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Identification of Vulnerable Sub-Systems for Continuous Miner-Based Underground Coal Mine Operation: A Reliability Analysis

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Abstract

In India, mining is one of the major activities contributing to significant revenue generation. Mining activity in India includes mining of ores, coal and other minerals. India is one of the global leaders in terms of coal production, specifically producing through opencast mining. Recent environmental conditions and regulations are forcing the government to think of some effective underground mining technologies, such as longwall and Continuous Miner (CM). This research work presents the case of a CM system installed in an underground coal mine in the eastern region of the country. In Working time as well as breakdown time data were recorded for three months to calculate the Time Between Failure (TBF) between two consecutive failures. Thereafter, a reliability analysis for thousands of minutes of operating period for the CM-based sub-systems was performed. Among the sub-systems considered, a thorough analysis revealed that, mine conveyor was the most vulnerable sub-system. Further, to lessen the vulnerability of the top three sub-systems, several corrective measures were recommended.

Keywords: *Continuous Miner, Reliability Analysis, Time Between Failure (TBF), Underground Coal Mining*

1.0 Introduction

Owing to increased mining rates, surface coal reserves are getting depleted very fast, increasing the likelihood that coal from deeper seams may need to be produced shortly. Up until now, the only practical method for extracting coal from reserves located farther below the surface of the earth has been underground mining. India ranks among the world's top five producers of coal. Paltasingh and Satapathy mention that[1] by 2040, global coal production will increase by at least 10%, where India will be one of the key players for that. Effective underground coal mining may become one of the major technologies for replenishing the production demand. Utilisation of Continuous Miner (CM) and Longwall machines for the purpose may be a viable solution. The Government of India have already implemented some of these machines in some selected underground coal mines. The current application scenario of the CM machines has revealed that their performance is satisfactory to only a few of the coal mining projects working with them for coal winning. Few publications on reliability analysis of CM and other coal mining machines are highlighted as follows: Vayenas and Peng focused on reliability analysis and a reliability-centred maintenance planning for mining equipment deployed in the Sadurbury area of Canada using the statistical package GenRel[2]. Banerjee depicted reliability analysis through a graphical approach for CM packages deployed in two underground coal mines in the eastern part of India[3]. Sarkhel and Dey presented

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the availability estimation for maintenance planning of the SDL machine in Indian underground coal mines[4]. Samanta *et al.* performed a reliability analysis of shovel machines deployed in coal mining fields of India[5]. Harish Kumar *et al.* demonstrated the reliability analysis of the shovel dumper system in connection with a coal mine[6]. Rahmani *et al.* presented a case study for reliability analysis in connection with mining trucks[7]. Banerjee and Dey further presented some results of reliability analysis through a graphical approach for two CM machines deployed in India[8]. Boloz *et al.* presented a case study on failure rate analysis of a Longwall machine based on the type of failure[9]. Kumar *et al.* demonstrated the reliability, availability and maintainability analysis methodology corresponding to the dragline machine deployed in an opencast mine[10]. Zhou *et al.* focused on reducing the cost of production and ensuring safety and efficiency in production through filling mining using the long wall method[11]. Roy *et al.* focused on the development of a productivity model of CM-based mine operation for a hazardous mine condition[12]. Bazagur *et al.* presented a review study focusing on the reliability analysis of the underground mine communication system[13]. Banerjee and Dey further focused on determining a few interrelationships between input and output parameters pertaining to CM-based underground coal production[14]. Balaraju *et al.* presented a case study on the performance investigation of machinery used in mining activities.

Here in this paper, an effort has been made to identify the vulnerable sub-systems for a CM package working in India to further identify the reasons for low system availability. This information further helped in a recommendation for the mitigation of those causes of low system availability.

2.0 Methodology

The following Figure 1 shows the representation of the methodology for this research work. The initial step is a selection of a mine site working with the CM package; in this case, a mining project was selected in the central part of the country under the control of a major mining company of the country. A field visit of almost three months was conducted to identify the potential factors and gather relevant information. The information and data include the geo-mining parameters of the working panel, equipment specification, working time and downtime-related information, as well as daily production-related data. For this study, the overall CM package was divided into a few sub-systems, namely- electrical, cutter, gathering arm, traction, hydraulic chassis, ram car, feeder breaker, CM conveyor and mine conveyor. Subsequently, the gathered information was used to calculate the Time Between Failure (TBF) data for each sub-system as mentioned above. Then those TBF datasets were tested for the presence of any trend or correlation; further, trend and correlation-free TBF data were used for reliability analysis through the distribution fitter application of MATLAB. From where the best fit distribution for each TBF dataset corresponding to each sub-system was identified, and the reliability depletion trend was obtained. Further, some recommendations were suggested on the most vulnerable sub-systems, showcasing the lowest trend of reliability.

