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A prognostic view on the continuous mining machine based system-reliability to augment availability of allied sub-systems

Continuous miner (CM) is an underground coal mining machine, capable of producing coal from underground at a considerably higher rate. With incessant modernization, demand for power is increasing rapidly, which deserves a boost in coal production in India. Opencast mining in India contributes to maximum share of overall coal production as compared to underground coal mining. Opencast mining is feasible for the seams near the surface. However, with higher rate of extraction the near surface seams are getting quickly depleted, this necessitates the implementation of an effective cutting edge underground mining technology to sustain the level of coal production to support the indigenous demand of coal.

Government of India has recently taken the initiative to implement cutting edge underground mining technology; such as CM and other mass production technology to boost underground mine productivity. These machines are getting implemented recently, having a broad scope of research and development in Indian as well as global mining scenario.

This paper focuses on the mechanical factors contributing to equipment downtime along with statistical reliability analysis of two continuous miner machines working in two different panels of an underground mine in a leading coal producing company of the country. Reliability analysis includes statistical methods such as, trend test, serial correlation test including distribution fitting. Through trend test and serial correlation test, Time Between Failure (TBF) data is first checked whether it is free from any trend and serial correlation or not, data free from trend and serial correlation are suitable for distribution fitting. This TBF data is fed to proper probability distribution, from where the reliability curves are obtained.

In this machine mining based study, the overall CM package is divided into few sub-systems such as; electrical, cutter and gathering arm, traction, hydraulic, chassis, feeder breaker, shuttle car, conveyor, CM conveyor etc. The availability and reliability of all these sub-systems are calculated to identify the vulnerable sub-systems contributing to maximum percentage of undesired equipment stoppage, hence lowering productivity. Some important mechanical factors are identified from physical verification in those two panels about the machines and systems of the mine. Out of which the potential factors are; conveyor breakdown, power cut and cable fault, traction chain wear out and pad change etc. The possible reasons of this lower reliability trend for that specific sub-system is discussed with experienced mining personnel working in the mine and based on that few recommendations as well as new maintenance strategy are suggested to avoid recurrence of these failures and to ensure better availability of the system.

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1. Introduction

Coal is the major sources of energy and one of the most important raw materials for thermal power plants. Most of the countries, including India depend largely on coal for power generation. India is one of the largest producers of coal globally, more specifically, India ranks third in coal production. In 2017-18 India produced 730 Mt of coal [1], though the produced coal is not sufficient to replenish the indigenous demand. Coal production in India largely depends on opencast projects, which generally extracts coal from near the surface reserves; underground mines contribute only 7% of the total coal production [2]. Therefore, near surface coal seams are gradually getting depleted and necessity to produce coal from deeper reserve is felt important. This deserves effective underground coal mining techniques with mass production capability. Continuous miner (CM) is one of such machines, compatible with underground mining method adopted in India. In the last decade government of India has felt the necessity of these mass production technologies in Indian mining sector and implemented these machines in some of the selected mines of the country. The feedbacks of these machines are not as expected by the manufacturer as well as end user company. Therefore, there is a huge scope of research in the pre-commissioning period.

These mass production technologies are working efficiently with other major coal producers globally, after having few minor modifications to the machine as per their local demand and geo-mining condition [3].

India adopts room and pillar technique of coal production for producing coal from underground coal reserves. CM is found perfectly compatible machine to work out with this technique even for extraction of coal from existing panels.

In-depth observation on the trends of failure shows that non-optimal maintenance strategy as well as equipment stoppage and breakdown are major out of many other reasons against inferior performance from the CMs.

This paper is concentrated on the reliability of the sub-systems of two CMs working in two panels of same underground mine. Reliability analysis of different sub-systems within a system is the parameter to identify the vulnerable sub-systems, which deserves more care during maintenance.

