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A Review on Development of Effectiveness Evaluation in the Manufacturing System

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Abstract: *In the global market scenario, sustaining in the ecumenical organization concentrates on their manufacturing and system. For this, the manufacturing industries were adopted to various world-class manufacturing implements in their organization. In which Total Productive Maintenance (TPM) implement plays a significant role. The implementation of TPM has been understood well by its effectiveness evaluation. The evaluation has also aimed to assess the current manufacturing performance status and execute amendments for further magnification. The evaluation has been carried out by sundry researchers in different indices for their desiderata and requisites under the substructure of Overall Equipment Effectiveness (OEE). The index has been developed to evaluate individual equipment and elongate it for the whole manufacturing system. A detailed literature review has been carried out and summarized with deference to the past three decenniums; the review includes the researcher's highlights or contribution with the difficulties associated with evaluating it in manufacturing industries.*

Keywords: *Performance Measurement, OEE, TPM, Benchmarking, Index Establishment, Losses.*

I. INTRODUCTION

A. Manufacturing System

Manufacturing is one of every business's principal strategic roles. It is an economic concept that refers to producing products and providing services to meet human needs [1, 2]. As shown in Figure 1, the production system takes inputs of material and energy and produces products as its output for the customer [3]. Total Productive Maintenance (TPM) is a manufacturing-driven methodology aimed at optimizing equipment availability and ensuring efficient management of plant assets, involving all levels of employees in an organization.

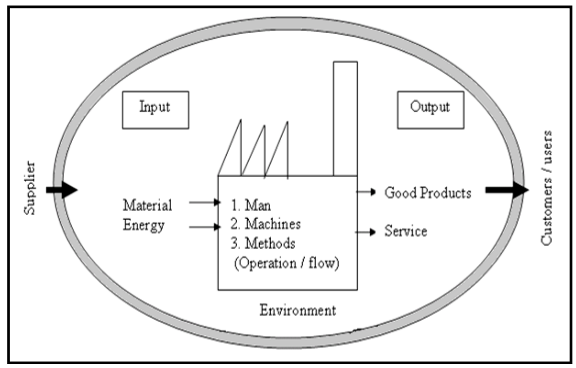

Fig. 1: The Basic Manufacturing System and its Components

After the introduction, the effectiveness evaluation related to TPM implemented manufacturing organization is considered. The various method of estimating effectiveness evaluation has been discussed in the literature review. The review part shows various indexes developed by researchers concerning their requirements and expectations. The summary part illustrated each index's lacuna, which acts as a reference index for all researchers. This article seeks to analyze the evolution of the different effectiveness index over time and how it was applied to the different sectors' needs.

B. Effectiveness Evaluation

The effectiveness calculation shows the amount to be achieved by the machine/appliance (a significant part of the manufacturing system). The level of compliance (output requested quantity) must be demonstrated to customer demand. Modern efficiency/effectiveness metrics, such as output and utilization levels, do not help assess the underlying challenges and efficiency improvement opportunities in a production system. The method of measuring output efficiency and the Effectiveness of the transformation process can be described. Productivity is defined as the actual output over the actual input. The comparisons between efficiency and Effectiveness are presented in two-dimensional matrixes in Figure 2 for easy to understand.

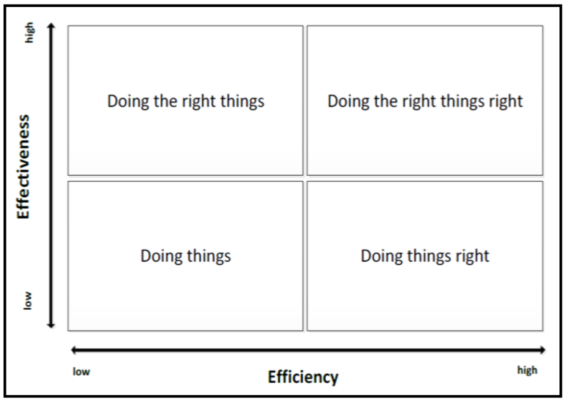

Fig. 2: Effectiveness and Efficiency Matrix

II. LITERATURE REVIEW

A. For Individual Equipment (without weightage)

Existing six major losses: The quantitative metric of the efficiency of individual manufacturing equipment in one plant, the father of TPM suggested OEE as in expression 1 and express 2 as suggested and expression 3 as estimated [4-7].

