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# Machine performance index (MPI): a method to evaluate the performance of mining dumper

*Efficiency and effectiveness of equipment play a dominant role in modern mining industry to determine the performance of mining equipment as well as mines. Greater the efficiency and effectiveness more productive is the organization (mine). As it is known that mining industry is a very capital intensive industry. Hence, a proper performance measurement is very necessary in this field. Since last many years, overall equipment effectiveness (OEE) has been used in different industries as a measure of performance, but due to limitations in the original OEE, it has been modified continuously time to time by different researchers and practitioners in the different field accordingly. Since, last two decades OEE has also been used in mining industry. This research assigns different weightage to different components by using analytical hierarchy process (AHP), and thereby determines the weighted OEE i.e., machine performance index (MPI). The main purpose of assigning the weightage is to show the influence of each component in the evaluation of OEE. In original OEE, the weightage given to each component was equal which was not justifiable logically. To check the applicability of this new method, a case study was done on dumper in an opencast coal mine of India.*

***Keywords:*** *Dumper; OEE; Performance; weightage; AHP, MPI.*

## Introduction

The topic performance measurement has received considerable attention during the last few decades. There are many objectives for using performance measures in any field, but perhaps the most crucial one is that they will help to improve the performance and productivity. The main purpose of performance measurement (PM) is to provide the reliable information to support the decision-making process. The nature of today's business is unique, and with the increasing trend of globalization, the organization's performance measurement system (PMS) requires a different dimensional approach which covers all aspects. Performance measurement is main concern in any industry or organization. Hence, time to time the improvement in the performance measurement tools has been done accordingly. Overall equipment effectiveness (OEE) is one of the best tool to monitor the performance of any manufacturing process. Later on, OEE was modified by different researchers and practitioners in different industries and organizations accordingly. It is a very good indicator to compare the status of performance with designed capacity as well as best practices in the similar industry.

Initially, Nakajima (1988) [1] proposed the concept of overall equipment effectiveness (OEE) to evaluate the effectiveness of equipment in manufacturing industries. Nakajima (1988) [1] included six big losses (Fig.1) to describe the OEE of the equipment in manufacturing industries. According to Nakajima (1988) [1], OEE was defined as the multiplication of availability, performance, and quality losses are shown in Fig.1. OEE tells whether the equipment is in under-utilization or over- utilization.

The Semiconductor Equipment and Materials International (SEMI) (2000) [2] has developed a standard for the definition and measurement of OEE as introduced by Nakajima (1988) [1]. The standard is directed towards measuring the effectiveness of equipment. SEMI renamed the metric overall equipment efficiency, as it is expressed entirely in terms of time. The standard has been described by SEMI (2000) [2] and uses definitions as laid down by SEMI (2001) [3]. A guide for the application of OEE is described by Ames et al. (1995) [4].

Previous research has targeted various aspects of OEE. For example, Ljundberg (1998) [5] states that the definition of OEE does not take into account all factors that reduce the capacity utilization, e.g. planned downtime, lack of material input, lack of labour. In addition, the available time would be a more appropriate basis for time measurement than the loading time as it was originally used by Nakajima (1988) [1].

The description given by Nakajima (1988) [1] and SEMI (2000) [2] is directed towards equipment, but OEE is impacted greatly by factors beyond the equipment itself, including the operator, recipe, facilities, material (input items) availability,