2. Subsystems of CM based systems

CM packages basically have four individual units namely; cutting unit, ram car, feeder breaker, and quad bolter. This overall package is intended to accomplish preparation and transportation of coal, size the oversized chunks of coal as well as support the freshly exposed roof. The overall system is further categorized in following sub-systems: electrical, cutter, gathering, traction, hydraulic, chassis, feeder breaker, conveyor, ram car and CM conveyor. Failure of any of these sub-systems either partially or fully stops the overall CM based underground coal production.

3. Basic operation of CM package

Four individual machines are deputed to work simultaneously to bring success to the overall package. The CM produces coal by shearing the coal face through cutting picks and it moves forward to cut the next layer of coal and to gather by the gathering arrangement followed by supply of the coal to the CM conveyor, which loads the coal to the ram car. Generally, two ram cars are associated with one CM for uninterrupted operation. After collecting coal from CM one ram car starts the journey to the feeder breaker, in the mean time another ram car must have completed its cycle of carrying coal, unloading, return and should wait for immediate engagement to the cutting unit. If this cycle time is maintained properly then only flawless production from CM is possible. When the ram car unloads the coal to the feeder breaker it breaks the over sized chunks of coal. After reaching a certain cut out distance through the face; generally in Indian condition 10-14m, the CM is marched to another face and continues cutting there till the cut out distance is reached, this concept of cut out distance is considered from the safety aspect of the workers as well as machine.

4. Description of the mine site under study

The mine site considered for this study is situated in the south-central part of India and belongs to one of the major coal producing public company of the country. There are two CM machines deployed for coal production from two different panels of the mine. The geo-mining conditions of these two panels are depicted in Table 1.

There is certain range of the above mentioned geo-mining parameters for better performance through CM. The gradient of 1 in 10 or less and thickness of the seam within 3.5m to 6 m is suitable for CM based panel [4]. According to Coal Mines Regulation 2017 the gallery width of a panel should be maximum up to 4.8 m, which is not at all suitable for working with CM as it is a large machine and requires sufficient space for easy manoeuvrability. Therefore, seeking proper permission from the concerned authority to extend the gallery width approximately near to 6m is a prerequisite of implementing the CM machine to any underground panel. From the above table it can be seen that, all the parameters of both the panels of the mine under study lies within the optimum range as stated above.

5. Methodology

Reliability analysis of each sub-system is the key to identify the most vulnerable one and improvement of which is expected to help in improvement of the system availability as well as overall productivity of CM based underground mine operation system.

The mine site considered for study has deputed two CM machines in each panel, data related to downtime and working time was collected from these two mines for a period of two months. Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), availability and reliability of each sub-system was calculated. Reliability value of each sub-system aids in identification of vulnerable sub-systems for each CM machines. Based on this a discussion is made with experienced mine personnel, which was specifically useful to draw suitable recommendations for improvement of the system reliability as well overall productivity of CM based underground mine operation system. Overall methodology can be seen from the schematic diagram (Fig.1).

6. Statistical procedures of reliability analysis

Downtime and working time related data more specifically; Time Between Failure (TBF) data are prerequisites for reliability analysis of sub-systems of a machine. Trend test and serial correlation tests are first performed with the help

TABLE 1: GEO-MINING CONDITIONS OF THE MINE SITE UNDER STUDY

Machine	Seam	Pillar dimension	Gallery width	Depth of cover	Thickness of seam	Gradient
CM-1	5	39m×35m	5.8m-5.9m	398m	3.8m-4.2 m	1 in 18
CM-2	5	48m×50m	6.0m	425m	3.8m-4.2m	1 in 18

