Mine Production Index (MPI): New Method to Evaluate Effectiveness of Mining Machinery

Amol Lanke, Hadi Hoseinie, Behzad Ghodrati

Abstract—OEE has been used in many industries as measure of performance. However due to limitations of original OEE, it has been modified by various researchers. OEE for mining application is special version of classic equation, carries these limitation over. In this paper it has been aimed to modify the OEE for mining application by introducing the weights to the elements of it and termed as Mine Production index (MPi). As a special application of new index MPi$_{shovel}$ has been developed by authors. This can be used for evaluating the shovel effectiveness. Based on analysis, utilization followed by performance and availability were ranked in this order. To check the applicability of this index, a case study was done on four electrical and one hydraulic shovel in a Swedish mine. The results shows that MPi$_{shovel}$ can evaluate production effectiveness of shovels and can determine effectiveness values in optimistic view compared to OEE. MPi with calculation not only give the effectiveness but also can predict which elements should be focused for improving the productivity.

Keywords—Mining, Overall equipment efficiency (OEE), Mine Production index, Shovels.

I. INTRODUCTION

WITH highly competitive environment, organizations need to improve with losses occurred during the operations. These losses include losses due to breakdown, low speed, idle time, and defect and rework [1]. A key performance index (KPI) which includes these operational losses for equipment was developed by Nakajima, 1979 [1] termed overall equipment efficiency (OEE). OEE can be calculated by (1).

$$\text{OEE} = \text{Performance rating} \times \text{availibility rating} \times \text{quality rating} \quad (1)$$

where, performance rating includes comparison between ideal time and the operating time of equipment. Availability rating refers to part of total working time and effectively addresses the losses such as breakdowns, setups, adjustments [2]. Quality rating element of OEE presents measure of yield. Quality rating is ratio of total good pieces produced by equipment to total defective pieces produced by equipment.

OEE is considered as a key performance indicator of a company [3]. This KPI can be used to measure and improve the overall performance of an industry [4]. The case studies illustrate that OEE is applicable in variety of industries. Use of OEE as a metric to improve the equipment performance leads to increase in overall performance of system as indicated in many studies.

As a successful case study, OEE was used as a major measure of factory performance indicator and thus an enabler for better operation in polypropylene manufacturing. This was compared with automotive assembly where this measure was absent, causing it to be an inhibitor of manufacturing strategy [5]. OEE is used under umbrella of total production management (TPM), in survival of a government owned bearing manufacturing company as documented by [6]. Reference [7] reveals that OEE is associated with six big losses, leading to loss of revenue. It has been showed that increase in OEE from 62% to 85% of world class manufacturing level decreases the loss by 40% causing increase in revenue [8]. Also achieving more accurate delivery schedule for increased market share and reputation, OEE can be part of maintenance strategy. According to [9] railway infrastructure improvement can also be positively affected by use of OEE.

For evaluation of TPM and thus maintenance performance OEE serves as a metric to evaluate the production capability and impact of quality [10]. One of the most important strength of OEE can be defined as its ability to integrate different aspects of manufacturing into one single measurement tool [11].

While OEE is effective parameter to determine the performance it has limitation. Considering the interaction of parameters in a factory the performance of equipment in its isolation cannot determine its impact thoroughly on the system. OEE considers improvement of system performance by improving individual equipment itself. The characteristics of one equipment may not be same as the next one i.e. Normalization of system performance with respect to OEE measure of single equipment can not enough [12].

The evolution of OEE and its various modifications are well reviewed by [11] as shown in Table I. As seen from table, OEE limitation of application to system level was identified and rectified by various researchers so far.

