Performance evaluation of continuous miner based underground mine operation system: An OEE based approach

Sumit Banerjee
Depratment of Mining Engineering, IIEST, Shibpur, **India**

INTRODUCTION

Mining is the backbone of industrialization and continuous development of modern civilization. Coal is one of the major sources of energy and is one of the key raw materials of thermal power station. India is one of the leading players in the field of coal production; more specifically it ranks third in this domain globally. India produced 730 Mt of coal in the year 2017-18 (Ministry of Coal, Government of India, 2018). In India 93% of overall coal produced comes from opencast mining, whereas underground mining contributes to only 7% of total coal production (Ministry of Mines, Government of India, 2017). Higher exploitation of the near surface seams through opencast mining is resulting in their fast depletion. Now a day the environmental concern and higher exhaustion of the near surface reserve is forcing the government to think about underground mining with some effective and compatible cutting edge technology.

Continuous Miner (CM) and Long-wall are such underground mining machines. These high productivity underground mining techniques are very efficient as well as highly expensive. Therefore, the end user of these machines expects higher machine availability with continuous better performance. The only drawback of these machines is that, failure of any of the sub-system results in complete system stoppage. Therefore, proper scheduled maintenance programme is essential to avoid unwanted stoppages.

Government of India has already implemented few CM machines to some selective underground coal mining projects. The performance of these machines neither satisfied the expectations of the end users nor the claims by the manufacturer. Therefore, there is a extensive scope of research and development on these machines to improve the overall productivity.

This mining machinery based paper focuses on the effectiveness of two CM machines working for coal production in two different panels of a mine, which belongs to India's one of the largest coal producing company. Here, Overall Equipment Effectiveness (OEE) is used as the basic tool to benchmark the effectiveness of this machine. Correspondingly a discussion on the problem of

lower OEE was made with concerned mining personnel to fetch the possible recommendations to overcome this issue.

OVERALL EQUIPMENT EFFECTIVENESS (OEE) IN MINING SECTOR

Overall Equipment Effectiveness (OEE) is the benchmarking parameter for evaluating the performance of any equipment. It takes into account all the major losses in production sector through three parameters, indicating effectiveness of equipment individually from different viewpoints (Elevli and Elevli, 2010). Namely these, three parameters are availability, performance and quality.

Availability

Maximum time available for a machine to perform the desired task is called as net available time; basically this is the time remaining after exclusion of scheduled downtimes for maintenance from total scheduled time for production. When the downtimes due to failures and idle times are excluded from the net available time it results in operating time.

Availability is the ratio of operating time to net available time.

Performance

Performance defines the capability of a particular machine to perform its desired task effectively. It can b defined as the ratio of actual production to the expected production.

For a CM based underground mine operation system, let the expected production for a specific duration is X, whereas, the actual production for that duration is Y

Then performance can be expressed as $\frac{Y}{X}$.

Quality

It can be defined as the percentage of products that meet the quality specification.

For, mining industry it is really troublesome to compare the quality of the end product with the expected quality. Therefore, for CM based underground mine operation system the bucket fill factor of the ram car is considered as the quality of the product (Elevli and Elevli, 2010). Bucket fill factor is the ratio of the actual coal carried by ram car to the maximum carrying capacity of the ram car. Bucket fill factor signifies that some amount of coal gets lost during loading of the ram cars, which is similar to low quality products that gets discarded in other production systems.

OEE = Availability × Performance × Quality

DESCRIPTION OF THE MINE SITE UNDER STUDY

The mine site selected for this study belongs to one of the largest coal producing company of the country. In that mine, two CM machines along with their allied sub-systems are deployed in two different panels. A primary glimpse on the geo-mining conditions indicates that, the parameters of geo-mining condition falls well within the specified range to apply CM machines (Modi et al., 2017).

Therefore, it is feasible to implement CM for coal production in this particular mine. The geo-mining condition of the mine is shown in the following Table 1.