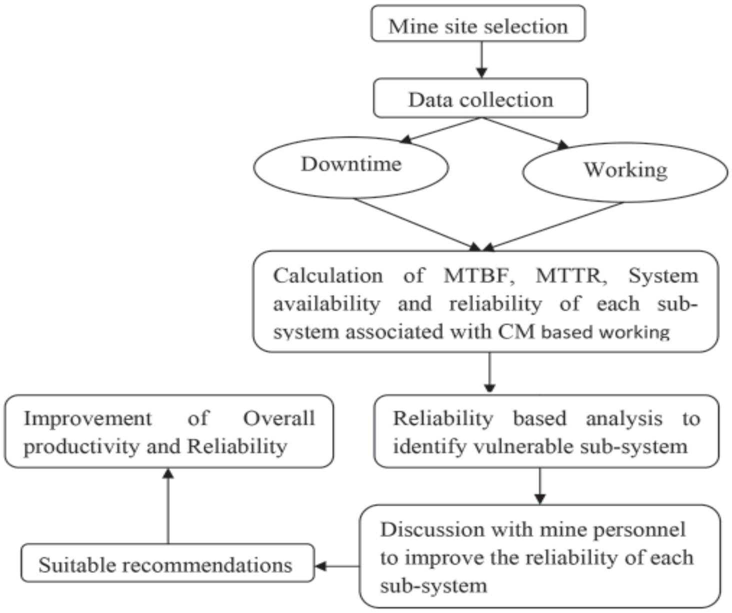

Fig.1: Schematic diagram of methodology for the study

of TBF data set to identify the presence of any trend or correlation in the data sets. Data sets free from any trend and serial correlation are suitable for workout with conventional statistical distributions.

Trend test is the line plot between cumulative failure number and cumulative time between failures [5]. Whereas, serial correlation plot is the scatter plot between i^{th} TBF and $(i-1)^{th}$ TBF [5]. Few trend test and serial correlation plots are shown in Figs.1 and 2.

Trend test and serial correlation test are plotted for all the sub-systems, few of the trend test and serial correlation test plots are depicted in Figs.2 and 3. The plotted graphs as depicted in above figure show that, all trend test plots are linear and serial correlation plots does not depict any specific pattern. Therefore, all these data sets are free from any trend and correlation and hence suitable for classical statistical distributions [5].

