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# EVALUATION OF THE CONTRIBUTORS OF OEE (OVERALL EQUIPMENT EFFECTIVENESS) USING SHAPLEY VALUE: A CASE STUDY

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**Abstract**
Overall Equipment Effectiveness (OEE) is a powerful metric of manufacturing performance incorporating measures of the utilization, yield and efficiency of a given process, machine or manufacturing line. Three measurable components: Performance Rate (PR), Quality Rate (QR) and Availability (A) are working together to achieve an OEE and their combinations in each period are always different. The best tool to evaluate the contribution of these components or contributors is the Shapley value, proposed by Lloyd Shapley. This paper estimates how each component has contributed to OEE at a decided period, and estimates during which period the activity was best performed and the best contributed component using the Shapley value in a continues process industry.

**Keywords – Performance Analysis, Overall Equipment Effectiveness, Shapley Value.**

## 1. INTRODUCTION

Overall Equipment Effectiveness, or OEE for short, is a productivity and performance metric that is widely discussed in the manufacturing industry. While the theoretical merits of the metrics are understood and accepted, the application is a challenge to any manufacturing organization. Overall Equipment Effectiveness (OEE) is a powerful metric of manufacturing performance incorporating measures of the utilization, yield and efficiency of a given process, machine or manufacturing line. When associated with the reasons for performance loss, OEE provides the means to compare and prioritize improvement efforts. The term Overall Equipment Effectiveness takes into account the most common and significant sources of manufacturing productivity loss and organizes them into three classes: Availability, Performance and Quality. All three factors, and OEE itself, are generally expressed as percentages, allowing for ease of comparison and improvement measurements.It is a set of broadly accepted, non-financial metrics which reflect manufacturing success. Good data collection and analysis are key requirements for a successful

OEE project. While calculating OEE, we could understand that the Production department is responsible for Performance Rate, the Quality department and Maintenance department are responsible for Quality rate and Availability, respectively. Knowing the contribution factors of each distribution helps with ease of managing activities. The best tool to evaluate the contribution of these components or contributors is the Shapley value, proposed by Lloyd Shapley in 1953(Muhamad Arifpin Mansor, Ario Ohsato, 2010).

This paper attempts to find the plant performance indicator through OEE and to evaluate its contributing components in a manufacturing industry. The level of contribution involves the best performing parameter or department and also the period.

## 2. LITERATURE REVIEW

The object of production improvement activities is to increase productivity by minimizing input and maximizing output. More than sheer quantity, "output" includes improving quality, reducing costs and meeting delivery dates while increasing morale and improving safety and health conditions and the working environment in general (Nakajima, 1988:12)USE et al.

Overall Equipment Effectiveness is the primary metric of Total Productive Maintenance. It indicates a single piece of equipment's actual contribution as a percentage of its potential to add value to the value stream (Bernstein, 2005:66).

According to Bernstein (2005:101), OEE = availability rate × performance rate × quality rate.

According to Davis (1995:37), overall effectiveness is a measure of all three of these factors (percentage availability, percentage performance, percentage quality) and, although it is not strictly a percentage, it is usually represented in percentage terms and is calculated as overall effectiveness = % availability % performance efficiency % quality.

Shapley Value is a concept of Game Theory, aimed at proposing the fairest allocation of the profits collectively obtained between the players in cooperation. It evaluates the contribution of each component of combinational efforts. The tool was proposed by Lloyd Shapley in 1953.

## 3. OVERALL EQUIPENT EFFECTIVENESS

Nakajima (1988) defines six large equipment losses:

a. Equipment failure/breakdown losses.
b. Set-up/adjustment time losses.
c. Idling and minor stop losses.
d. Reduced speed losses.
e. Start up losses.

f. Quality defects and reworks losses. The first two losses are known as downtime losses and are used to calculate the availability, A, of equipment, and is defined as:
Availability= (Loading time-Downtime)/Loading time.

The third and fourth losses are a speed loss, which determine the performance efficiency, PE, of equipment and is defined as:
Performance=(Processed amount - Actual cycle time)/Operating time.