Table 1 Geo-mining condition of the panels under study

Machine	Seam	Pillar Dimension (m)	Gallery Width	Depth of Cover	Thickness of Seam	Gradient
CM1	5	3 9m × 35 m	5.8 m – 5.9 m	398 m	3.8-4.2 m	1 in 18
CM2	5	48 m × 50 m	6.0 m	425 m	3.8-4.2 m	1 in 18
Optimum Range		20 m – 30 m	6.0 m		3.5m – 6 m	1 in 10 or less

METHODOLOGY

General background and sample of research:

The mine was selected for this study as there were two CM machines working in two different panels of the same mine. Production data along with working and downtime related data were collected for these two machines and their allied sub-systems for a subsequent period of time. The brief methodology of this paper can be seen from Figure 1.
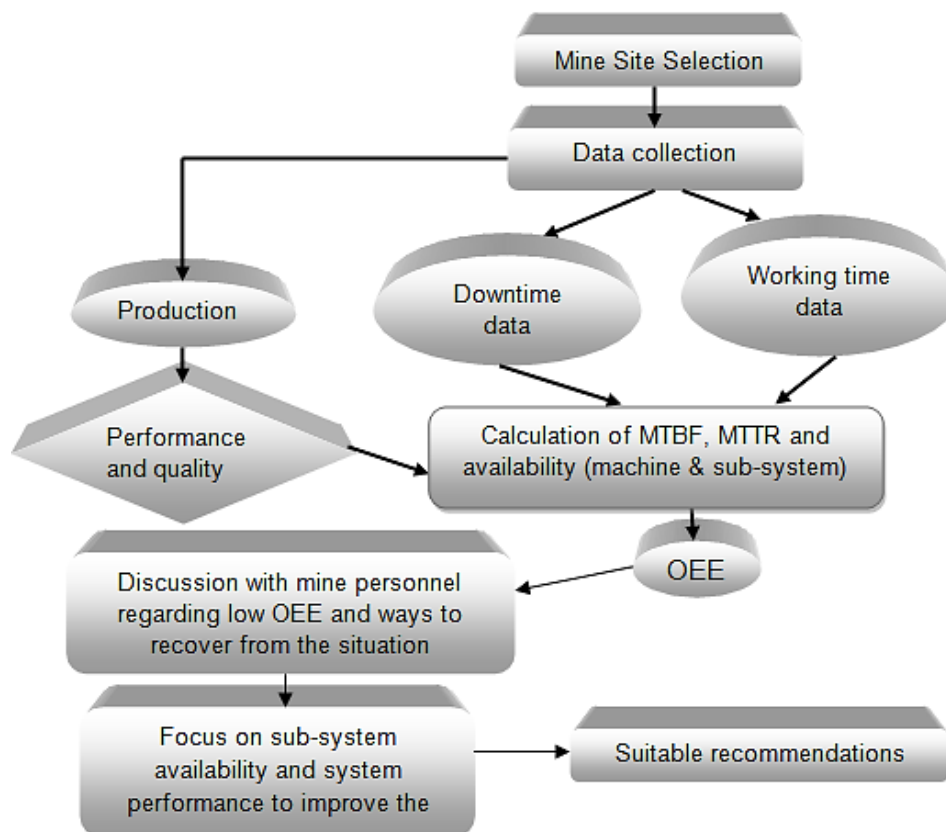

Fig. 1 Schematic diagram of working methodology

Instruments and procedures

CM package actually is a combination of four individual machines, namely; cutting unit of CM, ram car, feeder breaker and bolting unit. Failure of any of these units either fully or partially affects the overall production system. For the ease of this analysis all the equipments responsible for CM based production are divided into few sub-systems, namely; electrical, cutter, gathering, traction, hydraulic, chassis, feeder breaker, CM conveyor, out-bye conveyor, shuttle car

or ram car, feeder breaker. Working time and downtime data collected from mines were used to calculate Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR) and availability of the subsystems. In addition to the previous parameters overall availability of each machines, overall machine performance as well as end product quality within the study duration were also evaluated; these parameters were used to determine the effectiveness of each machines by calculating the OEE.

