervise Hitter	Inspect Vacuum Point	Inspect Water Line	Check Preheater	Check Hopper	Inspect Circuit Board	Check Ejector Pin	Check Toolbox	Do Clamping	Inspect Crane	Jamming	Check Power Supply
Sat	09.00		√	√				√	√		√	√					√
	11.30	√			√		√			√	√			√	√	√	
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	17.00																

Supervised By: ……………………

Necessary Code: √: Ok ×: Problem found, call for mechanics θ: Problem found, report high authority

Figure 3. Preventive maintenance schedule plan.

5.10. OEE Calculation after Adopting Maintenance Plan

After implementing improvement policy i.e. WWBLA and preventive maintenance schedule, it is been seen that there is drastic change in data in unplanned stoppage and rejected items. Previously maximum unplanned stoppage was 21 hours in a week. Now it decreases to 14 hours in a week. Maximum rejected items was 455 pieces in one week, which steps down to maximum 220 pieces in a week only. So, further OEE is calculated upon the improved data.

Table 9. Final OEE calculation.

Week	Scheduled production (hrs)	Unplanned stoppage (hrs)	Effective running time (hrs)	Availability %	Targeted production (pcs)	Actual production (pcs)	Performance Rare %	Rejected Items (pcs)	Acceptable items (pcs)	Quality Rate %	OEE
1	168	14	154	91.7	10990	10065	91.6	220	9845	97.8	82.1
2	168	14	154	91.7	10990	10065	91.6	190	9875	98.1	82.4
3	168	12	156	92.9	10990	10196	92.8	154	10042	98.5	84.9
4	168	11	157	93.5	10990	10261	93.4	150	10111	98.5	86.0

So, final OEE for 1 month (4 weeks) is 83.85%.

5.11. Comparison between Initial OEE and Final OEE

Comparison between previous OEE and conclusive OEE is shown in Table 10 below.

Table 10. Comparison between Initial OEE and Final OEE.

Week	Initial OEE				Final OEE			
	Availability %	Performance Rate %	Quality Rate %	Overall OEE	Availability %	Performance Rate %	Quality Rate %	Overall OEE
1	87.5	87.4	95.3	72.9	91.7	91.6	97.8	82.1
2	88.7	88.6	95.6	75.1	91.7	91.6	98.1	82.4
3	88.7	88.6	95.6	75.1	92.9	92.8	98.5	84.9
4	89.3	89.2	95.8	76.3	93.5	93.4	98.5	86.0

6. Discussion

Total productive maintenance integrates all activities of a manufacturing system with maintenance department .It also involves the operators in maintenance activities. It provides a scheduled work to do maintenance policy effectively. In this study, firstly cause effect diagram for each rejection reason is identified. Then problem associated with only machines is identified. From that it is seen that raw material proper preheating problem, mold load/unload problem, lack of proper mold load/unload equipment, machine parameter setting, power problem, screw broken, heater damage come from injection molding machine. Machine parameter setting, power problem, heater damage come from compound machine. Auto loader jam, power problem come from autoloader. As there was no daily maintenance policy, the condition of equipment was poor and shortage of spare parts. In RFL industry, the Overall Equipment Effectiveness (OEE) of the injection molding machine was 74.9% where the availability was 88.54% of the production time and the performance was 88.5%, while the quality rate was 95.6%. After adopting some set of techniques like preventive maintenance activities and some counter-measures, the productivity is subjected to an improvement. After adopting above techniques, the Overall Equipment Effectiveness (OEE) of the injection molding machine become 83.8% where the availability becomes 92.4% of the production time and the performance becomes 92.3% while the quality rate becomes 98.2%. This improved OEE not only increase productivity but also keep pace with international standards of OEE which was discussed before. The improvement policy includes continuous improvement, empowering the employee, and standardizing every activity to prevent sudden breakdown. Thus, from this research work, it can be expected that the OEE could be increased to a very high content by implementing TPM to an industry.

7. Conclusions

Nowadays, production systems must be highly competitive, so the resources administration is for the company survival in order to obtain as much benefits as they can [16]. By adopting this process, a company can easily increase its productivity. This process will help to maintain the machine condition good and empower employees. But this policy should be maintained properly thoroughly the whole production process and the production engineers must supervise the maintenance policy at a fixed time interval. Although this experiment increases OEE in a great content, but there are some barrier and condition to this method. This process needs a continuous production line. Fault tree analysis could be used for identifying rejection reasons. SPC could be used to minimize losses. Overall, this process will be effective in a continuous production line and this should be subjected to further improvement.

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