OEE = Availability × Performance × Quality ... (1)

OEE= Valuable operating time/Loading time ... (2)

OEE= Fully productive time/Net available time ... (3)

Special Features / Contribution

(i) Basic, simple, and easy to understand.
(ii) The initial OEE measurements can be correlated with future OEE values as a 'benchmark' by quantifying the progress degree achieved.
(iii) For an individual machine, the loss structure was framed in a tree format (until it reaches the root level).
(iv) OEE targets equipment incorporated in a manufacturing system such that OEE integrates environmental factors.

Problem / Lacuna

(i) Concerning organization (manufacturing types), losses will be more (non-categorized into these six major losses).
(ii) Capacity utilization/machine utilization has not been addressed, i.e., planned downtime, lack of material, human resources.
(iii) The term loading time is confusing towards evaluation; instead of that available time would be more appropriate.

A calculation of output was proposed in expression 4 by combining the terms for Availability and loss of use with system rate efficiency and quality expression and obtains OEE [8].

$$\text{OEE} = \{1.0 - \text{DT} - \text{IT}\}\ \text{x}\ (\text{RE})\ \text{x}\ (\text{RQ}) \quad \dots (4)$$

Special Features / Contribution:

(i) I am combining availability expressions and utilization losses with system performance and output levels expressions.
(ii) Simple to calculate and understand.

Problem / Lacuna:

(i) Since theoretical times, all factory service changes are stable, excluding technological changes in the equipment or final asset replacement.
(ii) Statistically, operator inefficiencies are difficult to measure and extremely maintenance intensive.
(iii) The parameters/components needed to be taken to account in technical data are not clear.

Total Equipment Effectiveness Performance (TEEP) proposed [9] is very similar to OEE, as given in expression 5.

TEEP=Valuable operating time/Total available time ... (5)

Special Features / Contribution

(i) MTBF and MTTR are called equipment performance metrics related to targets such as functional efficiency and processability.
(ii) A thorough review of timeout and time down would imp rove equipment access by increasing the MTBF or reducing the MTTR.

Problem / Lacuna

(i) The TEEP calculation is identical to OEE and is limited to the efficiency of the equipment.
(ii) This shall also refer to a processing plant or flow shop that can handle the production cycle as a single manufacturing entity.

Design the Equipment Effectiveness (EE) focused on a systematic equipment approach [10] as given in expression 6.

EE = Yield x Rate factor x Availability ... (6)

Special Features / Contribution

(i) Infrastructure and facilities are treated as a device by EE. This machine executes the output role. The requirements imposed by the program have been met to fulfill the manufacturing role.
(ii) EE is considered the rework phenomenon and decreases linearly with rework.
(iii) Equipment dependant failures are only considered.
(iv) EE is explicitly determined by output and productive period, which does not reply on equipment usage.

Problem / Lacuna

(i) Machine utilization does not change Effectiveness.
(ii) EE will vary only if the improvement in the design of equipment only not by the input or feeding parameters.
(iii) We are not linked with six losses.

(iv) Equipment independent (surrounding) failures are not considered.

In addition to an existing OEE calculation process [11] called updated OEE in expression 7.

Modified Overall Equipment Effectiveness = Availability x Performance Efficiency x Usability x Quality rate ... (7)

Special Features / Contribution

(i) Due to the expected and induced stoppage time but not because of equipment malfunction or malfunction, OEE's equipment output is poor.
(ii) Examines the stop time, as a different agency would be based more on change, both the planned and unplanned stop times.
(iii) The performance efficiency is measured based on the run time (the difference between running time and stop time) rather than the running time (the difference between expected production time and unexpected downtime).

Problem / Lacuna

(i) The difference in the category of calculation will not be much higher.

An index suggested by combining the existing effectiveness index OEE with the energy management technologies [12] in expression 8 as Overall Equipment and Energy Efficiency (OEEE).