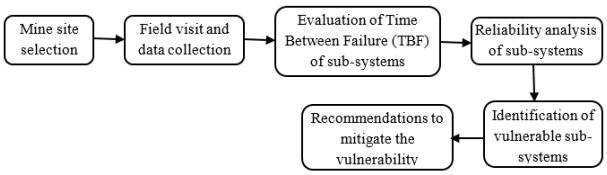


Figure 1. Schematic representation of methodology.

2.1 Description of Mine

The mine site selected for the study was situated in Chhattisgarh, under the control of Southeastern Coalfields Limited (SECL). During the study, the CM machine was deployed for development purposes, where the seam thickness of the mine was higher as compared to other CM projects. The geo-mining conditions of the panel can be seen from the following Table 1.

Table 1. Geo-mining conditions of the mine under study

Seam thickness (m)	Gradient	Pillar size (m × m)	Gallery width (m)	Uniaxial Compressive Strength of coal (MPa)	Pillar area (m^2)
5.05	1 in 16	36 × 36	6	19.77	900

2.2 Reliability Analysis Results

In the equipment working life-cycle, the rate of failure is higher during the initial stages of operation; however, with time, the rate of failure gets reduced and follows a stable or constant pattern. Then with ageing, this failure rate again follows a higher pattern. This influences the Time Between Failure (TBF) pattern. However, in this study, the age-related variation of TBF is not considered. In the current work, reliability analysis was performed using Time Between Failure (TBF) datasets for all the sub-systems. The steps for reliability analysis include- trend and serial correlation test for TBF datasets, distribution fitting and reliability analysis. The TBF data set for each sub-system during one month among the total three months of study is mentioned in the following Table 2. Similar kinds of TBF datasets for a period of three months of operation were used for overall reliability estimation.

At first, the trend test and serial correlation tests were performed graphically for all TBF datasets. Reliability analysis utilises trend test and serial correlation test to identify the randomness of failure data. The serial correlation test basically examines the interrelation between a failure time with its previous one, whereas the trend test indicates a systematic increment or decrement of the rate of failure with time. The serial correlation test with a random point position refers to the presence of no serial correlation, whereas a trend test plot showing a linear trend is free from any trend. Trend test is the scatter plot between Cumulative Time Between Failure and Cumulative Failure Number[3]; a trend test plot showing a linear trend signifies the TBF dataset is free from any trend. Whereas the serial correlation test is the scatter plot between $(i-1)^{th}$ TBF and i^{th} TBF[3]; it must be a random scatter plot and should not represent any specific trend for the data sets free from any correlation. Datasets free from any trend and correlation are suitable for distribution fitting using software packages like MATLAB. The following Figures 2 and 3 depict the trend test plot and serial correlation plot for the electrical sub-system of the CM package considered for the study.

From the above two Figures (2 and 3), it can be seen that the trend test depicts a linear trend, whereas the serial correlation test depicts a random scatter plot. Therefore, the TBF dataset corresponding to the electrical sub-system is free from any trend and correlation and thus suitable for statistical distribution fitting[3]. A similar kind

Table 2. TBF dataset (in minutes) of each sub-system for one month of study

Electrical	Cutter	Gathering	Traction	Hydraulic	Chassis	Ram car	Conveyor	Feeder Breaker	CM Conveyor
985	6264	14328	17928	2088	3816	1065	2810	13668	26280
1070	3312	6192	1717	4896	15264	1154	1275	1140	9072
3384	1191	3456	21888	10224	2365	16416	4680	2345	6768
1250	1241	5904		1190	8928	2026	1270	7776	3168
1190	1351	10656		1260	4464	1175	1650	5140	1290
1715	1171			4464	2448	1417	3096	2250	
4104	3170					2271	1088		
1917	2017					3460	1165		
2295	4752					1100	4780		
1017	1975					4176	1944		
2160	3487					3312	1258		
1240	1017						1655		
1605	2018						1905		
1975							1240		
1617							3096		
1895									
1245									

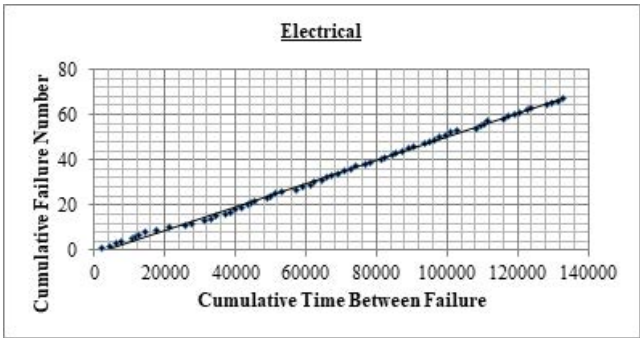


Figure 2. Trend test plot for electrical sub-system.