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TABLE I
VARIOUS MODIFICATION OF OEE (ADOPTED FROM [11])

TEEP [13]	Can be applied to whole processing plant as a single entity and includes effect of maintenance.
PEE [14]	Considers effects of parameter on the elements of OEE [14] thus proposed weights for element of OEE.
OFE [11]	Measure gives effectiveness over the factory rather than single equipment.
OAE [11]	To consider losses on overall production process Discussed in [11]
OPE [11]	To consider losses on overall production process Discussed in [11]
OWEE [15]	Uses the weighted approach and stating that OEE neither does nor prioritize the problematic equipment appropriately. [13]

II. OEE IN MINING INDUSTRY

Mining industry is characterized by high volume of output and high capacity of equipment. This industry is deeply dependent upon use of equipment for achieving targets of profitability. High amount of production time is lost due to unplanned maintenance in mining industry [16] i.e. lack of availability. For early return on investment and reduction of production cost equipment utilization is very important [17]. This emphasizes crucial need for higher utilization in mining industry. Standby equipment increases cost of operation, whereas machinery subjected to downtime causes less output. This directly affects the delivery assurance for mining industry. Hence performance of mining equipment is an important factor. Therefore OEE in mining application should involve elements of availability, utilization and performance. According to [19] OEE can be used along with other parameters for improvement of mining performance.

OEE has been used to determine the loaders and trucks performance in Namibian mines with results of suggestions to improve the availability of the equipment [18]. Referring to [19] OEE through TPM is applicable for improvement dragline performance in terms of reliability, cost of operation and productivity. As evident by the literature analysis and application, OEE can be used to determine the performance in mining industry as well. Elevli and Elevli in application of OEE to mining industry have shown benchmark formation for improvement for shovel and trucks performance [17]. They applied quality parameter with respect to defect loss with net operating time. Where the case study in Namibian is mines quality loss as was used as ratio of loaded capacity to full capacity [19].

Since quality parameter is not used as it is defined in original OEE equation, quality rate cannot be used for mining industry in its original definition [19]. The original definition of quality rating includes processed and defect amount. In mining, it is quite difficult to define such a distinction for extracted ore. Considering these limitations, a new OEE was developed which shown in (2) [19], [16].

$$OEE = (AV) \times (PE) \times (U) \qquad (2)$$

where Availability (AV) is given by

$$AV = \frac{TH-DT}{TH} \times 100 \qquad (3)$$

where TH = total hours, DT= downtime in hours, and SH= standby hours.

Where production efficiency PE is given by;

$$PE = \left[\left\{\frac{AP}{TH-DT-SH}\right\}/RC\right] \times 100 \qquad (4)$$

AP = Actual production
RC= Rated capacity of equipment in hours
and Utilization U is given by;

$$U = \left[\frac{TH-DT-SH}{TH-DT}\right] \times 100 \qquad (5)$$

For the mining applications, OEE equations elements can be termed as production efficiency, utilization and availability.

III. METHODOLOGY

This modified OEE can be used to determine the performance of mining production. However mining operation is characterized by high degree of uncertainty. Depending upon the delivery schedule, types and number of available machine, age of machinery, production performance can change [20]. Each mining equipment is selected during mine design process for a specific purpose. Studies on truck optimization for mining have shown that cycle time for truck is important [21]. The cycle time for trucks involves time spent in loading, hauling, dumping, standby time. Since the main purpose of shovel excavation is to move material, the payload and digging rate are key performance measures [22].

In total above mentioned parameters and restrictions affect the production performance. To take account for these considerations it is necessary to modify the OEE equation for mining applications. For example the payload or capacity factor for shovel can directly relate to performance efficiency in equation rather than availability of shovel. Cycle time requirement for truck can be directly attributed to need of higher utilization. Equipment with high criticality for performance index may be hampered in performance due to less availability during the operation.

Taking these operational constraints into consideration the OEE for mining application can be modified with introduction of weight for each factor. Since assigned weights can be applied to all equipment and can give impact of each factor on entire mine production, it is termed as Mine Production index (MPi) for equipment.

The MPi equation can be given as;

$$MPi = Av^a \times PP^b \times U^c \qquad (6)$$

where Av is Availability, PP is Performance and U is Utilization and

$$0 < a, b, c <= 1 \text{ and } \sum a, b, c = 1.$$

In order to calculate and assigned the weights (a, b, c) a reliable and quantitative analytical method is needed. One the applicable approach is to use the multifactorial decision making techniques. Based on the past experiences of the

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authors, the analytical hierarchy process (AHP) method can be used for assigning the weights to the main parameters used in the MPi formula.