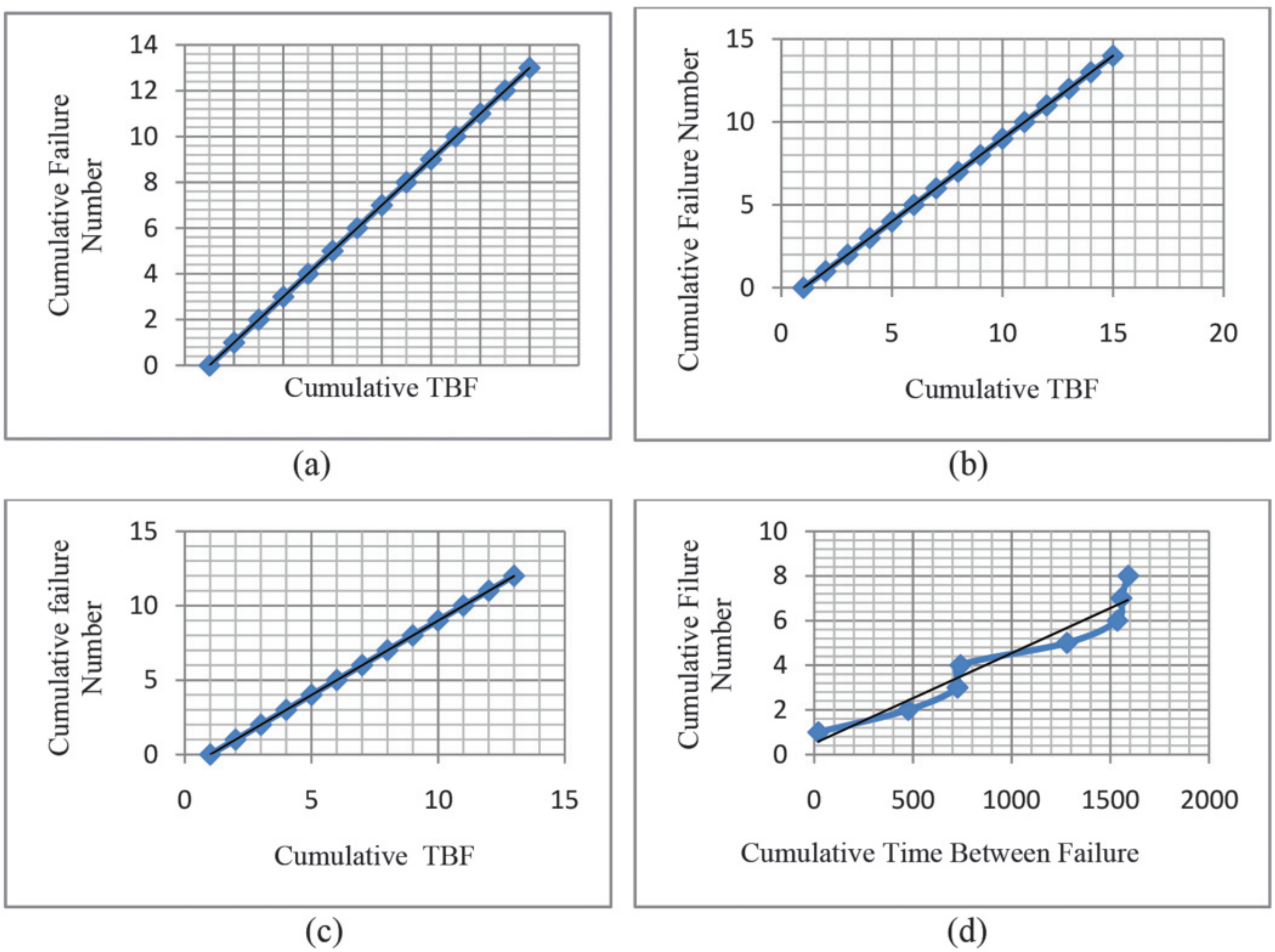

Fig.2 Trend test plot of: (a) Electrical sub-system of CM-1in first month, (b) Electrical subsystem of CM-1 in second month, (c) Quadbolter of CM-2 in first month,(d) Quadbolter of CM-2 in second month

