A Review on the experimental study of Overall Equipment Effectiveness of various machines and its improvement strategies through TPM implementation

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Abstract *— The numero uno objective of this paper is to make a literature review on the experimental study of the Overall Equipment Effectiveness in various machines and its improvement scheme through TPM implementation. In the global competition of world class manufacturing, emphasis has been laid on innovative techniques like Total Productive Maintenance, Total Quality Management, Enterprise Resource Planning to name a few. Global world with assorted researchers have anthologized eclectic data's to improve the working procedure of machines to enhance their Overall Equipment Effectiveness. The focus lies on improving the three primal parameters i.e. availability, performance and quality. Moreover to establish a preventive maintenance plan for the whole life cycle of equipment, covering all departments like planning, user and maintenance and involving all staff members from shop management to shop floor workers are within the premises of their detailed studies.*

Keywords *— OEE, Availability, Performance, Quality, Total Productive Maintenance*

I. INTRODUCTION

OEE is a procedure used to determine effectiveness of a machine. Though the definition implies that OEE is a measure of a particular machine, but it can be also used to determine efficiency of product lines, sections of plant or even the entire plant. It continuously focuses the plant on the concept of zero waste.

The losses are divided into six pivotal categories which influence the overall performance of the equipment. These are:

1. Equipment failures/breakdown losses mean the time and quantity loss due to defective products.
2. Set up and adjustment losses mean time loss due to defective products and downtime loss that occur when production of one item ends and the equipment is adjusted to fulfil the desired requirements.
3. Idling and minor stop losses when the production is interrupted by a temporary bottleneck or when a machine is not running.
4. Reduced speed losses refer to the difference between speed of equipment design and speed of actual operation.
5. Reduced yield losses occur during the early stages of production from start of machine to stabilization.
6. Quality defect and rework are losses in quality caused by malfunctioning of production parts.

Among all the losses the first and the second are termed as downtime loss and are used to calculate "Availability" of machinery. However the next two are speed losses which determine the performance efficiency and the final two losses are taken to be losses due to defect found in the product.OEE is calculated in terms of these six losses, which are function of performance rate, availability and quality rate of the machine, production line or factory. These losses can be negated by a tool known as Total Productive Maintenance.

Fig. 1 shows the block diagram of various types of OEE losses in a production line.

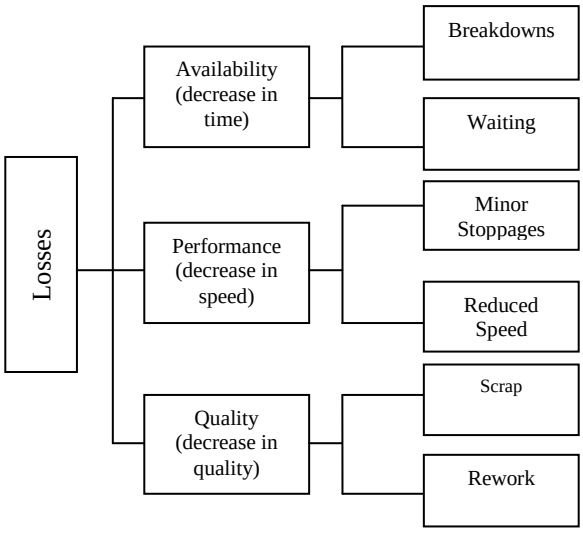

Fig 1: OEE losses

A. OEE Parameters

1) ***Availability (A)***: It takes into account Down Time loss, which includes all events that cease planned production for a perceptible length of time(typically several minutes or longer).It is calculated as the ratio of Operating Time to Planned Production Time, wherein Operating Time is simply Planned Production Time minus Down Time. Down Time includes job setting time, defect and rework time, meal break, idle time, job replacement time, material unavailability time.

A = Operating Time/Planned Production Time

2) ***Performance (P)***: It takes into account speed loss, which includes all factors that generate the production process to operate at less than the maximum possible speed when running. It is the ratio of Net Operating Time to the Operating Time. The Net Operating Time is the product of processed number of parts and the theoretical cycle time of each part.

P = (Theoretical Cycle Time*Processed number of parts)/Operating Time

3) ***Quality (Q)***: It takes into account quality loss, which factors out manufactured parts that do not meet quality standards or dross parts, including parts that require rework. It is calculated as the ratio of Fully Productive Time (fastest possible time for good parts) to Net Operating Time (fastest possible time for total parts).