OEEE = OEE x E … (8)

Special Features / Contribution

(i) To estimate industrial energy demand and particularly for the estimation of energy requirements of alternative production strategies, energy consumption is important.
(ii) Towards sustainability in their production optimization schemes, it is necessary to consider energy utilization.
(iii) Manufacturing operations are among the most energy-intensive in the world. This index has extended the traditional Overall Equipment Effectiveness index with energy consumption aspects.

Problem / Lacuna

(i) The collection of components of 'E' is difficult.
(ii) Estimation (quantification with units) of E from particular physical devices/equipment is difficult.
(iii) Matching of units of different energy quantification will lead to error.

Modified the Effectiveness estimated [13, 14] and suggested in expression 9 as Overall Resource Effectiveness (ORE) as the degree of the manufacturing resources' overall active time.

ORE = Readiness x Availability of facility x Changeover efficiency x Availability of material x Availability of human resources x Performance efficiency x Quality efficiency ... (9)

Special Features / Contribution

(i) Combination of time and quantity related measures.
(ii) Equipment utilization is considered.

Problem / Lacuna

(i) Concentrate more on the resources.
(ii) Loses are not categorized.
(iii) The bottleneck process is not able to identify it easily.

With additional losses [15], a standard for the description and measurement of OEE has been established by Semiconductor Equipment and Materials International (SEMI) in expression 10.

OEE = AE x (OE x RE) x QE ... (10)

Special Features / Contribution

(i) Additional losses are considered.
(ii) In addition to machine availability of machine operational status has been considered.

Problem / Lacuna

(i) Production time is ideally purely sufficient time without loss of efficiency at purely technically speaking levels, which is impossible to achi eve.
(ii) Environmental effects on the OEE can be more commonly tackled by considering usage.
(iii) Even if the downtime is doubling, the AE and OE sub metrics are altered due to the rise in downtime, but their output has not changed because processing time has not changed. The OEE won't adjust as a result.
(iv) The rework percentage does not depend on OEE.

The Effectiveness of the modification was found by employing additional losses suggested [16] given in expression 11.

OEE = Time Efficiency x Speed efficiency x Quality Efficiency ... (11)

Special Features / Contribution

(i) Hidden time losses are initiated.
(ii) Because of considering Machine utilization, it is more suitable for the capital intensive industry.

Problem / Lacuna

(i) It is difficult to calculate losses such as uncontrolled time, unscheduled time for repairs, engineering time, WIP, lack of idle time without the operator in a real-

world environment, and a good data collection system. Therefore for the industry of small scale, it is not suitable.
(ii) It is challenging to identify engineering time, R&D time with deployment, and modification losses.
(iii) The contributing parameter is calculated using a similar phenomenon, which leads to an error.

B. For Individual Equipment with Weightage

A new computing effectiveness method is described in expression 12 for a discrete process and expression 13 for the continuous process as Production Equipment Effectiveness (PEE) for a discrete process [17].

PEE = (Ak1) (Ek2) (Qk3) ... (12)

$PEE = (A_1)^{k1} (A_2)^{k2} (E)^{k3} (QR)^{k4} (PSE)^{k5} (OU)^{k6}$ $0<k_i\leq 1$ and $\sum_i k_i = 1$ ... (13)

Special Features / Contribution
(i) By assign weightage, the organization evaluates the realistic data.
(ii) All PEE variables are not as relevant, and the different weights (k_i) should be calculated with proven techniques.
(iii) Adopted two different methods of estimation towards the discrete and continuous process.

Problem / Lacuna
(i) Weightage is arbitrary, as these disparate effectiveness values (assigned by senior managers based upon their opinions and experience) indicate the difficulty of comparing OEEs between processes.
(ii) The stage set is not uniform with all various divisions of divisions and industries.

Estimate the Effectiveness as Overall Weighted Equipment Effectiveness (OWEE) with weightage to the existing effectiveness estimation method suggested [18] in expression 14.

$OWEE = W_A\, A \times W_p \times P \times W_Q \times Q$ ... (14)

C. For Group of Equipment (Simple Configuration)

Drawing an organizational approach to a rough efficiency assessment as an OEE process [19] is expressed in equation 15.