The final two losses are considered to be losses due to quality defects, i.e. scrap, rework and start-up

losses, defining as the quality rate, QR, and is defined as:
Quality rate= (Processed amount - Defect amount)/Processed amount.

The three components above contribute to the determination of indicator OEE that globally expresses the production line effectiveness, and is defined as:
OEE=Availability x Performance x Quality rate.

TPM seeks to improve the OEE, which is an important indicator, deployed to measure the success of TPM program in an organization. TPM has the standards of 90% availability, 95% performance efficiency and 99% rate of quality (Levitt 1996). An overall 85% benchmark OEE is considered as world-class performance (Blanchard 1997, McKone et al. 1999). For continuous discrete processes, the OEE should be higher to 90%, whereas for continuous on stream processes industries should have OEE values of 95% or better (Hansen 2002).

## 4. SHAPLEY VALUE

Shapley value is a concept of Game Theory, aimed at proposing the fairest allocation of the profits collectively obtained between the players in cooperation. It evaluates the contribution of each component of combinational efforts. The tool was proposed by Lloyd Shapley in 1953.The steps in finding out the Shapley value is shown below.

Assume that there are n players with m contributor and let w be the weight to the contributor. Any subset S of the player set N= (1… n) is called a coalition The record for the coalition S is defined by

$$x_i(S) = \sum_{j \in S} x_{ij} \qquad (i = 1, \ldots m)$$

Where $x_y$ is the record of player j to the contributor i.

This coalition aims at obtaining the maximal outcome c(S):

$$c(S) = \max \sum_{i=1}^{m} w_i x_i(S)$$
$$\text{s.t} \sum_{i=1}^{m} w_i = 1, \quad w_i \geq 0 \ (\forall i)$$

Thec(S), withc(φ)=0 , defines a characteristic function of the coalition S. Thus, we have a game in coalition form with transferable utility, as represented by (N,c)[2]

The Shapley value of the game (N,c) for the player k is the average of its marginal contribution to all possible coalitions:

$$\varphi_k(c) = \sum_{\text{all } S} \gamma_n(S)\left[c(S) - c(S - \{k\})\right]$$

With weights of probability to enter into a coalition S defined as following:

$$\gamma_n(S) = \frac{(s-1)!(n-s)!}{n!}$$

In (3) and (4), n is the total number of all the participants, s is the number of members in the Sth coalition, and is the characteristic function used for estimation of utility for each coalition. If a subset S ( N) includes player k, k's marginal contribution is obtained as

$c(S)-c(S-\{k\})$[3][4]

## 5.CASE STUDY

5.1 Company Profile

The case study pertains to a Cable manufacturing industry doing business in quality cables, wires, conductors etc.

A deep study about the plant, organizational structure, production process maintenance schedule, quality assurance policies etc was done before the data was collected to calculate the OEE value. The OEE value was calculated for three consecutive years (2010, 11,12).

5.2 Flow Process Chart

The flow process chart of the production line of power cables is shown in the figure shown below

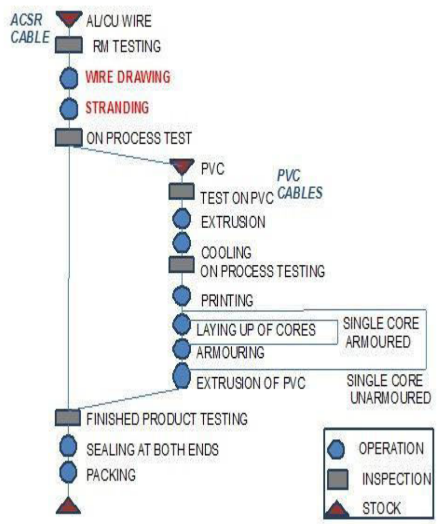


FIGURE 1. FLOW PROCESS CHART.