Q = (Total parts-Defect parts)/Total parts

B. OEE Benchmark

A good OEE score can be classified as:

1) An OEE score of 100% is perfect production, manufacturing only good product, in shortest time, with no down time.

2) An OEE score of 85% is considered world class for discrete manufacturers.

3) An OEE score of 60% is fairly typical for discrete manufacturers, but indicates that there is substantial room for improvement.

4) An OEE score of 40% is not uncommon for new manufacturing firms that are just starting to track and improve their performance. It is a low score and is to be readily improved.

II. TOTAL PRODUCTIVE MAINTENANCE (TPM)

TPM evolved way back in 1951 when preventive maintenance was introduced in Japan from the USA.Nippondenso of Toyota Group became the first company to attain TPM certifications. It is a maintenance program with a newly delineated concept for the main parts and equipments. The objective of TPM is to commercially increase production and simultaneously increasing confidence of the employees and contentment at work. Total Productive Maintenance is nothing but an extension of Total Quality Management. In a nut shell, TPM can be summarised as the backbone of any sound production process occurring in a machine assembly.

The paramount targets of TPM are: no product defects, no equipment unplanned failures and no fatal injuries. It is accomplished by studying the past data of the aforesaid factors by using Ishikawa fishbone diagram analysis or why- why analysis and find out the hidden fuguai in the initial step of TPM autonomous maintenance.

The basic six losses mentioned above can be removed by TPM with the help of continuous improvements. Japanese technologies are suffused to achieve the target of “zero”.TPM has 8 pillars of activity which are set to eliminate wastes.

Figure 2 shows the block diagram of the eight pillars of TPM.

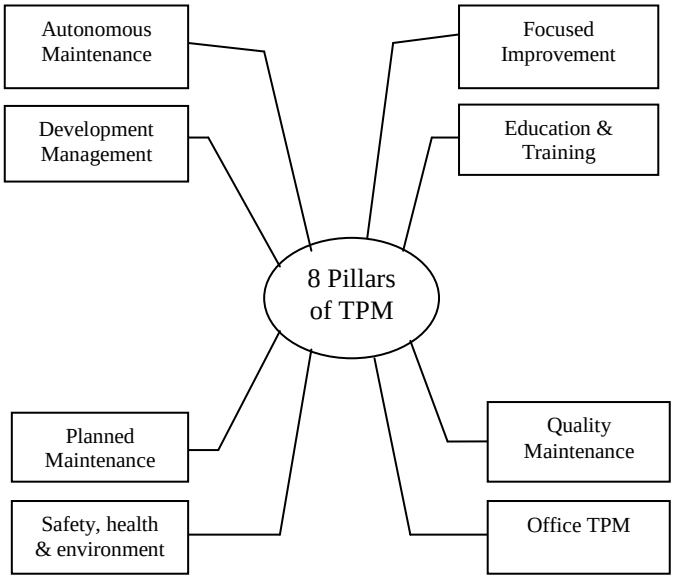

Fig 2: 8 Pillars of TPM

1. ***Autonomous maintenance*** –It is a process to keep the place clean to make maintenance easier to perform. The features are:
   a) Incubating operating skills and ownership
   b)Undergoing cleaning, lubrication, inspection on the production machineries.

2. ***Focused improvement***- It focuses on the following features:
   a) Working out loss structure and loss mitigation.
   b) Achieve improved system efficiency.
   c) Improve OEE on production systems.

3. ***Planned maintenance*** –Its function is to minimize unplanned failures in a production process. The features are:
   a) Effective and efficient planned maintenance, TBM (Time Based Maintenance) systems over equipment life cycle.
   b) Improving MTBF (Mean Time before Failure), MTTR (Mean Time to Repair).

4. ***Quality maintenance*** –It tends to no scrap. The features are:
   a) Achieving zero defects and breakdowns.
   b) Tracking and addressing equipment problems and root causes.
   c) Setting 3M (machine/man/material) conditions.

5. ***Development management***-The features are:
   a) Machine development to achieve high equipment effectiveness.
   b) Rapid methodology to develop new products.

6. ***Education and training***-Its function is to help involving and enhancing human resource in industries. The features are:
   a) Multi-skilling of employees.
   b) Aligning employees to organizational goals.
   c) Periodic skill evaluation and updating.

7. ***Safety, health and environment***- Its motive is making the working area more comfortable. The features are:
   a) Provide appropriate work environment
   b)Eliminate incidents of injuries and accidents.
   c) Provide standard operating procedures.