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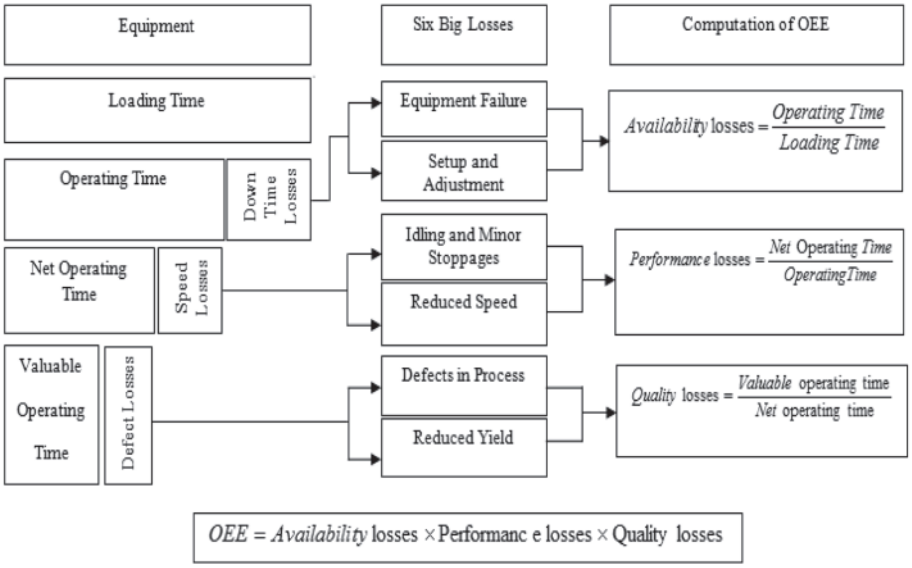
measure (Mckone and Schroder, 1999) [9] for driving plant improvement and it continuously focuses the plant on the concept of zero-waste. Except these, some other researchers like Prickett (1998) [10], Jonsson and Lesshammar (1999) [11], Jeong and Phillips (2001) [12], Ljungberg (2001) [13], and Bamber et al. (2003) [14] have done research in the same field.



Source: Nakajima (1988) [1]

Fig.1 OEE and computation procedure

Raouf (1994) [15] has not followed the traditional method of computing OEE given by Nakajima. In Nakajima's concept of OEE, he has given equal weights to all the three components of OEE (A, P, and Q) in ideal conditions but in real life situation is different. Hence, he has given different weights to different components. He assumes that quality has different weight from performance and different from availability contrary to the basic assumption in OEE that the three elements have the equal weight. He introduces another metrics as production equipment effectiveness (PEE) is calculated as follows:

$$PEE = A^{x1} \times P^{x2} \times Q^{x3} \qquad \text{... (1)}$$

$x_1$ are the weights of the PEE elements (for $i$ = 1 to 3), $0 < x_i < 1$ and $\Sigma_{x_i} = 1$

Briefly, the evolution and its various modifications are shown in Table 1.

scheduling requirements, etc. As this may result in OEE values influenced by factors beyond the equipment itself, a distinction can be made between stand-alone equipment and integrated equipment. OEE is directed towards equipment integrated in a manufacturing environment, so that OEE includes the influences of this environment.

As OEE is an effective tool to determine the performance, it has limitations also.

In the conventional OEE calculation method, equal weightage has been given to all the multiplying factors of OEE which represents a rare situation when 1 per cent downtime loss has same financial impact as 1 per cent efficiency loss, 1 per cent quality loss. In practical situation, it may not be correct to assume equal weightage to all the OEE elements. These weightage factors are expected to vary from one industry to other depending on their nature of work. The weightages for these OEE elements can be assigned by using analytical hierarchy process (AHP). According to Satty (1990) [6], AHP is a multicriteria decision-making mathematical technique. It is used many times in a number of different complex problems by governments, education sectors, healthcare and businesses. It is a flexible and powerful decision-making technique to help researchers and practitioners to set priorities and assign weightages.

## Evolution of OEE

The evolution of OEE and its different modifications are reviewed by Muchiri et al. (2008) [7]. Godfrey (2002) [8] had just adapted the Nakajima's concept and described that the effective operation of individual pieces of production equipment, assembly lines or a whole factory are dependent on three factors of OEE – availability, performance efficiency and quality rate. OEE is considered as the most effective