The evaluation of equipment effectiveness through OEE depicted the necessity for an in-depth analysis on performance as well as on availability of sub-systems of the machine.

Finally, a discussion was made with the experienced mine personnel regarding the low OEE and a thrust was given on the analysis of sub-system availability and performance of each CMs to improve the overall OEE. Calculation of MTBF, MTTR and availability is done in the following way (Vagenas et al., 1997):

Mean Time Between Failure (MTBF) =
(Total actual working time)/(Total number of failure)   (1)
Mean Time To Repair (MTTR) =
(Total time to repair)/(Total Number of repair)   (2)
Availability = MTBF/(MTBF+MTTR)   (3)

RESULTS AND OBSERVATIONS

Production as well as working time and downtime data, which were collected from mine was used to calculate the availability, performance and quality of end product. These are the prerequisites for the calculation of OEE. The results obtained from the calculations are depicted in the following Table 2.

Table 2 Results of calculated parameters

Sl. No.	Parameters	CM-1	CM-2
1.	Downtime	25481	31269
2.	Scheduled working time (minutes)	87840	87840
3.	Net Available Time	62359	56571
4.	Availability of the CM	0.71	0.64
5.	Quality	0.9	0.9
6.	Performance	0.38	0.42
7.	**Overall Equipment Evaluation (OEE)**	**0.2428**	**0.2434**

From Table 2 it can be seen that the OEE value for both the CMs is considerably less which may be an issue of concern to the mine management. After obtaining lower OEE value, in-depth analysis on system performance and availability of each sub-system was evaluated and their results are graphically represented in the following figures.