AHP method was developed by Satty in 1980 [23] that provides a visual structure of complex problems in form of two or more levels of hierarchy [24] and facilitates evaluation of active parameters in decision making process. It can be used for solving the problems with qualitative and quantitative parameters.

The General stages of AHP method are enumerated as follows,

1. Goal objective definition, which takes head for which evaluation is done.
2. Development of a hierarchy between the criteria related to the goal. i.e. second or more level of hierarchy.
3. Pairwise comparison of elements and evaluation of factors impact.
4. Formulate paired comparison of criteria as ratio. This paired comparison is used to determine the weights of each criterion in terms of its effect on the objective goal.
5. Consistency index is calculated by equation

$$CI= (\lambda max - n) / (n-1) \qquad (7)$$

where λ is maximum Eigen value of matrix, n= size of pairwise matrix.

In evaluation, comparison and assigning the weights to each factor involved in MPi the following cases are considered:

1) Cost of operation.
2) Production capacity
3) Production cycle time of the equipment
4) Criticality to production

It should be concluded that MPi is a general index which should be developed for each type of mining machineries individually. It means that the final aim of this index is to present a special MPi for each mining machine for example MPi for trucks, shovels, drilling machines, etc.

In this paper the MPi which has been developed for shovels is discussed and the details are presented in case study part.

IV. CASE STUDY

In production process of mines, shovels play a critical role and have significant impact on whole operation productivity. In order to evaluate its productivity; MPi is applicable as a practical indicator.

To evaluate the weights of parameter of MPi considering the shovel operation, a team of experts in field of mining machinery in Luleå University of Technology were gathered. They discussed on the importance of each parameter of shovel productivity. Some industrial consultation and field visits were also done. It was asked from experts to mark the importance of each parameter in questionnaires in multifactorial decision making software: Expert choice.

Based on the expert decisions and comments, the assigned weights for MPi's parameter are as shown in Table II. Based on the expert decisions and comments, the assigned weights for MPi's parameter are as shown in Table II.

Based on the resulted weights, the MPi formula for shovels is shown in (5);

$$MPi_{Shovel}= Av^{0.2944} \times PP^{0.3375} \times U^{0.3681} \qquad (8)$$

TABLE II
WEIGHTS OBTAINED FOR MPi FACTORS FOR SHOVELS

Parameters	Weights obtained
Availability	0.2944
Production performance	0.3375
Utilization	0.3681

In the next stage of this research after developing MPi$_{Shovel}$, in order to check the applicability of this index a case study was done on four electrical and one hydraulic shovel in a Swedish mine. Data for availability, utilization and production performance of these shovels in period of December 2013 to April 2014 was used. Figs. 1 to 3 show the collected data in graphical format for comparison.
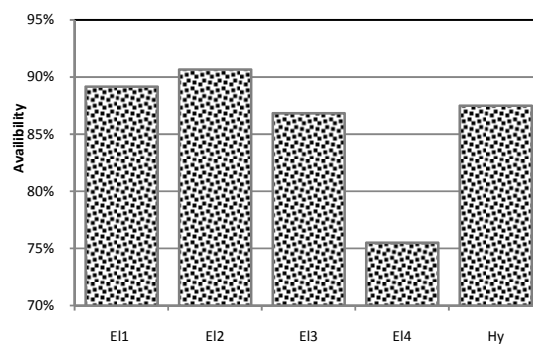

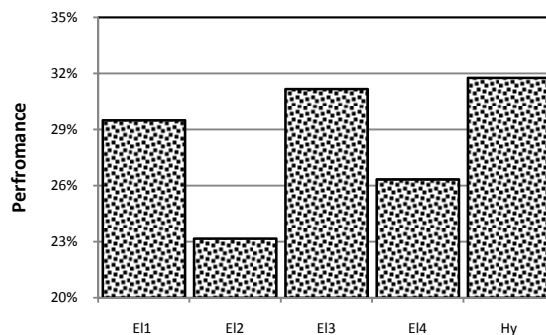Fig. 1 Average availability of studied shovels for 5 months