8. ***Office TPM*** – Its motive is to extend TPM principles to offices. The features are:
   a) Remove procedural skirmish.
   b) Focus on addressing cost-related issues.
   c) Apply 5S in office and working areas.

III. LITERATURE REVIEW

Researchers have implemented the OEE improvement tactic on various machines and machine production lines. But the pinnacle of all these researches is to find the maximum possible OEE, which can only be attained by TPM implementation. They have used different tools like kaizen, jishu -hozen, one point lessons, why-why analysis, fishbone cause effect diagram analysis or a combination of these tools to augment the OEE.The literature related to this has been discussed below:

Ljungberg O, et al. (1998) [1] studied that in order to implement Total Productive Maintenance (TPM) it is imperative to determine the value of various types of manufacturing losses, in order to command activities and allocate resources in an optimal way. In many firms, major time losses are taken care off rather than focusing on the minor causes.
He worked on a method for implementing data collection by a simple model and developed this to a combined model with computerised systems and

manual recording. This gave him both an exact assessment of the magnitude of the disturbance and an in-depth view of the rationale for losses. In about 20 cases, the overall equipment effectiveness was only around 55 per cent as surveyed by him. Further, he opined that performance losses are the dominating ones. He also stated from his research work that if the production process is new to the firm the Overall Equipment Effectiveness will be less than if the firm is habituated to the manufacturing layout.

Jonsson P & Lesshammar M, et al. (1999) [2] wrote a paper which focused on four critical dimensions (what to measure) and two characteristics (how to measure) of a total production measurement process. The overall equipment effectiveness (OEE) measurement calculations in such a system are planned against the general needs. The current measurement systems and the prospect of OEE are evaluated by them by comparing with some standard data. They found that the general shortcomings of the production lines were their inability to gauge flow exposure or external effectiveness to any great extent. They also performed field experiments in the studied organisations which showed that use of OEE in combination with an open and a not necessarily central organisation design could ameliorate several of those enfeeblements.

Ireland F & Dale B.G, et al. (2001) [3] focussed on a research paper based on TPM implementation in three companies, because of financial disturbances in them. Senior management in each of these companies had taken the initiative for TPM implementation by setting up appropriate organisational structures.Nakajima's seven steps of autonomous maintenance is taken into due consideration. Several other TPM pillars were set up which included education and training, quality improvements, quality maintenance and safety. However, the main differences in the aforesaid implementation related to the use of ABC machine classification system and the role of facilitators.

McKone E Kathleen & Schroeder G Roger, et al. (1998) [4] proposed a plan of Structural Equation Modelling (SEM) by relating Total Preventive Maintenance (TPM) and manufacturing performance. Total Productive Maintenance was to share a positive and vital relationship with low cost, high levels of quality and strong delivery performance. Further, they found that the relationship can be explained by both direct and indirect relationships. Just- In- Time (JIT) practice was incorporated to derive a significant bond between TPM and manufacturing performance. They suggested a speculative frame for deducing the utility of TPM and how it depends on managerial factors such as Just-in-Time, Total Quality Management and Employee Involvement as well as environmental and organizational factors.
They experimented this framework using data from 97 plants in three different countries to determine what type of companies are most likely to aggressively pursue TPM practices. Consequently they discovered that specific contextual variables necessarily explained a significant portion of the variance in the level of TPM implementation. Finally they found the outcome of the study and concluded that while environmental ambient factors like country aids in explaining discrepancy in TPM execution, management related factors that are under the jurisdiction of managerial body of plants, are more pivotal to the execution of TPM programs.

Pomorski R Thomas, et al. (2004) [5] developed a research whose sole objective was "perfect manufacturing". He examined the basic concepts of TPM and reviewed the significant literature related to design, implementation and maintenance of TPM programmes in manufacturing processes. His detailed study included the organizational structures, human interactions, analytical tools and success criteria associated with the enforcement of Total Productive Maintenance process.

Gupta K Amit & Garg R.K, et al. (2012) [6] developed a paper on OEE improvement through TPM keeping in mind the global competition in manufacturing and production sector and customer satisfaction. Customers' delight lies in product quality, delivery time and cost of product. Hence, a maintenance system must be incorporated by the firms to improve and increase both quality and productivity continuously. Total Productive Maintenance is a policy aimed at increasing the availability of existing equipment thereby minimising the essence of extra capital investment.
The fundamental objective of this research paper is to study the effectiveness and implementation of TPM programme in an automobile manufacturing organization. They stressed on the case study of implementing TPM in an automobile manufacturing organization, the increase in efficiency and productivity of machines in terms of Overall Equipment Effectiveness (OEE). On the basis of results they developed a database which can be further used.