5.3 Plant Performance Indicator

The OEE value for the three consecutive years and are as shown in the table below.

| OEE PARAMETERS | 2012(t1) | 2011(t2) | 2010(t3) |
|---|---|---|---|
| PERFORMANCE(P) | 0.49 | 0.63 | 0.57 |
| AVAILABILITY(A) | 0.50 | 0.66 | 0.59 |
| QUALITY(Q) | 0.99 | 0.99 | 0.99 |
| OEE | 0.24 | 0.41 | 0.33 |

TABLE 1. OEE VALUE

### 5.4 Analysis Using Shapley Value

Shapley value analysis can be used for evaluating the best year of performance and the best department for contributing the best towards OEE. Each player's Shapley value by the highest value of Shapley value to obtain a score for each player known as "Scale of Balance" (SOB).The SOB indicates the position of each player against the best performing player.

The simulation matrix, normalization matrix, Coalition matrix and the permutations for finding the best year of performance are shown in the tables below.

TABLE 2: SUMMATION MATRIX

| OEE PARAMETERS | (t1) | (t2) | (t3) | SUM |
|---|---|---|---|---|
| PERFORMANCE (P) | 0.49 | 0.63 | 0.57 | 1.69 |
| QUALITY(Q) | 0.99 | 0.99 | 0.99 | 2.97 |
| AVAILABILITY (A) | 0.50 | 0.66 | 0.59 | 1.75 |
| OEE | 0.24 | 0.41 | 0.33 | |

TABLE 3: NORMALIZATION MATRIX

| OEE PARAMETERS | (t1) | (t2) | (t3) | SUM |
|---|---|---|---|---|
| PERFORMANCE (P) | 0.29 | 0.37 | 0.34 | 1 |
| QUALITY(Q) | 0.33 | 0.33 | 0.33 | 1 |
| AVAILABILITY (A) | 0.29 | 0.38 | 0.34 | 1 |
| OEE | 0.24 | 0.41 | 0.33 | |

TABLE 4: COALITION MATRIX.

| OEE PARAMETERS | (t1,t2) | (t2,t3) | (t3,t1) | (t1,t2,t3) |
|---|---|---|---|---|
| PERFORMANCE (P) | 0.66 | 0.71 | 0.63 | 1 |
| QUALITY(Q) | 0.66 | 0.66 | 0.66 | 1 |
| AVAILABILITY (A) | 0.67 | 0.72 | 0.63 | 1 |
| OEE | 0.24 | 0.41 | 0.33 | |

TABLE 5: PERMUTATIONS

| PERMUTATIONS | t1 | t2 | t3 |
|---|---|---|---|
| t1,t2,t3 | 0.33 | 0.34 | 0.33 |
| t1,t3,t2 | 0.33 | 0.34 | 0.33 |
| t2,t1,t3 | 0.29 | 0.38 | 0.33 |
| t2,t3,t1 | 0.28 | 0.38 | 0.34 |
| t3,t1,t2 | 0.32 | 0.34 | 0.34 |
| t3,t2,t1 | 0.28 | 0.38 | 0.34 |
| SHAPLEY VALUE | 0.3 | 0.36 | 0.33 |

TABLE 6. SHAPLEY VALUE FOR BEST PERFORMING YEAR

| | t1 | t2 | t3 |
|---|---|---|---|
| SHAPLEY VALUE | 0.3 | 0.36 | 0.33 |
| SOB | 0.83 | 1 | 0.92 |
| OEE | 0.24 | 0.41 | 0.33 |

For finding the Shapley Value to determine the best contributor the transpose of the performance indication matrix is taken and the above steps are repeated.

TABLE 7. SHAPLEY VALUE FOR BEST PERFORMING DEPARTMENT

| | A | P | Q |
|---|---|---|---|
| SHAPLEY VALUE | 0.265 | 0.27 | 0.47 |
| SOB | 0.56 | 0.57 | 1 |

5.5 Findings

From the analysis we could easily compare the contributors and periods. During the year 2011(t2) the activities were well performed followed by 2010(t3) and 2012(t1). Also the Quality department contributed the maximum to OEE followed by Production and Maintenance departments.

## 6. CONCLUSION

From the case study, the contribution of components of OEE by the Shapley value was able to carry out two kinds of evaluations by changing the position of the player and contributor. That is, components of OEE as the contributor and period as the player, and vice versa. The former is to measure during which period the activity was best performed. The latter measures how each operator has contributed to OEE at the determined period. By knowing the value of a contribution, it becomes easy to identify on which section needs further improvement.

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