Graphs in Figure 2(a),(b),(c),(d), depicts abrupt variation in machine performance within a very short span of time for both the CM in two months. From analysis the system availability was found to be the issue behind this highly fluctuating machine performance characteristic. The graphical representation of the availability of each subsystems and effect of extended maintenance or no manpower is depicted in Figure 3.
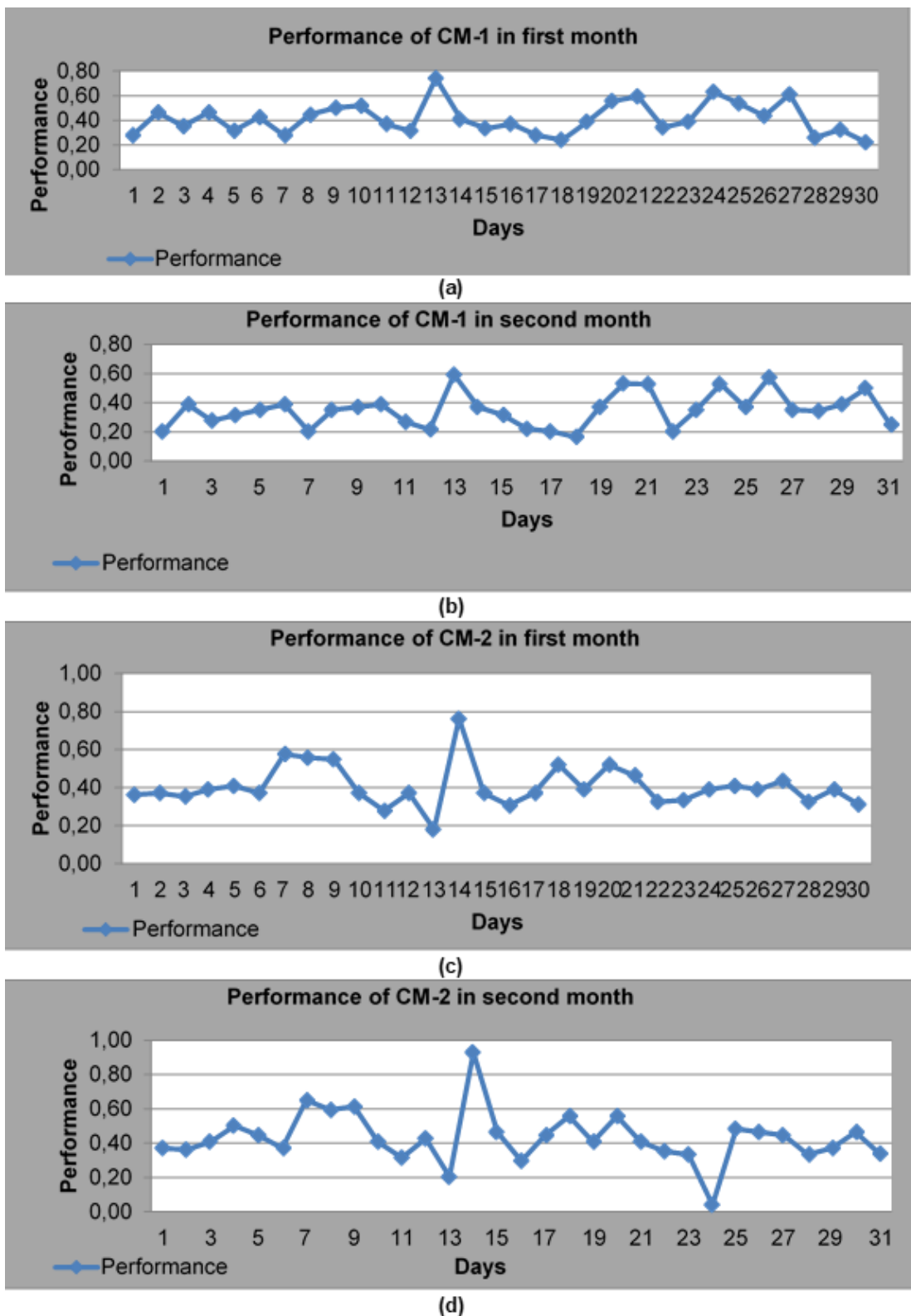
(a)

(b)

(c)

(d)

**Fig. 2 (a) Performance of CM-1 in first month, (b) Performance of CM-1 in second month,
(c) Performance of CM-2 in first month, (d) Performance of CM-2 in second month**

