# Performance Measurement of Mining Equipments by Utilizing OEE

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*Over the past century, open pit mines have steadily increased their production rate by using larger equipments which require intensive capital investment. Low commodity prices have forced companies to decrease their unit cost by improving productivity. One way to improve productivity is to utilize equipment as effectively as possible. Therefore, the accurate estimation of equipment effectiveness is very important so that it can be increased. Overall Equipment Effectiveness (OEE) is a well-known measurement method, which combines availability, performance and quality, for the evaluation of equipment effectiveness in manufacturing industry. However, there isn't any study in literature about how to use this metric for mining equipments such as shovel, truck, drilling machine etc. This paper will discuss the application of OEE to measure effectiveness of mining equipment. It identifies causes of time losses for shovel and truck operations and introduces procedure to record time losses. The procedure to estimate OEE of shovels and trucks has also been presented via numerical example.*

**Key words**: OEE, Equipment Utilization, Mining, Time Losses

## Introduction

All industries are dependent on their assets as well as mining companies. The increase in automation, compounded by the increase in the size and capacity of equipment over the years has drastically changed the consequences of equipment ineffectiveness. Current economic conditions, severe global competition, environmental regulations and a continually improving focus on safety are also causing mine managers to consider creative and proven methods to determine effectiveness of their equipment so they can take necessary precautions to increase the effectiveness of their equipment and to reduce the total production cost.

Mining is a very capital-intensive industry, and it is known fact that the equipment utilization and accurate estimation of this utilization are very important since mine managers want to utilize their equipment as effectively as possible to get an early return on their investments as well reducing total production cost. Many studies have been carried out on selection of mining equipments [1-5]. But there has been a little attention on the measurement of effectiveness of those equipments. Only maintenance policies have been studied and implemented in order to improve availability of these equipments [6-10]. Therefore the aim of this study is to introduce a method, which is widely accepted in manufacturing industries, used in measuring overall effectiveness of equipments known as Overall Equipment Effectiveness (OEE).

During 1980's, Total Productive Maintenance (TPM) has become known in manufacturing industries and OEE was proposed by Nakajima [11] to evaluate the progress of TPM. It is interpreted as the multiplication of availability, performance and quality. Since that time, many studies have been done in this area such as Jeong and Phillips [11], Jonsson and Lesshammar [12], Prickett [13], Ljungberg [14], Dal et al [15] and Bamjer et al [16].

## What is OEE?

OEE is a simple tool that will help manager to measure the effectiveness of their equipment. It takes the most common and important sources of productivity loss, which are called six big losses and given in Table 1. These losses are quantified as availability, performance and quality in order to estimate OEE as given in equation (1).

$$OEE = Availability \times Performance \times Quality \quad \text{.....(1)}$$

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*Tab. 1. Six Big Losses [10].*

| Six Big Loss Category | OEE Loss Category | OEE Factor |
|---|---|---|
| **Equipment Failure** | Downtime Losses | Availability (A) |
| **Setup and Adjustment** | | |
| **Idling and Minor Stoppages** | Speed Losses | Performance (P) |
| **Reduced Speed** | | |
| **Reduced Yield** | Defect Losses | Quality(Q) |
| **Quality Defects** | | |

The factors given in equation 1 are generally calculated as shown in Table 2. For equipment to operate effectively, it needs to achieve high levels of performance against all three of these parameters.

*Tab. 2. OEE Parameters.*

| | | | |
|---|---|---|---|
| **Total Time** | | | |
| **Net Available Time** | | | **Scheduled Downtime** |
| **Operating Time** | | **Downtime Losses** → | $A = \frac{\text{Operating Time}}{\text{Net Available Time}}$ |
| **Net Operating Time** | **Speed Losses** → | $P = \frac{\text{Net Operating Time}}{\text{Operating Time}}$ → | $P = \frac{\text{Actual Output}}{\text{Target Output}}$ |
| **Fully Productive Time** | **Defect Losses** | $Q = \frac{\text{Fully Productive Time}}{\text{Net Operating Time}}$ → | $Q = \frac{\text{Good Output}}{\text{Actual Output}}$ |

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 failures, waiting times, and etc. Then, availability is determined as follows:

$$\text{Availability} = \frac{\text{Net Available Time - Downtime Losses}}{\text{Net Available Time}} \times 100 \quad \text{.....(2)}$$

Performance takes into account "speed loss", which includes any 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. Then performance is determined as follows:

$$\text{Performance} = \frac{\text{Operating Time- Speed Losses}}{\text{Operating Time}} \times 100 \quad \text{.(3)}$$

Quality takes into account "product loss", which is determined as follows:

$$\text{Quality} = \frac{\text{Net Operating Time - Defect Losses}}{\text{Net Operating Time}} \times 100 \quad (4)$$

The next step after the estimation of OEE is to compare it with the benchmark values. Accepted benchmark value for the manufacturing industries is about 85% [17,18]. If the estimated OEE is below the benchmark value, then system should be evaluated for improvement. It is also apparent that the successful computation of OEE depends on the ability to collect necessary data. Unreliable or inadequate data may not reflect real equipment utilization. It is also very important to recognize that each loss classified corresponds to an equipment state.