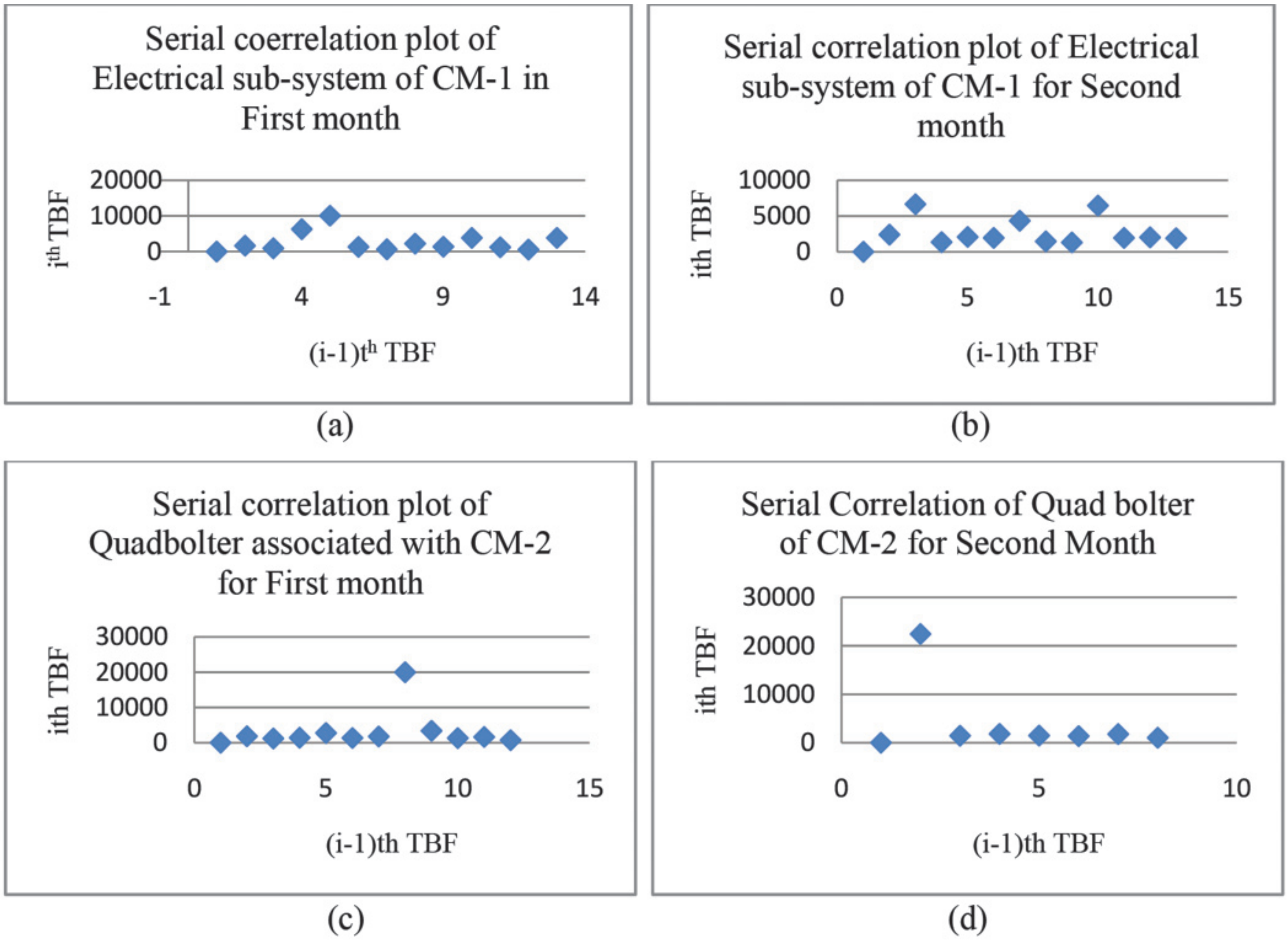

Fig.3 Serial correlation plot of: (a) Electrical sub-system of CM-1 for first month, (b) Electrical sub-system of CM-1 for second month, (c) Quad bolter of CM-2 for first month, (d) Quad bolter of CM-2 for second month

7. Results and observations

After trend and serial correlation test proper probability distributions are fitted to the data sets to quantify the reliability of each sub-system over time. Reliability analysis of each sub-system is performed and here only top three vulnerable sub-systems of each CM for each month are represented graphically (Fig.4).

The graphs in Fig.4 depict three sub-systems with lower reliability trends for CM-1 during the first month of study; quad bolter is found to be least reliable by reaching 50% reliability within 1600 minutes of operation, whereas, conveyor and shuttle car reaches half of their reliability within 1900 minutes and 2000 minutes of their operation.

From Fig.5 it can be observed that for CM-1 in second month the ram car is found to be least reliable, reaching 50% reliability within 1900 minutes of operation, this is followed by quad bolter and conveyor; they reached half of their reliability after 2000 minutes and 2300 minutes of operation.

Fig.6 depicts the reliability of three sub-systems with lowest reliability during first month for the CM-2. From the figure we can see that the conveyor reached 50% reliability after 1500 minutes of operation. Whereas, the next two sub-systems depicting low reliability trend are quad bolter and ram car; they reached 50% reliability after 2100 minutes and 4100 minutes of working.

Fig.7 depicts the reliability plots for the CM-2 during second month. From these graphs it is seen that conveyor is least available sub-system for CM-2 during second month. whereas, next vulnerable sub-systems are quad bolter and ram car. The conveyor reached 50% reliability after 2100 minutes of operation, while quad bolter and ram car reached half of their reliability after 2400 minutes and 2600 minutes of operation.