Graphs in Figure 3 depict the availability of sub-systems of each CM for both the months. From these figures three sub-systems for each CM having lowest availability can be easily identified. For CM-1 in first month quad bolter depicted least availability, followed by ram car and cutter. Whereas, in second month ram car depicted least availability, followed by quad bolter and electrical systems.
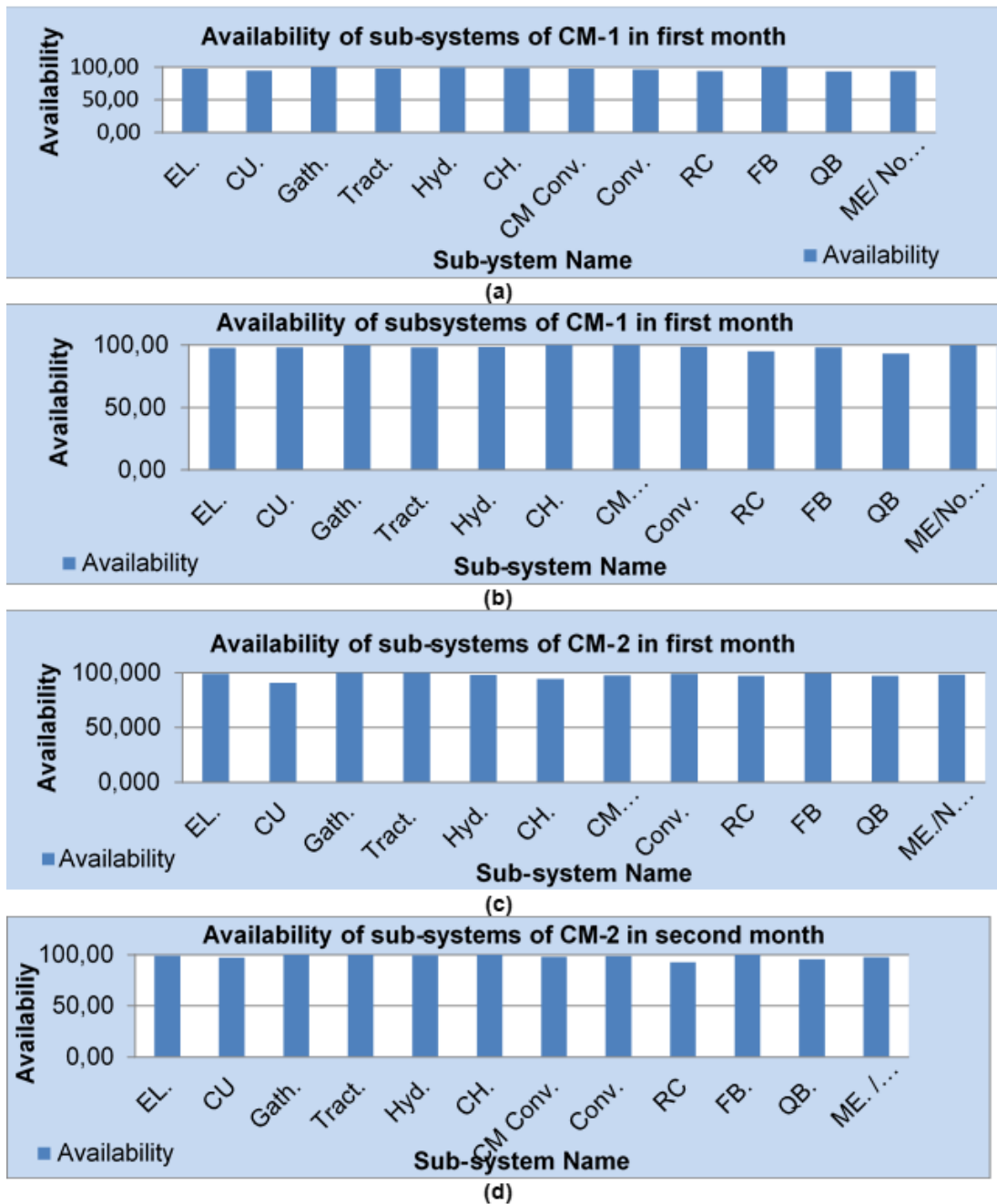
Fig. 3 (a). Availability of sub-systems of CM-1 in first month, (b). Availability of sub-systems of CM-1 in second month, (c). Availability of sub-systems of CM-2 in first month, (d) Availability of sub-systems of CM-2 in second month

Legends: EL = Electrical, CU = Cutter, Gath = Gathering, Tract = Traction, Hyd. = Hydraulic, CH. = Chassis, CM Conv. = CM Conveyor, Conveyor = Out-bye conveyor, RC = Ram car, FB = Feeder breaker, QB = Quad Bolter, ME/No manpower = Maintenance Extended/No manpower

For CM-2 in first month cutter depicted least availability, followed by chassis and quad bolter whereas, in second month ram car, quad bolter and cutter shows least availability. From the study few common systems such as; quad bolter, ram car, cutter including chassis and electrical systems are found vulnerable which needs intensive care during maintenance.

DISCUSSION WITH MINE PERSONNEL

Discussion was made on the performance of these machines and major hindrance for the operation as well as production. The potent factors were, improper maintenance of the sub-systems, especially ram car and out-bye conveyor. Other factors affected the working were the improper training and ignorance of workers towards the operation of machine as well their job responsibility. Unavailability of spares is sometimes the cause of unwanted stoppage and delay.