Fig. 2 Average production performance of studied shovels for 5 months

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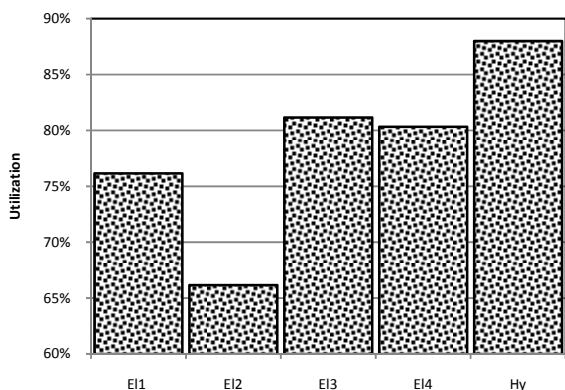International Journal of Geological and Environmental Engineering
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Fig. 3 Average utilization of studied shovels for 5 months

As it seems availability of shovel 4 is lowest among the other shovels and rest of the fleet have similar availability level range of 85 to almost 90%. As it is obvious from figures above El4 is critical machine in viewpoint of availability and in rest of parameters El2 is critical with lowest values of performance and utilization. However, low value of utilization of El4 is also evident. It's obvious that it is too difficult to recognize weakest shovel in this mine in viewpoint of operational aspects. Therefore using a comprehensive index is essential to be able to evaluate loading machinery in open pit mines and MPi$_{Shovel}$can be a suitable approach for this purpose.

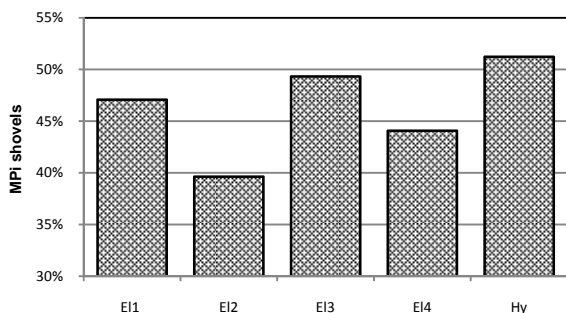After data analysis, MPi$_{Shovel}$ were calculated for each machine (Fig. 4).

Fig. 4 Calculated MPi$_{Shovel}$

As it can be seen El2 has lowest MPi value and El4 is second weakest machine. El1 and El3 are following ones whereas Hy has highest MPi value.

As it was discussed before, MPi$_{Shovel}$ is a modified version of classic OEE i.e. (2) for mining application thus the comparison of these two measures will be valuable for future applications. As shown in Fig. 4 the new index gives optimistic values of machinery effectiveness inherent characteristics of MPi equation. Nevertheless, the classic OEE gives very low and pessimistic values which sometimes are not representative of actual effectiveness of equipment. This problem leads mine engineers to underestimate the actual production ability of their fleet and sometimes can add higher cost to mining operations. Application of MPi helps to explore operational condition of studied fleet in an acceptable level because when effectiveness values are as low as represented by OEE, it means that operational condition is not good at all. For example 13% OEE is almost negligible. This also means that equipment is not up to par with performance and can be considered obsolete. However it is against current condition and reality of case study conducted because this machine works and produces the ore in low level but not as bad as OEE depicts.

V. CONCLUSION

In this study a new index termed as mine production index is proposed and special case of termed MPi shovel was conducted on shovel in a Swedish mine. Following is the list of main results and findings of this study:

1. OEE for mining applications, includes utilization has limitations, hence needs to be modified with addition of weights to the elements of OEE.
2. The weights in MPi proposed will underline effect of parameters involved on OEE of equipment.
3. MPi will give optimistic values of effectiveness with respected to OEE.
4. MPi with calculation not only gives the effectiveness but also can predict which elements should be focused for improving the productivity.
5. Regarding comments of expert team, utilization is most important factor in calculating the overall effectiveness of shovels in case study and performance and availability follows in the order
6. The case study showed that new developed MPi index is applicable for evaluation of overall productivity of shovels and in future research special MPi's consisted on different weights can be developed for each mining machine such as trucks, dozers and crusher etc.
7. The calculation of MPi and weights should be done more frequent as per the requirement of mining industry. A simulation approach can be used to determine the impact on intended production assurance

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