From the analysis it is found that most vulnerable sub-systems for both the CMs during two months of observation are common, which are namely: quad bolter, conveyor and ram car.

8. Discussion with experienced mine personnel

A detailed discussion with experienced mine personnel is carried out based on a properly designed questionnaire. From

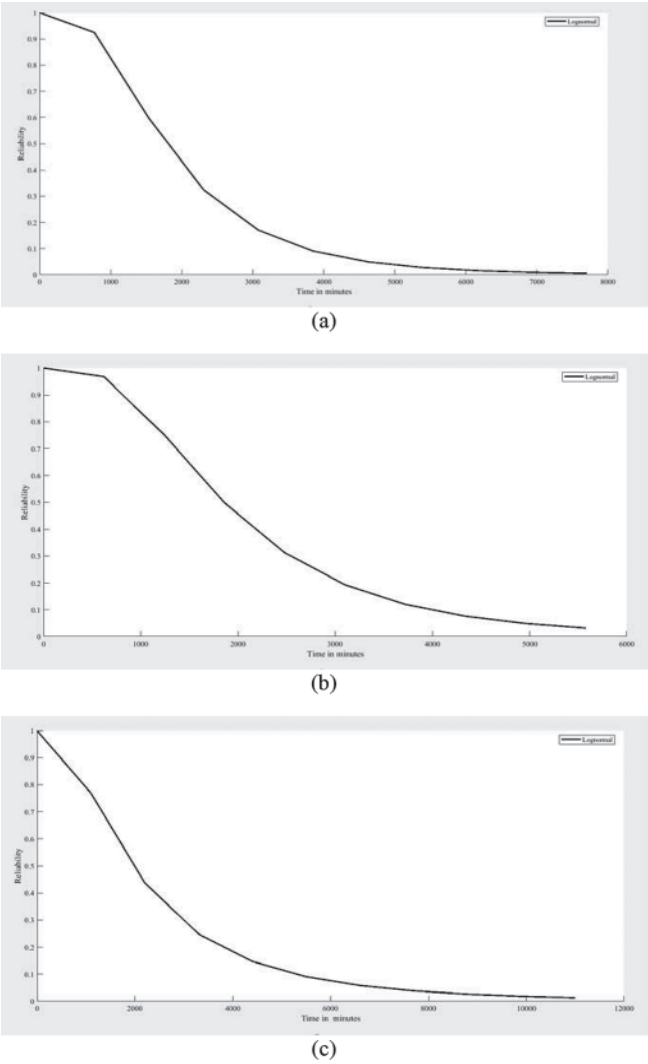

Fig.4 Reliability plot of following sub-systems of CM-1 in first month: (a) Quad bolter, (b) Conveyor, (c) Ram car