One point needs to be discussed in the estimation of OEE is **total time**. Total time given in Table 2 is the time available for production in a given period. This type of total time estimation is known as loading time-based approach and most of the previous estimation carried out on this base. However, this approach results in overestimation of OEE and may not reflect the real equipment utilization. Another approach namely calendar time-based approach is more preferable to loading time-based approach since it measures real equipment utilization [11]. Calendar time is theoretical calendar time during which company owns the equipment. The researchers proposed to use calendar time-based approach for capital-intensive industries.

Since mining is a very capital-intensive industry, it is more appreciate to use calendar time-based approach to estimate OEE.

## OEE for mining equipment

OEE applications in mining industry differ from manufacturing industry. Therefore, it is necessary to develop equipment's own classification framework for the losses, which should be associated with the components of availability, performance and quality [16]. The necessary data classification to be collected will vary from equipment to equipment. In addition to that, it is more difficult to gather data for mining equipments due to following reasons:

- Mining is a serial operation of drilling-blasting, loading, hauling and dumping. Therefore, the production of equipments used in each step depends on the production of previous equipment. That means utilization of each equipment affects the others.
- The capacity of mining equipment is huge. Therefore the effect of utilization on total production is very high.
- The physical environment under which mining equipment operates is less than ideal.
- The operating environment of the mine is dynamic with many unknowns that can affect the equipment utilization drastically.

In this study, OEE of shovels and trucks have been considered since they are the main equipments for the most of the Open Pit Mines.

## OEE calculation for Shovel

Shovels are used in open pit mining as primary loading equipment. Their performance and production controls the total output of operation. Therefore any production loss in shovel causes an increase in total production cost. Therefore the trend for those equipments require that the manager consider every possibility to make sure the equipment producing 24 hours a day, seven days per week. In order to provide that every steps of equipment should be recorded so that time losses can be determined. It is more appreciateable to use calendar time-based approach for OEE estimation of shovel, therefore it will be presented in this paper. During the shovel operation the following time losses may occur;

| No | Loss Classification | | Description |
|---|---|---|---|
| **1.** | Nonscheduled time | : | time duration for which equipment not scheduled to operate. |
| **2.** | Scheduled maintenance time | : | time spent for periodic maintenance of shovel. |
| **3.** | Unscheduled maintenance time | : | time spent for breakdown. |
| **4.** | Setup and adjustment time | : | time spent for setup and adjustment. |
| **5.** | Idle time without operator | : | equipment is ready but no operator (such as lunch break). |
| **6.** | Truck waiting time | : | time duration for which shovel waits for truck to load. |
| **7.** | Propel time | : | time duration for which shovel moves to another loading point. |
| **8.** | Time losses due to job conditions | : | Since working environment is dynamic, it is possible to loss time due to management, climate and job conditions. |
| **9.** | Speed loss | : | time loss due to the equipment that is operating under the standard speed (Swing time, loading time, etc. ). |
| **10.** | Qality loss | : | Due to fragmentation size and operator ability, shovel bucket can not be loaded to its full capacity. That is equivalent to unqualified products and known as filling factor. |

The above loss classifications are calendar time-based approach and they can be grouped as availability, performance and quality. Thus, the procedures to compute OEE of shovel can be represented as given in Table 3.

If we want to estimate OEE of shovel on the base of loading time-based approach, nonscheduled time and scheduled maintenance time will be removed from losses list. The rest of parameters will be the same. It should also be noted that quality loss in Table 3 is not actual loss time. It is just to represent the amount of material which shovel is supposed to load. In applications quality is assumed to equal to filling factor.

Numerical Example for Shovel Operation: The table 4 contains hypothetical data, to be used for OEE calculation of a shovel. These data represent time lengths of items during one month of shovel period.