Process $OEE = A_{BN} \times P_{BN} \times Q_{Tot}$ ... (15)

Special Features / Contribution
(i) Easy to calculate for the total line.
(ii) Consider the rework quantity in the quality percentage.

Problem / Lacuna
(i) All the workings are based on the performance of the Bottleneck machine. But the bottleneck machine identification is identified using only the ideal cycle time, not based on the losses present in the processes/machine in the product line.
(ii) Theoretical only and not validated with any case study.
(iii) Planned downtime is not considered in availability evaluation.
(iv) Calculation and categorization of losses in different processes of the line without software or computer is difficult.

To evaluate the Effectiveness (in expression 16) of a continuous line manufacturing system was developed [20] in terms of Overall Line Effectiveness (OLE) obtain as the Product Line Availability (LA) and Line Production Performance (LPQP).

OLE = LA x LPQP ... (16)

Special Features / Contribution
(i) To test the OLE in product line systems with n numbers of computers, a computer simulation was performed.
(ii) Validated with a case study of the car tyre manufacturing industry.
(iii) OLE can be used to calculate the initial output of the enti re production facility.
(iv) Sensitivity analysis is used to recognize the process of the bottleneck in LA/LPQP.

Problem / Lacuna
(i) It will underestimate the performance of the line
(ii) It will not consider the losses that occur during transfer (material handling)
(iii) The inventories between the equipment/process of the product line are not addressed.

A new index was suggested [21] to Evaluate the Effectiveness of the line with inventory between the product line processes in expression 17 and the Overall Equipment Effectiveness of a Manufacturing Line (OEEML).

$$OEEML = \frac{\text{Actual Output}}{\text{Reference Output}} = \frac{O_{LM}}{LT/_{CT_{BN}}} \quad \text{... (17)}$$

Special Features / Contribution
(i) The crucial points of the line are found and quantified.
(ii) With the line comprising buffers/inventories, it can be extended without underestimating device effectiveness.
(iii) Additional losses in the travel line (other than equipment related) have also been considered.
(iv) This is ideal for a manufacturing case with an automated line for the production of engine basements.

Problem / Lacuna
(i) OEEML fails to explain how the inventories lie between the processes improve the Effectiveness.
(ii) The optimum quantity of items stored between the processes and its associated cost is not considered.

(iii) The ideal machines (ideal cycle time) are considered, but they lack a real-world scenario.

D. For Group of Equipment (Simple Configuration) with Weight Age

The OEE is just half of the maximum output equation [14], regarded as the Overall Performance Equipment (OPE) shown in expression 18.

$$TEE = OIE \times OEE \quad \text{... (18)}$$

Special Features / Contribution

(i) In a shorter time, the OEE side generates more valuable goods from the same used energy. Overall Input equipment Efficiency (OIE) side changes that production costs at the same performance.
(ii) As the OEE reaches its maximum, the avoidance of wast e is an integral distinction between a business and its riv als.
(iii) The Management may define each system's relative trouble areas by benchmarking the main downstream components of the related devices so that specific benchmarks are given for adjustments for all suppliers of goods or machinery.

Problem / Lacuna

(i) No systematic measurement of OIE is available.
(ii) The analysis is never located on the optimal input stage.
(iii) Direct benchmarking of TEE is difficult.

E. For Group of Equipment (Multiple/Complex Configuration)

The entire production system architecture division into single subsystems like 'sequence, parallel, assemblies, and expansion' can encourage monitoring and evaluation [22] of plant rates, as shown in Figure 3. For increasing of these subsystems, the Overall Throughput Effectiveness (OTE) calculation is then obtained, shown in expression 19 to 22.

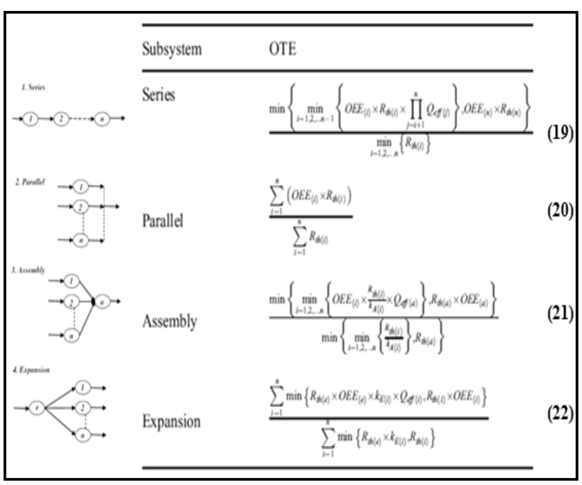

Fig. 3: OTE for Four Subsystems

Special Features / Contribution

(i) In addition to calculating factory output, the part of the device that limits efficiency is also indicated.
(ii) The total value of OTE shows theoretical enhancement.