TABLE 1 CRONOLOGICAL EVOLUTION OF OEE

| Metric | Applied for |
|---|---|
| OEE (Nakajima, 1988)[1] | First coined the concept and applied in manufacturing industries |
| PEE (Raouf, 1994)[15] | Uses the effects of parameter on the elements of OEE and proposed weights for elements of OEE |
| OFE (Scott & Pisa, 1998)[16] | Gives the effectiveness of the whole factory rather than single equipment |
| TEEP (Ivancic, 1998)[17] | Considers the effect of maintenance and applied to whole processing plant as a single entity |
| OTE (Huang et al., 2003)[18] | Uses to calculate the OEE of a manufacturing line |
| OAE (Muchiri, 2008)[7] | To consider losses on overall production process |
| Modified OEE (Badiger, 2008)[19] | Added a new factor called usability in the existing method of OEE evaluation |
| OWEE (Wudhikaran, 2010)[20] | Gives weighted approach and stating that OEE neither does nor prioritize the problematic equipment appropriately |

## OEE in Mining industry

It is well known that mining is a very capital intensive industry and it is a known fact that the equipment utilization and accurate estimation are very important. Today's mining equipment are highly productive, gigantic in size and have high technical complexity. Hence, performance measurements of these equipment are very necessary. The scope for application of OEE to the coal mining industry is vast. The OEE applications in mining industry totally differ from the manufacturing and production industries (Bamber 2003) [14]. Hence, it is necessary to develop equipment's own classification framework for the losses, which should be related to the components of availability, performance, and quality.

Before Elevli and Elevli (2010) [21], there was no study in the literature that how to use OEE for mining equipment. They identified different causes of time losses for shovel and dump truck operations. Mohammadi et al. (2015) [22] have translated the OEE concept for BELT (bucket, excavating, loading and transport) equipment and have given the OEE concept as multiplication of availability, utilization, speed factor and bucket capacity utilization factor.

Yadav et al. (2017) [23] translated OEE concept for mining equipment by introducing another term environmental losses in the OEE concept for the mining machinery. Hence, according to the new concept of Yadav et al. (2017) [23] the Modified OEE for the mining machinery will be as:

$$\text{Modified OEE} = (A) \times (P) \times (Q) \times (E) \quad (2)$$

Where, A = availability losses, P = performance losses, Q = quality losses, and E = environmental losses occurring outside the system.

Each term in the above expression has been described below in the perspective of dumper system in the Indian coal mine scenario.

### Methodology to compute the availability of the dumper

A machine is considered available when it is fit to be put to perform its duties. Availability takes into account "lost time" which includes any events that stop planned production for an appreciable length of time. This is usually because of equipment maintenance, failures, etc. Then, availability is determined as follows:

$$\text{Availability} = \frac{\text{Available time (AT)}}{\text{Total time (TT)}}$$

$$\text{Availability} = \frac{-\ \text{TT(MNT+BDT)}}{\text{TT}}$$

### Methodology to compute the performance rate of dumper

Performance takes into account "speed loss," which includes many factors that cause the equipment to operate at less than the maximum possible speed when running. Reasons for that can be substandard materials, operator inefficiency, and job conditions. The performance is determined as follows:

$$\text{Performance} = \frac{\text{Actual output}}{\textit{Target}\ \text{output}}$$

### Methodology to compute the quality of the dumper

It is a measure of the percentage of output that meets designed specification compared to how much were produced. Quality takes into account "product loss," which is determined as follows:

$$\text{Quality} = \frac{\text{Actual amount of production} - \text{Non-accepted amount of production}}{\text{Actual amount of production}}$$

### Environmental losses

Every country has its own environmental rules and regulations, according to which the organization had to take certain action to reduce the pollution. In India, the environmental protection act was enacted in 1986 with the objective of providing for the protection and improvement of the environment. In this case study, environmental losses has been expressed in terms of carbon tax. Carbon tax is a tax on the carbon contents of fuels. The carbon tax has been calculated as

$$\text{Carbon tax} = \frac{\text{Revenue generated} - \text{Tax on diesel consumption}}{\text{Actual amount of production}}$$

In the above Modified OEE expression, Yadav et al. (2017) [23] have assumed equal weightage to all the four components, but in real life, the weightage to each component should be different because of their different influence on the OEE. Hence, in this research, the weightage has been assigned to each component by the help of AHP. The Modified OEE has been renamed as the machine performance index (MPI) after assigning the weightage which will be written as

$$MPI = A^a \times P^b \times Q^c \times E^d \quad (3)$$

$a, b, c, d$ are the weights of the MPI elements, and $\Sigma\ a, b, c, d = 1$ and $0 < a, b, c, d < 1$.