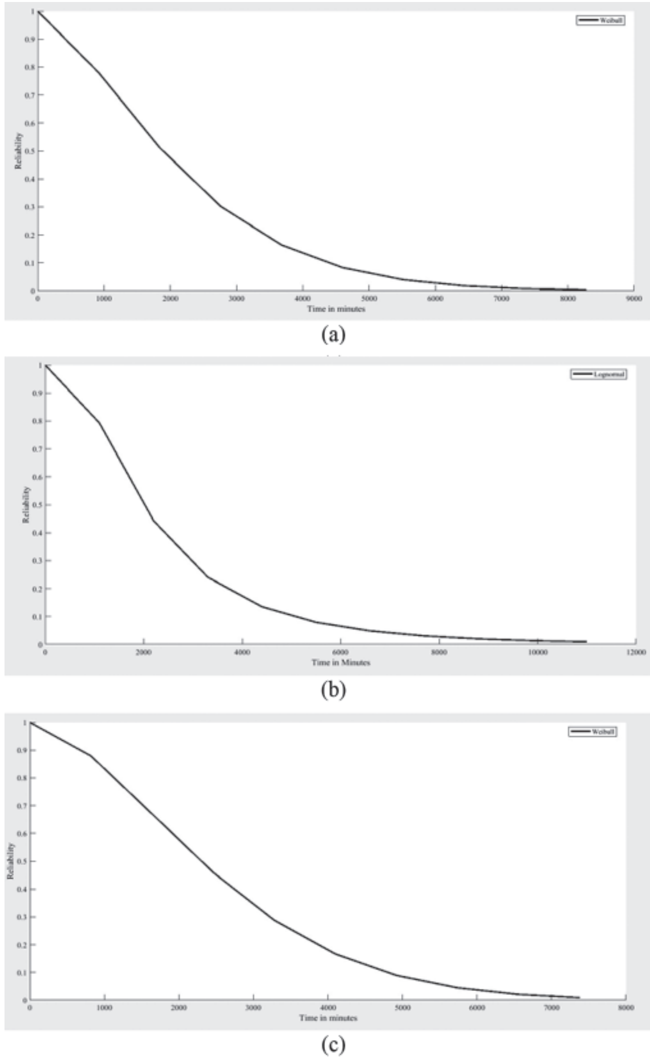

Fig.5 Reliability plot of following sub-systems of CM-1 in second month: (a) Ram car (b) Quad bolter, (c) Conveyor

that discussion it is clear that the maintenance strategies as well as lack of awareness of workers towards their responsibilities are the main reasons for the vulnerable performance of the machines.

Senior mining personnel identified the maintenance of the quad bolter, ram car, out-bye conveyor requires intense care during maintenance. This actually depicts the requirement of a new and optimum maintenance strategy; where the maintenance time as well as production time should be well balanced, so that the productivity requirement is met along with higher equipment availability.

9. Recommendations

Based on the overall study and discussion, few of the remedies to improve the condition are recommended. Some of them are as follows:

(a) Design of a proper preventive maintenance programme with balanced maintenance time and production time.

(b) Visual inspection of conveyor motors, driving and driven pulleys and movement profile of the belt. This helps in identifying any damage in a preliminary stage.

(c) Proper sealing of the motors and other electrical components.

(d) Proper lubrication of the bearings.

(e) Change spares before MTBF, as this may help to avoid sudden failure of components.

(f) Training of the maintenance team to accomplish the maintenance work effectively within the stipulated time of maintenance.

(g) Educational workshops to make people aware about their role and responsibility towards job.

10. Conclusion

Mass coal producing underground mining machines are highly cost-intensive and hence require better care and maintenance for uninterrupted targeted production. This