Singh Ranteshwar, Gohil M. Ashish, Shah B. Dhaval, et al. (2013) [7] proposed a research on TPM implementation in a machine shop. They studied that for a world class manufacturing process, none but Total Productive Maintenance (TPM) and Total Quality Management (TQM) are

inevitable. They investigated TPM on a company manufacturing automotive component. In a CNC machineshop, they used the concept where turning centres of varied capacities were used.OEE was used as a measure of success of TPM implementation. They identified the losses incurred, tried to lessen these with TPM pillars and thereby improved the CNC machine utilisation.

Ahuja I.P.S & Khamba J.S, et al. (2008) [8] proposed a paper on the literature of Total Productive Maintenance (TPM) and to enlighten an overview of the TPM processes practiced by different manufacturing firms. They further focused on eliminating the barriers in TPM implementation in these firms. They systematically studied the various issues like Overall Equipment Effectiveness (OEE), TPM framework, TPM implementation practices, obstacles and success factors. They categorized the published literature and analysed and reviewed it methodologically.

KumarPradeep, Varambally K.V.M, Rodrigues L.R Lewlyn, et al. (2012) [9] developed a methodology for TPM implementation in manufacturing industries. Due to the increasing competitiveness in global world to achieve superlative manufacturing processes, their study intended to help companies to look for new strategies to cost reduction, boosting employees to tackle unseen obstacles and bring about a new culture at work place.

First and foremost, they did literature review to understand the underlying concepts of TPM.Secondly, they conducted an empirical study about the high end Printing press machines &Packaging machines based on real time data and analysis was done to obtain achievable results. Last but not the least; questionnaires were distributed by them to assess information on successful implementation of TPM. Results gained through the empirical study revealed the varying drift in the total effectiveness of equipments and Total Productivity of the machines taken up for the study. They found that the average values of OEE lay between the ranges of 15% to 60% against world class standards of 85% and Total productivity (TP) laid between 0.09 to 0.34. Hence major causes resulting in the downtime and abatement in the productivity was highlighted by them. They conducted a comparative study between World Class industries with TPM and industries without TPM and henceforth identified the various problems leading to substantial decline in the overall efficiency of the industry and provided useful inputs prioritizing on the boon and methodology for implementing TPM in industries.

Poduval S Prasanth, Pramod V.R, et al. (2013) [10] proposed a paper on the barriers in TPM implementation in industries. They tried to study the problems faced by the industries in improving their manufacturing processes through TPM.Initially they explained the detailed concept of TPM and the momentousness of TPM in organisations in a complex business scenario. Later their motive of study became the hindrances encountered in TPM implementation in industries. Finally they provided a brief study to eliminate such barriers and ensure a smooth and flexible running of TPM.

Bangar A,Sahu Hemlata, Batham Jagmohan et al. (2013) [11] worked on a research work for improving Overall Equipment Effectiveness in an Auto Industry by TPM implementation through Pareto analysis and Kaizen methodology. Their foremost goal of the work revolved around OEE improvement and its three parameters viz. availability, performance and quality. They reduced the production losses and improved the OEE of the industry upto 96% by redesigning the workforce and improving the maintenance function.

Khan FirdosJahan, T.Z Quazi et al. (2014) [12] worked on the implementation of Kobetsu Kaizen pillar in improving Overall Equipment Effectiveness of machines. They studied that Kobetsu Kaizen approach is an important pillar of Total Productive Maintenance which had a major task of unifying the kaizen effort across the division. Furthermore they found that the pillar looks into all the losses, analyses the losses using various quality control tools and comes up with suggestions that need to be implemented to reduce recurring losses. They conducted the research for the implementation of the Kobetsu Kaizen pillar in a manufacturing company that is in project business and does not deal in repetitive products. They stated that the fundamental aim of this extended work study is to reduce the losses of the machine and a case study of a machine had been taken for a definite duration.

Jayaswal Pratesh, Rajput S Hemant et al. (2012) [13] worked on the implementation of Kaizen and Jishu Hozen to enhance Overall Equipment Effectiveness in a manufacturing industry. The case study was conducted in leaf spring manufacturing company and an attempt was made to identify the requisite areas of improvement. They implemented TPM pillars Kaizen and Jishu Hozen to increase the OEE and thereby enhance productivity. They also used why- why analysis to eliminate the root causes. They mentioned that before improvement, the

OEE was found to be 43%.But after the implementation of the above mentioned pillars, the OEE increased dramatically to a whooping 68% and labour cost decreased upto 43%.The increase in OEE resulted not only in better productivity but also excellent resource exploitation, high quality products and enriched employee morale and motivation.