## Methodology

The general steps which are carried out in the weightage calculation are shown in the flowchart as indicated in Fig.2.

Satty (1980) [24] developed analytical hierarchy process method to provide the visual structure of the complex problems in the form of two or more levels of hierarchy that facilitates the evaluation of the active parameters in the decision-making process. It can be used for solving both types of problems, i.e., qualitative as well as quantitative parameters.

1. Definition based on goal objective.

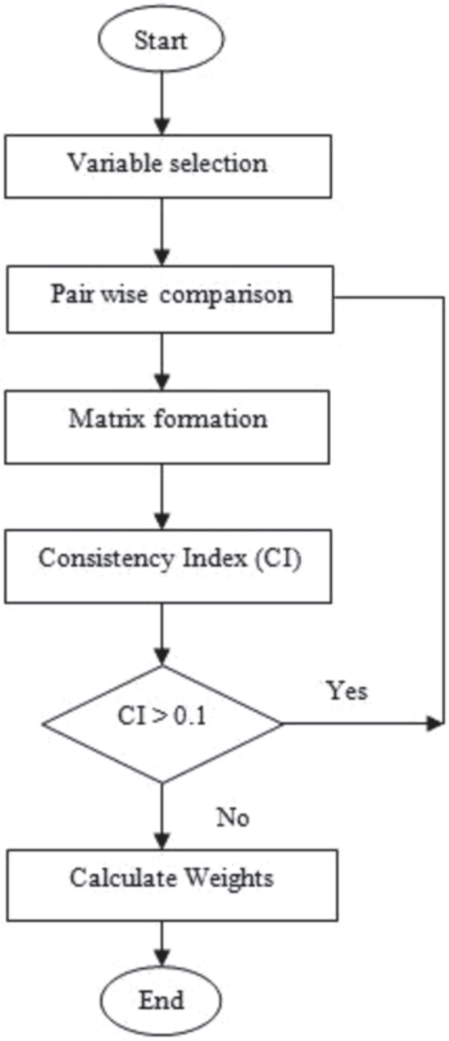



Fig.2 Flowchart of the whole process

2. Hierarchy development between criteria related to the goal.
3. Pairwise comparison of the elements and evaluation of factors impact.
4. Formulate pared comparison of criteria as ratio. This paired comparison is used to find the weights.
5. Consistency index (CI) is given by the equation.

$$CI = \frac{(\lambda_{\max} - \mathrm{n})}{n-1} \quad \text{... (4)}$$

Where, $\lambda_{max}$ = maximum eigenvalue of the matrix, $n$ = size of the pairwise matrix. . max .

Following cases are considered in the comparison, evaluation and assigning the weights to each component involved in modified OEE

1. Production efficiency
2. Cost of production
3. Criticality to production
4. Production cycle time of the equipment
5. Environmental losses due to the equipment operation

The general approach of the AHP is to decompose the problem and to make the pairwise comparison of all the elements. The degree of preference of the decision maker in the choice for each pairwise comparison is quantified on a scale of 1 to 9 and these quantifies are placed in a matrix of comparisons. Comparing objective *i* and objective *j* (where *i* is assumed to be at least as important as *j*). Give a value $a_{ij}$ as follows:

| | |
|---|---|
| 1 | Objective *i* and *j* are of equal importance |
| 3 | Objective *i* is weakly more important than *j* |
| 5 | Objective *i* is strongly more important than *j* |
| 7 | Objective *i* is very strongly more important than *j* |
| 9 | Objective *i* is absolutely more important than *j* |
| 2,4,6,8 | Intermediate values |

## Case study

In transportation process of coal in mines, dumpers play a crucial role and have a considerable impact on the productivity of coal. Hence, it is important to evaluate the performance of dumper properly keeping in mind which parameter has how much influence on MPI, for which weight assignment to each component has been done.