Recommendations

Few methods to overcome the existing problems, identified based on the study and discussions are recommended as follows:

- Proper maintenance of the meshing and rotating components of the machines.
- Proper sealing of the motor.
- Proper training of the maintenance team to accomplish the maintenance work effectively within time.
- Availability of spares before MTBF for each machine.
- Checking of cuter picks and cutting drum regularly.
- Design a proper preventive maintenance programme highly compatible with that specific mine.

CONCLUSION

OEE is a key parameter for evaluating the performance of a production system. Manufacturer as well as end user of any equipment demands better performance of an equipment. Continuous miner is a high cost incurring machine, designed to extract underground coal at a very fast rate. This paper depicts the performance of a pair of such machines where, ram car, quad bolter, cutter, electrical as well as chassis needs special care during maintenance to keep up the sturdiness of this production system. It was found during the course of field observation that, out-bye conveyor is another system that needs better maintenance though have depicted better availability. A short discussion with mine personnel on the hindrance of CM based underground production is presented through this paper and finally few recommendations are made to overcome this situation. This OEE based approach for CM based underground mine production system can be an effective approach to design a proper site specific preventive maintenance programme.

ACKNOWLEDGEMENT

REFERENCES

Elevli, S. and Elevli, B., 2010. Performance measurement of mining equipments by utilizing OEE. Acta Montanistica Slovaca, 15(2), p.95.

Government of India, Ministry of Coal. (2018). Chapter-6,Coal and Lignite production, Annual Report 2017-18. Available at: https://coal.nic.in/sites/upload_files/coal/files/coalupload/chap6AnnualReport1718en.pdf (Accessed: 30 June, 2019)

Government of India, Ministry of Mines, Indian Bureau of Mines. (2017). Indian Minerals Yearbook 2017 (Part-III, Mineral reviews). Available at: https://ibm.gov.in/index.php?c=pages&m=index&id=1008 (Accessed: June 30, 2019)

Modi, J., Bharti, S. and Kant, R., (2017). Applicability of continuous miner in room and pillar mining system: higher production and productivity with safety. In International Conference on Deep Excavation, Energy Resource and Production, Kharagpur.

Vagenas, N., Runciman, N. and Clément, S.R., (1997). A methodology for maintenance analysis of mining equipment. International Journal o/Surface Mining, Reclamation and Environment, 11(1), pp. 33-40.

Abstract.

CM is a globally renowned machine, designed to work as a mass production technology for underground coal. Different major coal producers across the globe are using this technology for decades to produce underground coal efficiently. India is also one of the major players globally in the arena of coal production and adopted this cutting edge technology since last decade by implementing at. few of the selective underground coal mining projects. Performance of CM technology is influenced by the geo-mining condition, fleets of other ancillary units and reliability of subsystems while implementation of this system depends largely on the extent of reserve. These aspects generate a scope of large scale research and development in this field. Overall Equipment Effectiveness (OEE) is the parameter to benchmark the equipment performance globally. OEE is the product of equipment availability, performance and product quality. This mining machine based paper focuses on the Overall Equipment Effectiveness (OEE) of the complete CM based operation to identify the vulnerable systems, which helps to design proper preventive maintenance programme. The CM based system is divided into few subsystems, such as; electrical, cutter, gathering arrangement, traction, hydraulic, chassis, feeder breaker, shuttle car, CM conveyor and out-bye conveyor. The downtime data used for this analysis is collected from an underground coal mine situated in the central part of India, belongs to one leading coal producing company of the country. From analysis it was found that, electrical systems and conveyors are among most vulnerable systems and deserves more care during maintenance. On the basis of these results recommendations are made to redesign the Preventive Maintenance Programme, in order to avoid the lower availability as well as lower OEE.

Keywords: Continuous Miner, Overall Equipment Effectiveness, Availability, Performance, Quality, Reliability