Problem / Lacuna

(i) More theoretical.
(ii) The calculation, monitoring, and bottleneck attacking in a practical production line are difficult. So, automation in data capturing and calculation is fundamentally required. Automating the established modeling method and metric analysis of manufacturing systems will enable factory professionals to calculate the plant-level output and efficiently conduct diagnostic analyses.
(iii) In the series system, the second machine has an inactive schedule due to decreased production compared with the first machine.
(iv) Deciding as good or bad using the OTE is wrong. The product and method depend on it.

The Effectiveness as Overall Line Effectiveness (OLE) metric was developed [23] and shown in expression 23.

$$OLE = A_{line} \times P_{line} \times Q_{line} \quad \text{... (23)}$$

Special Features / Contribution

(i) The calculation of Availability, productivity, and consistency of such processes along the manufacturing line is an important measure of manufacturing success.
(ii) OLE's value can help the organizations recognize the gap from benchmark criteria in the same industry.
(iii) Consider the rework quantity in the quality percentage.

Problem / Lacuna

(i) The values of losses at different processes in the line are summed and deducted from planned time / designed time, which is more theoretical.
(ii) Planned downtime is not considered in availability evaluation.
(iii) Calculation and categorization of losses in different processes of the line without software or computer is difficult.

F. For Complete Factory without Weightage

Overall Throughput Effectiveness (OTE) was referred for metrics as the ratio of the number of good parts produced by the system in total time to the theoretical number of parts produced by the system in total time [24].

Special Features / Contribution

(i) Easy to estimate.
(ii) Output-based.

Problem / Lacuna

(i) Identification of losses is difficult.
(ii) Design speed and actual speed matching are different concerning the environment (operating conditions).

OEE definition is applied to the factory level [25], known as the Overall Throughput Efficiency (OTE) as the ratio of good product output from the factory to theoretical attainable product output (units) from the factory in total time.

Special Features / Contribution

(i) OTE has been used as quantitative benchmarking and productivity improvement for comparison of various factories.
(ii) Simply to estimate (output/quantity oriented).

Problem / Lacuna

(i) The benchmarking of various equipment or working stations that make up the business is not easy and realistic because it can not reflect, quantitatively, the output at the OEE level.
(ii) Identification of losses is difficult.
(iii) Analysis at the factory level instead of equipment level.

A new index was proposed for productivity indicators as Overall Factory Effectiveness (OFE) as the production efficiency and yield efficiency [26].

Special Features / Contribution

(i) OEE only is not sufficient; controlling single tools seems to be not sufficient.
(ii) Different parameters which are important for effectiveness evaluations like delivery, yield, ramp-up time, capacity utilization is considered.

Problem / Lacuna

(i) Contributing parameters are not easy to capture.
(ii) The calculation is difficult.

A theoretical measure was developed as Global Production Effectiveness (GPE) with the average of ME, SE, TE, STE, and PE [27, 28].

Special Features / Contribution

(i) Easy to calculate/ estimate.
(ii) To understand the performance of the complete factory at one stretch to decide.

Problem / Lacuna

(i) The losses and their contributing parameters are not able to identify.
(ii) Average will mislead the manager in decision making.
(iii) It is only a theoretical one, and practical computations of these sub-parameters are very difficult.

G. For Complete Factory with Weightage

The effectiveness evaluation metric was suggested for a complete factory [29], as shown in expressions 24 and 25 as Overall Factory Effectiveness (OFE).

$$OFE = \text{Average of } [(W_1 \times OEE_1) \times (W_2 \times OEE_2) \times (W_n \times OEE_n)] \quad \text{... (24)}$$

$$OFE = [(W_1 \times OEE_1) \times (W_2 \times OEE_2) \times W_n \times OEE_n)] \quad \text{... (25)}$$

Special Features / Contribution

(i) Easy to calculate/ estimate.
(ii) To understand the performance of the complete factory at one stretch to decide.