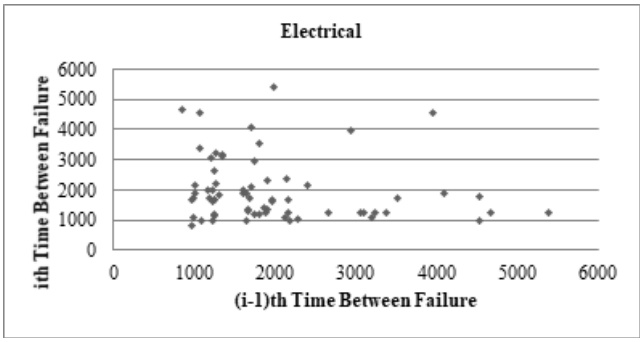


Figure 3. Serial correlation plot for the electrical sub-system.

of trend and serial correlation were seen for TBF datasets corresponding to all sub-systems; therefore, those are not shown here to reduce the redundancy. Therefore, TBF datasets of all sub-systems are suitable for distribution fitting through MATLAB. Further, the distribution fitting application of MATLAB R2021a was used for identifying best best-fit statistical distribution for TBF datasets of each sub-system, and further, the reliability depletion trends were identified. The compatible distributions as identified for all sub-systems are one of the three common for the purpose, namely- lognormal, Weibull and exponential distribution. These distributions are useful for modelling various kinds of failure mechanisms; where the exponential distribution is useful for independent failures, the lognormal distribution is useful where failure is caused by the cumulative effects of various factors, and the Weibull distribution is flexible to be used for modelling various failure rate patterns. The compatible distributions for each sub-system can be seen from the following Table 3.

The reliability depletion trend for five sub-systems showing the highest reliability depletion tendency for a period of 15000 minutes of operation is depicted graphically in the following Figure 4.

3.0 Discussion

From Figure 4, it can be identified that electrical and mine conveyors are the sub-systems accounting for the

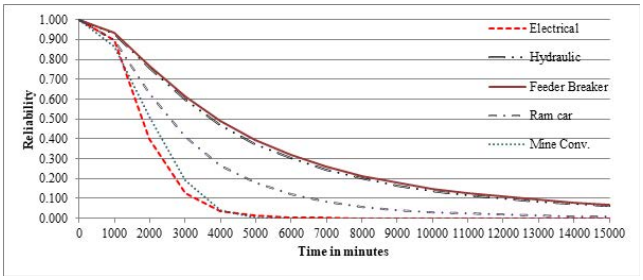


Figure 4. Reliability depletion trends for the five sub-systems with the highest reliability depletion tendency.

Table 3. Details of best-fit distributions for each sub-system

Sl. No.	Name of sub-system	Best fit distribution	Corresponding parameters for best best-fit distribution
1	Electrical	Lognormal	μ = 7.48133, σ = 0.455081
2	Cutter	Weibull	A= 5879.17, B= 0.913092
3	Gathering	Weibull	A= 12528.8, B= 1.35884
4	Traction	Exponential	μ = 11590.8
5	Hydraulic	Lognormal	μ = 8.22652, σ = 0.905537
6	Chassis	Exponential	μ = 8240.8
7	Ram car	Lognormal	μ = 7.83988, σ = 0.732925
8	Conveyor	Weibull	A= 2387.88, B= 2.22259
9	Feeder breaker	Lognormal	μ = 8.26759, σ = 0.909425
10	CM conveyor	Exponential	μ = 9984.67

Table 4. Potential reasons for failure and recommendations to mitigate them

Sl. No.	Sub-systems	Potential reasons for failure	Recommendations
1	Electrical	Power transmission failure Trailing cable rupture Controller and remote malfunction	Regular inspection of transmission lines and use of advanced fault detection equipment. Ensure that the trailing cable is properly anchored. Maintenance of the controller unit and drying of the remote after every shift.
2	Mine conveyor	Motor breakdown Gearbox problems Bearing problem Belt damage	Regular monitoring of vibration levels of the motor and allied attachments Gearbox oil quality inspection after a regular interval Installing an automated lubrication system for bearings
3	Ram car	Drive failure Conveyor motor malfunction Braking system problems Engine-related problem	Pre-operational check for any unusual noise Maintenance of conveyor motor sealing Frequent inspection of the braking system and replacement of essential components when necessary Engine oil analysis and take a note on the level of emissions.