*Tab. 3. Procedures for estimation of OEE (Calendar time-based approach).*

| TOTAL TIME (TT) 24 (hr/day)x 7(days/week) | | | | LOSSES | OEE FACTOR |
|---|---|---|---|---|---|
| Actual Available Time (AAT) | | | Availability Losses | Nonscheduled time<br>Scheduled maintenance<br>Unscheduled maintenance<br>Setup and adjustment<br>Idle time<br>Truck waiting time | $\text{Availability} = \frac{\text{Actual Available Time}}{\text{Total Time}}$ |
| Net Production Time (NPT) | | Performance Losses | | Propel time<br>Job condition loss<br>Speed loss | $\text{Performance} = \frac{\text{Net Production Time}}{\text{Actual Available Time}}$ |
| Valuable Production Time (VPT) | Quality Loss | | | Quality loss | $\text{Quality} = \frac{\text{Valuable Production Time}}{\text{Net Production Time}}$<br>$\text{Quality} = \frac{\text{Volume of Average Load}}{\text{Actual Bucket Capacity}}$ |

*Tab. 4. Time Lengths of Items for a Shovel Operation.*

| Item | Description | Time (hours/month) |
|---|---|---|
| Total time | 24 hours/day x 30 days /month | 720 |
| Nonscheduled time | 2 days off | 48 |
| Scheduled maintenance | 3 days | 72 |
| Unscheduled Maintenance | breakdowns | 97 |
| Setup and adjustment | 0,5 hours/shift | 45 |
| Idle time | 0,6 hour /shift | 54 |
| Truck waiting time | 0,5 hour/shift | 45 |
| Job conditions | Equipment did not work due to rain, snow or fog | 25 |
| Speed loss | 0,5 hours/shift | 45 |
| Propel time | 4 moves/month, 2 hours per move | 8 |
| Quality loss | Filling factor (%87) | |
| Shovel Bucket Capacity | 15 $m^3$ | |
| Ideal production | 1,5 bucket per minute | |

By using data given in Table 4 and relations given in Table 3, OEE estimation of shovel has been estimated. The calculations are given in Table 5.

*Tab. 5. OEE Estimation of a Shovel.*

| | | Calendar time-based approach | Loading time-based approach |
|---|---|---|---|
| **Total time** | | 720 hours | (720 – 48-72) =600 hours |
| **Availability** | = | AAT / TT | AAT / TT |
| | = | (720 – (48+72+97+45+54+45)) / 720 | (600 – (97+45+54+45 )) / 600 |
| | = | 0,50 | 0,60 |
| **Performance** | = | NPT /AAT | |
| | = | (361 – (25+45+8 ) / 361 | |
| | = | 0,85 | 0,85 |
| **Quality** | = | 0,87 | 0,87 |
| **OEE** | = | Availability x Performance x Quality | |
| | = | 0,50 x 0,85 x 0,87 | 0,60 x 0,85 x 0,87 |
| **OEE** | = | 0,3698 (%37) | 0,4437 (%47) |
| | | | |
| **Total Production** | = | (720 x 60) x 1,5 x 15 x 0,37 =359445 $m^3$ | = (600 x 60 ) x 1,5 x 15 x 0,47 = 359397 $m^3$ |

As it can be seen in Table 5 that the OEE of shovel for calendar time-based approach is 37 %, and it is 47 % for loading time-based approach. But the resulting total production is almost the same, differences in production is due to rounding of numbers. It is clear that loading time-based approach results in overestimation of OEE. This is an important issue to set up benchmark value for shovel operation. It is desirable to have Availability > 90 %, Performance>90 % and Quality>95 % for mining shovels when it is scheduled to work. These values will result in an OEE > 77 % which is to be considered as a benchmark value.

Another important point on the estimation of OEE is to collect proper data for each item. If data are not properly collected then the resulting OEE will not reflect real utilization. Therefore, the time period of each shovel movement should be recorded second by second.

### OEE calculation for Trucks (off-highway)

Trucks are used in open pit mining as primary hauling equipment. Their performance and production controls the total output of operation as well as shovels. As it is said before that the time losses classification for truck is also different. Therefore, the possible time losses causes are defined as follows:

| No | Loss Classification | | Description |
|---|---|---|---|
| **1.** | Nonscheduled time | : | time duration for which equipment not scheduled to operate. |
| **2.** | Scheduled maintenance time | : | time spent for periodic maintenance of shovel. |
| **3.** | Unscheduled maintenance time | : | time spent for breakdown. |
| **4.** | Setup and adjustment time | : | time spent for setup and adjustment. |
| **5.** | Idle time without operator | : | equipment is ready but no operator (such as lunch break). |
| **6.** | Shovel waiting time | : | time duration for which truck waits to get position to be loaded<br>time which truck waits to be loaded. |
| **7.** | Loading time loss | : | time loss due to management, supervision, climate and job conditions |
| **8.** | Time losses due to job conditions: | | time loss due to the equipment that is operating under the standard speed. |
| **9.** | Speed loss | : | That is equivalent to unqualified products and depends on the fill factor of shovel. |
| **10.** | Quality loss | : | |

The above time-loss classifications are calendar time-based approach. Thus, the procedures to compute OEE of truck can be represented as given in Table 6.