Problem / Lacuna

(i) The losses and their contributing parameters are not able to identify.
(ii) Average will mislead the manager in decision making.

III. RECOMMENDATION AND SUMMARY

Effectiveness indicators about 29 types can be evaluated from the equipment level, organizational level, and total output or manufacturing level, as shown in Figure 4. These efficiency indices are defined as measuring the ability to operate the equipment with the speed and zero faults without failure.

The decade wise (first decade 1980-90, the second decade 1990-2000, third decade 2000-10, fourth decade 2010-20) summaries of Effectiveness indexed developed by various researchers are grouped and shown in Figure 5. Since the first index (OEE) of Effectiveness was developed in 1988 by Nakajima, it has been taken as the first decade. From Figure 5, it is inferred that the researcher will slightly be shifting their area of concentration from original equipment to a group of equipment and to complete factory.

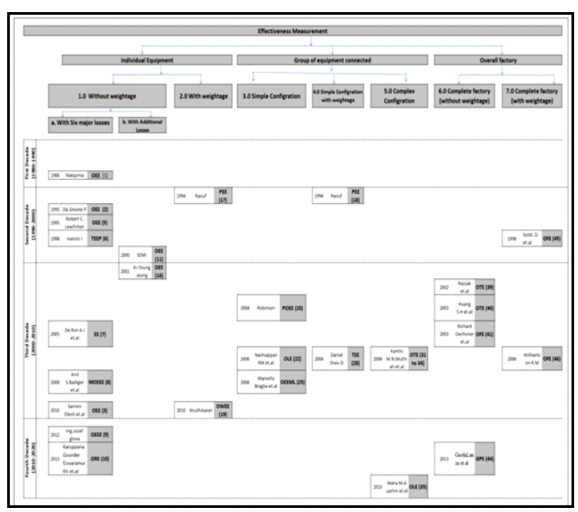

Fig. 4: Various Indexes used by Researcher to Estimate Effectiveness

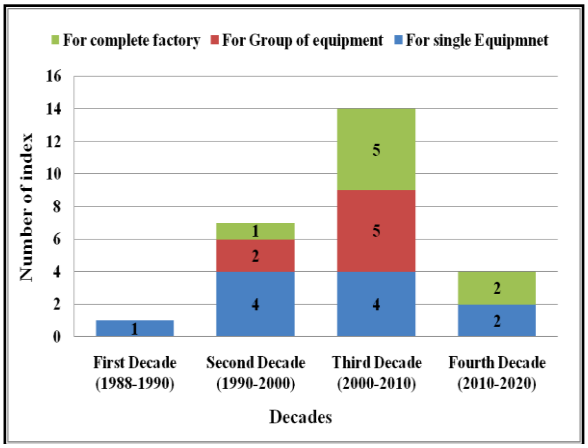

Fig. 5: Decade Wise Summary of Effectiveness Index

In the past four decades (1980-2020), based on the literature review related to TPM, out of 219 research article, nearly 87 percentages of articles (191) concentrate on effectiveness evaluation in the existing manufacturing/assembly/processing industries and present the level improvement achieved in the Effectiveness after implementing kaizen. The remaining (28 articles) researchers are only made efforts to establish effectiveness indexes, so the quantity of literature referred to in Figure 5 is less.

IV. CONCLUSION

The calculated output elements in the different indexes are not enough to describe a production method's efficiency. Some critical factors are not calculated (e.g., costs and flexibility). More work should look at the complexities of cost efficiency or cost loss conversion of equipment. This paper review of various indexes towards the Effectiveness of the manufacturing industries adopting the TPM tool is given briefly. All the researchers have modified the existing index concerning their needs and requirements. By analyzing those measures/index, a simple, consolidated, and general effectiveness performance measurement index must evaluate a complete manufacturing system's performance irrespective of the configuration/modeling of the equipment/processes.

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