lowest trend of reliability and equipment downtime; they reached 50% reliability after 1700 and 2000 minutes of operation. Whereas the other three sub-systems are- ram car, hydraulic and feeder breaker, they have reached 50% reliability after 2600 minutes, 3800 minutes and 3900 minutes of operation, respectively. The other sub-systems, however, depicted a better trend of reliability as compared to these five sub-systems; therefore, they are not shown here. The reliability trend of the top three vulnerable sub-systems mentioned above has shown an alarming trend; therefore, a questionnaire-based discussion was carried out with experienced mine personnel for the identification of potential reasons for failures and recommendations for the mitigation of such possibilities of failures. The details of which can be seen from the following Table 4.

4.0 Conclusion

This research work is aimed at identifying the vulnerable sub-systems in connection with the operation of a CM package deployed for underground coal mining in India. The sub-systems that constitute the overall CM package were studied for reliability analysis, through which the sub-systems with the highest trend of reliability depletion were identified as the most vulnerable sub-systems. From the study, it can be observed that electrical and mine conveyor are the two most vulnerable sub-systems, with a depletion of 50% reliability within 2000 minutes of operation since inception from the previous repairing. Other vulnerable systems are the ram car, hydraulic and feeder breaker. Further, based on this analysis, a questionnaire-based investigation to identify the causes was performed, and further, some measures were recommended to mitigate those causes. This paper may serve as a base to identify the vulnerable sub-systems for CM-based operation, and further in-depth analysis may help to design a proper maintenance program for the CM-based underground mine operation system.

5.0 References

1. Paltasingh T, Satapathy J. Unbridled coal extraction and concerns for livelihood: evidence from Odisha, India. Miner Econ. 2021; 34(3):491-503. https://doi.org/10.1007/s13563-021-00272/5 PMCID: PMC8204070
2. Vayenas N, Peng S. Reliability analysis of underground mining equipment using genetic algorithms: a case study of two mine hoists. J Qual Maint Eng. 2014; 20(1):32-50. https://doi.org/10.1108/JQME-02-2013-0006
3. Banerjee S. Performance augmentation of continuous miner-based system in India: a reliability-based approach. Min-Informat Autom Electr Eng. 2017; 55(3):42-8. https://doi.org/10.7494/miag.2017.3.531.42

4. Sarkhel S, Dey UK. Reliability modelling of side discharge loader for availability estimation and maintenance planning in underground coal mines. Int J Sci Eng Res. 2015; 6:847-54.
5. Samanta B, Sarkar B, Mukherjee SK. Reliability analysis of shovel machines used in an open-cast coal mine. Miner Resour Eng. 2001; 10(2):219-31. https://doi.org/10.1142/S0950609801000610
6. Harish Kumar NS, Choudhary RP, Murthy CS. Model-based reliability analysis of shovel-dumper system's mechanical failures used in the surface coal mine: a case study. Saf Reliab. 2020; 39(3-4):215-29. https://doi.org/10.1080/09617353.2020.1759260
7. Rahmani Z, Rahimdel MJ, Noferesti H. Reliability analysis of a fleet of mining trucks (a case study in Iran). J Geomine. 2023; 1(2):68-74.
8. Banerjee S, Dey NC. A prognostic view on the continuous mining machine-based reliability to augment the availability of allied sub-systems. J Mines Met Fuels. 2020; 5-10.
9. Bołoz Ł, Rak Z, Stasica J. Failure rate of longwall system machines by the type of failure-case study. Arch Min Sci. 2023; 68(3).
10. Kumar D, Gupta S, Yadav PK. Reliability, Availability and Maintainability (RAM) analysis of a dragline. J Mines Met Fuels. 2020; 68-77.
11. Zhou Y, Wang C, Liao C, Wang J, Zhang B. Sustainable longwall partial filling mining strategies and optimal design of paste filling process. 2024. https://doi.org/10.21203/rs.3.rs-3110543/v2
12. Roy S, Mishra DP, Agrawal H, Bhattacharjee RM. Development of a productivity model of continuous miner operators working in hazardous underground mine environmental conditions. Measurement. 2025; 239:115516. https://doi.org/10.1016/j.measurement.2024.115516
13. Banerjee S, Dey NC. Stochastic modelling of continuous miner-based underground coal mine production planning through curve-fitting and regression approach. Acta Montanistica Slovaca. 2024; 29(4). https://doi.org/10.46544/AMS.v29i4.23
14. Bazargur B, Bataa O, Budjav U. Reliability study for communication system: a case study of an underground mine. Appl Sci. 2023; 13(2):821. https://doi.org/10.3390/app13020821