To evaluate the weights of different parameters in the MPI, dumper has been used for the case study. An expert's team consisting professors and research scholars of Mining Engineering Department of IIT (BHU), Varanasi was gathered, to suggest the importance of each parameter of dumper operation. Some field visits and industrial consultation were also done. Many questions were asked from the experts to note the significance of each parameter in the questionnaires in expert choice, multifactorial decision-making software. Based on expert's opinion and comments, the weightage matrix has been given in Table 2.

TABLE 2 WEIGHTAGE MATRIX

| | A | P | Q | E |
|---|---|---|---|---|
| A | 1 | 2 | 1/5 | 1/3 |
| P | 1/2 | 1 | 1/2 | 1/3 |
| Q | 5 | 2 | 1 | 2 |
| E | 3 | 3 | 1/2 | 1 |

The different assigned weights for MPI parameters on the basis of above weightage matrix have been shown in Table 3.

TABLE 3 WEIGHTS OBTAINED FOR DIFFERENT MPI COMPONENTS

| Parameters | Weights obtained |
|---|---|
| Availability | 0.52 |
| Performance | 0.14 |
| Quality | 0.10 |
| Environmental loss | 0.24 |

Based on above-resulted weights, the expression for MPI of dumpers is shown as

$$MPI = A^{0.52} \times P^{0.14} \times Q^{0.10} \times E^{0.24} \quad \text{... (5)}$$

As it is discussed in equation (3), MPI of dumper is a modified version of classical OEE for mining machinery, hence, comparison of these two measuring index will be valuable for the future applications. After assigning the weightage, to check the applicability of this index, a case study was done on the dumper. Data for availability, performance, quality and environmental losses of the dumper in a period of January 2015 to June 2015 was used.

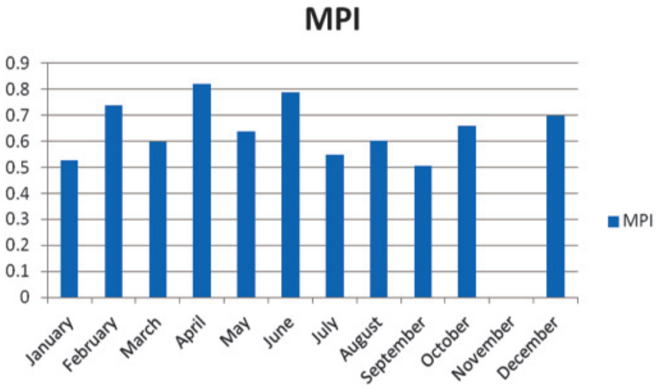



Fig.3 Calculated MPI for Dumper for the year 2015

From the Fig.3, it has been clear that the new index MPI gives optimistic values of performance of dumper. From the above equation (5), nevertheless, classical OEE gives very low and pessimistic values which sometimes do not represent the actual performance of the dumper. It has been clear that if less weightage is given to the OEE element having highest value and/or more weightage to the OEE element having lowest value, then the MPI value should decrease as compared to the conventional OEE value. Similarly, if less weightage is given to the OEE element having lowest value and/or more weightage to the OEE element having highest value, then the MPI values should increase as compared to the conventional OEE value.

## Conclusion

In this research, MPI, a new performance measuring index has been proposed for dumpers. The weights in proposed MPI, will consider the effect of parameters involved on the modified OEE of the equipment. This MPI gives more optimistic value of effectiveness with respect to OEE. This MPI not only gives the appropriate effectiveness but also can predict which parameter should be more focused for improving the productivity. Regarding the comments of the experts team, availability is the most important factor in calculation of machine performance index (MPI) of dumper and environmental losses, performance and quality follows in the order.

In future research, another index consisted on different weights can also be developed for different mining machines such as dozers, crushers etc.

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**DYNAMIC SIMULATION APPROACH TO ASSESS INFLUENCE OF CHARGING PARAMETERS ON BLAST INDUCED VIBRATION**

*(Continued from page 306)*

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