*Tab. 6. Procedures for Estimation of OEE via Calendar Time-Based Approach.*

| **TOTAL TIME (TT)**<br>**24 (hr/day)x 7(days/week)** | | | **LOSSES** | **OEE FACTOR** |
|---|---|---|---|---|
| Actual Available Time (AAT) | Availability Losses | | Nonscheduled time<br>Scheduled maintenance<br>Unscheduled maintenance<br>Setup and adjustment<br>Idle time<br>Shovel waiting time | $\text{Availability} = \frac{\text{Actual Available Time}}{\text{Total Time}}$ |
| Net Production Time (NPT) | Performance Losses | | Loading time<br>Job condition loss<br>Speed loss | $\text{Performance} = \frac{\text{Net Production Time}}{\text{Actual Available Time}}$ |
| Valuable Production Time (VPT) | Quality Loss | | Quality loss | $\text{Quality} = \frac{\text{Valuable Production Time}}{\text{Net Production Time}}$<br>$\text{Quality} = \frac{\text{Volume of Average Load}}{\text{Actual Bucket Capacity}}$ |

It should be noted that quality loss in Table 5 is not actual loss time. It is just to represent the amount of material which truck is supposed to haul, but it is not hauled due to shovel filling factor. Therefore, quality loss is considered as shovel filling factor.

*Numerical Example for Truck Operation:* The Table 7 contains hypothetical data, to be used for OEE calculation of a truck. These data represent time lengths of items during one month of truck operation.

*Tab. 7. Time Lengths of Items for a Truck Operation.*

| Item | Description | Time (hours/month) |
|---|---|---|
| Total time | 24 hours/day x 30 days /month | 720 |
| Nonscheduled time | 2 days off | 48 |
| Scheduled maintenance | 2 days | 48 |
| Unscheduled Maintenance | breakdowns | 65 |
| Setup and adjustment | 0,4 hours/shift | 36 |
| Idle time | 0,6 hour /shift | 54 |
| Shovel waiting time | 0,2 hour/shift | 18 |
| Loading time loss | 0,1 hour/shift | 9 |
| Job conditions | Equipment did not work due to rain, snow or fog | 25 |
| Speed loss | 0,6 hours/shift | 72 |
| Quality loss | Filling factor (%87) | |
| Truck Capacity | 120 ton | |
| Ideal production | 12 minutes per trip | |

By using data given in Table 7 and relations given in Table 6, OEE estimation of shovel has been estimated. The calculations are given in Table 8.

*Tab. 8. OEE Estimation of a Truck.*

| | | Calendar time-based approach | Loading time-based approach |
|---|---|---|---|
| **Total time** | | 720 hours | (720 – 48-48) =624 hours |
| **Availability** | = | AAT / TT | AAT / TT |
| | = | (720 – (48+48+65+36+54+18)) / 720 | (624– (65+36+54+18 )) / 624 |
| | = | 0,626 | 0,723 |
| **Performance** | = | NPT /AAT | |
| | = | (451 – (9+25+72) / 451 | |
| | = | 0,765 | 0,765 |
| **Quality** | = | 0,87 | 0,87 |
| **OEE** | = | Availability x Performance x Quality | Availability x Performance x Quality |
| | = | 0,626 x 0,765 x 0,87 | 0,723 x 0,765 x 0,87 |
| **OEE** | = | 0,417 (%42) | 0,481 (%48) |
| | | | |
| **Total Production** | = | ((720 x 60) /12) x 120 x 0,417 =180144 ton | = ((624 x 60 )/12) x 120 x 0,481 = 180186 ton |

As it can be seen in Table 8 that the OEE of truck for calendar time-based approach is 42 %, and it is 48 % for loading time-based approach. The question arises is that what should be the benchmark value for the OEE of trucks. This is a subject of another study.

## Conclusions

Utilization of equipment can only be improved and controlled successfully if an appropriate performance measurement system is used. OEE is a known method to measure performance of production equipment in manufacturing industries and adapted for mining industry in this paper. It aims to identify unproductive time losses within the system and these time losses affect availability, performance and quality.

This paper has shown that what are the possible time losses for mining equipments, more specifically shovel and trucks, and how they can be used in the calculation of OEE. The difference between calendar time-based approach and loading time-based approach is also discussed to set benchmark for improvement. Loading time-based approach provides higher OEE values than calendar time-based approach. Therefore, it is important to declare which approach is used when one talks about OEE of any specific equipment.

The importance of proper data collecting system to estimate OEE is also emphasized. If data are not properly collected then the resulting OEE will not be meaningful. Most of the equipment producers provide data collecting system for their equipments, the manager just needs to classify them according to definitions.

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