H Kamath Nagaraj, Rodrigues L.R Lewlyn et al. (2014) [14] developed a case study for Total Production Management in printing industry. In this research, they built a conceptual model for Total Production Management, where they fused Total Quality Management (TQM) with Total Productive Maintenance (TPM) and employed System Dynamics (SD) for attaining a total productive environment. They coined the entire framework as Total Production Management. They laid primary focus on healthy working practices, team working and continuous improvement thereby improving performance. In the experimental setup, they performed convergent and discriminant validity test of the variables using smart PLS software.

Paropate V Ravikant, Sambhe U Rajeshkumar et al. (2013) [15] worked on the implementation and evaluation of Total Productive Maintenance in a mid sized Indian enterprise. They carried out the following case study at a cotton spinning plant to identify the extensive deficiency associated with equipment effectiveness. They intended to analyse the practical problems accomplishing TPM program and hence improved the effectiveness of critical machine by significant value.

Fore S & Zuze L et al. (2010) [16] proposed a plan for Overall Equipment Effectiveness improvement through Total Productive Maintenance. They approached a case study where focus was made on improving the maintenance in a manufacturing setup using an innovative maintenance regime mix. They used different data collection methods like interviews, reviewing, documenting, and historical records in addition to direct and participatory observation. The production was based on total kilowatt of motors produced per day. The target was 75 kilowatts per day which accounted for 91% availability. The factors affecting the manufacturing process were reduced demand and lack of raw materials. Due to lower availability of machines, the company had to reset the usual figure of 250 kilowatts per day to 75 kilowatts per day. General machine breakdowns too contributed to the problem.
They suggested a number of recommendations like full employee participation, trained personnel to meet the present and future trends of manufacturing criteria, keeping a track record of all corrective maintenance jobs and preventive maintenance inspections. But they further stressed that that for large plants, these are impossible to handle manually. So they recommended the implementation of Computerised Maintenance Management System (CMMS).

Vijaykumar S.R &Gajendran S et al. (2014) [17] proposed a plan for Overall Equipment Effectiveness improvement in an injection moulding process industry. Injection moulding is used in automobile industries to manufacture a large number of plastic parts through a plastic forming process. They stated that for a good manufacturing plant, the first and foremost thing is quality, efficiency and operating cost which are direct functions of equipments used in industry. They also opined that organisations must introduce maintenance systems to increase and improve both production and quality.OEE to them is the driving force of any organisation to increase productivity. In the research work conducted in the injection moulding industry, they succeeded in increasing the OEE from a about par 61% to a substantially better 81% through implementation of availability, better resource utilisation, good quality products and enriching employee confidence.

Kumar Sandeep & Gahlot Pardeep et al. (2014) [18] applied Total Productive Maintenance in Auto sector with SonaKoyo Group, Gurgaon.Their main area of concern was on quality product, product delivery time and product cost. They tried to implement TPM as a measure to increase availability of existing equipment thereby reducing the essence of further capital investment. They stated that Sona Koyo Group implemented TPM way back in 2000 with all the eight pillars in a phased manner. They studied the tangible and intangible benefits derived at various stages of TPM implementation. They studied and enumerated the objectives, targets and implementation policy. Basically their motive of the case study was to aid the other industries in implementation of TPM successfully and beneficially.

Phoewhawm Ravee et al. (2014) [19] performed a case study on Kaizen as a learning tool for a management team. He studied that due to complexity of working system, management teams often face a challenge in administrating Kaizen.So he stressed that these teams need to defy the way of aligning Kaizen with the organisational characteristic structure and operational practice so as to serve the benefits and interests of all people involved in the process. He practised a case study on the management team practicing Kaizen.He used the results as an outline for management teams to reap the benefits of the tool for rational

decision making, determining the distance for accomplishing goals and discerning the course of direction for the organisation.

Hedge G Harsha, Mahesh N.S, Doss Kishan et al. (2009) [20] performed a case study on Overall Equipment Effectiveness improvement by TPM and 5S techniques in a CNC machine shop. They aimed at minimizing breakdowns, increasing performance and machine quality rate to improve effectiveness. At first, they studied the machine history to find the bottleneck machine, whose OEE was found to be 43%.They emphasized on the three OEE parameters availability, performance and quality and formed a TPM team to address a systematic approach towards effectiveness.TPM techniques like Cleaning with Meaning, Preventive Maintenance, Kaizen and Pokayoke were successfully implemented by the team under their supervision.Consequently,they were able to raise the OEE from 43% to 72% and the total savings per annum was Rs. 4,53,000/-.