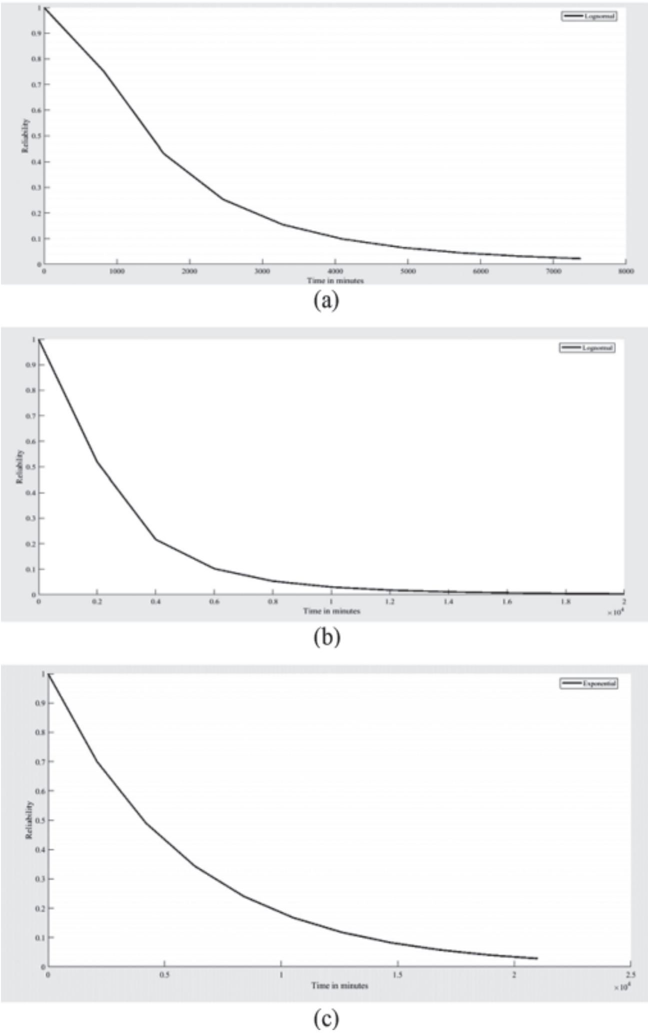

Fig.6 Reliability plot of following sub-systems of CM-2 in first month: (a) Conveyor (b) Quad bolter, (c) Ram car

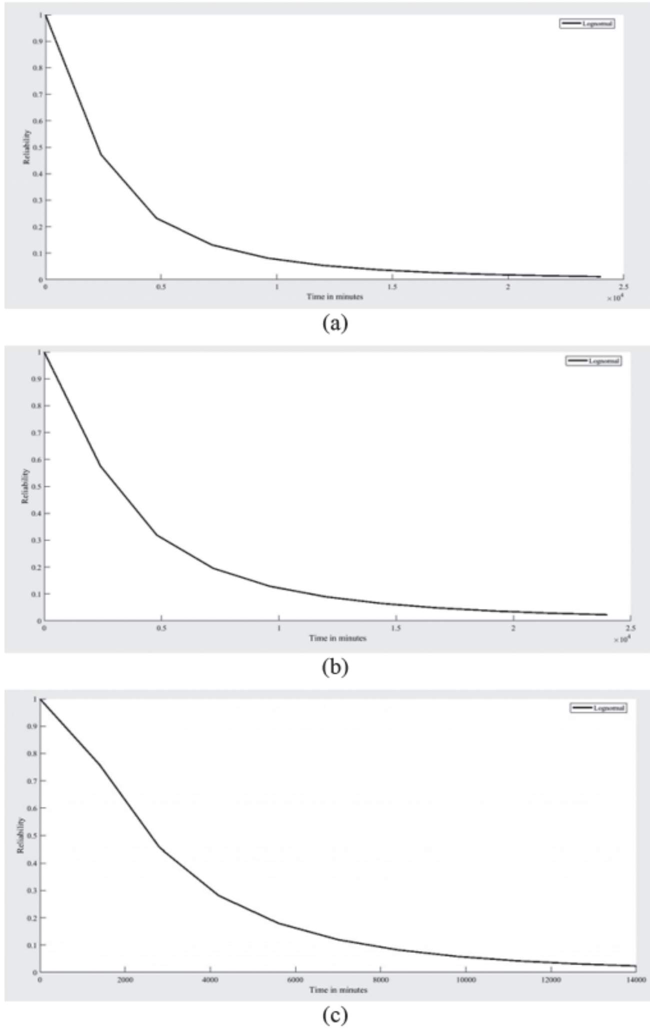

Fig.7 Reliability plot of following sub-systems of CM-2 in second month: (a) Conveyor (b) Quad bolter, (c) Ram car

paper focuses on the reliability analysis of two continuous miner (CM) machines deployed in two panels of one underground mine in India. Reliability of each sub-system within a production system is the basis to benchmark the efficacy of a production system. From detailed investigation it is found that out-bye conveyors, quad bolter and ram cars are the most vulnerable systems. In this paper the results of a detailed discussion with the experienced mine personnel is presented and few remedies based on the investigation and discussion is recommended to overcome this vulnerability. This reliability based approach to evaluate the equipment effectiveness for underground coal mines may be proven as an effective tool for the purpose in near future.

11. References

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