Ayane Nilesh & Gudadhe Mangesh et al. (2015) [21] performed a review study on improvement of Overall Equipment Effectiveness in construction equipments. They reviewed the objectives and benefits of TPM implementation and improving OEE of construction equipments. They presented a perfect picture of large construction companies whose success depends heavily on resources like man, materials and sophisticated machineries which are responsible for producing outputs. Thus the heavy and light construction companies are merely distinguished by the effectiveness of the machineries. They stated that OEE of a machine plays a vital role where performance and product quality are of paramount importance for such companies to sustain in the current competitive market. It can be improved by minimizing breakdowns, increasing performance and quality rate. They concluded that OEE can only be increased in the construction companies by improving the parameters like availability rate of machines, performance rate of machines and quality rate of products.

Relkar S. Anand & Nandurkar K.N. et al. (2012) [22] focussed on continuous availability of reliable sophisticated equipment with precision as need of the competitive market. They made a determined effort to measure and analyse existing overall equipment effectiveness of critical machinery producing important vehicle parts which are being used by a leading automobile company.
By measuring the performance of existing system, they obtained reference values for design of experiments. Using MiniTab15 software, they performed experimentation on three factors and two levels of OEE.Regression analysis and main effect plots gave the requisite information and correlation among performance rate, availability and quality rate was diagnosed precisely. In the analysis made by them, significance of each factor was indicated by P-value. Finally counplots and response surface methods resulted in finding the optimized values of the three factors of OEE.They concluded that simulated values of the output will be beneficial information to industry.

Sahu Shekhar, Patidar Lakhan, Soni K Pradeep et al. (2015) [23] of N.I.T, Bhopal worked on a research paper based on 5S transfusion to Overall Equipment Effectiveness for upgrading production levels. Their objective of the integrated concept was to create a clean, healthy workplace, improve quality and employee's satisfaction. They carried out an analysis to justify that the usage of 5S, calculation of OEE, analysis of current OEE status on manufacturing units helps access the current performance of assembly line and points out the vital factors for productivity improvement. They developed a model to identify a relationship among 5S, OEE and manufacturing productivity.

Vigneshwaran S, Maran M, Manikandan G et al. (2015) [24] proposed a literature review on the impact of TPM implementation. They tried to point out the tangible and intangible benefits obtained as a result of TPM implementation. They carried out the review by studying a number of research papers. It highlighted the involvement of TPM in improving OEE and employee morale.Finally; they made some conclusions and directions for future research.

Lalkiya Meet & Kushwaha K. Deepak et al. (2015) [25] proposed a research on optimizing and analysing OEE through TPM in a cement industry. They made an attempt to measure and analyse OEE of machinery producing pozolona portland cement. They measured the performance of the existing system and reference values were obtained for design of experiments. They used Mintab16 software to perform an experiment on three factors and two level of OEE.The most influential factor among them and the relationship between availability, performance rate and quality rate were obtained by them through main effect plots and regression analysis. They finally used the counter plots and response surface method to find the optimized value of the three factors of OEE.They concluded that simulated values of the output will be useful information to the industry.

IV. CONCLUSION

From the above analysis, it is found that all the researchers' fundamental priority is the improvement of Overall Equipment Effectiveness in any production or manufacturing organisation by the systematic and methodical implementation of TPM.Although the pillars of TPM formed the core of their study, the tools for improvement incorporated through TPM varied from researcher to researcher. Initial cleaning, cleaning with Meaning, Why-Why analysis, Fishbone cause effect diagram analysis, Kaizen analysis, Pokayoke analysis, Jishu-Hozen analysis became the backbone of OEE improvement strategy for all the analysts.

The three parameters of OEE viz. availability, performance rate and quality rate are taken special care off and their improvement directly contributed to improve effectiveness of the concerned machine or the entire production unit. Moreover, they emphasized on developing workplace conditions, developing machine conditions, zero defects, zero accidents, all employee participation, creating amicable work environment, engaging amiable behaviour among fellow employees, boosting employee morale and confidence to go with customers' satisfaction to the fullest as far as possible. It is thus observed that TPM forms the basis of OEE improvement in all industries and more research works are always invited to find an optimum possible method to improve the productivity.

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