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Reliability, availability and maintainability (RAM) analysis of a dragline

Dragline is one of the crucial heavy earth moving machines (HEMM) which is used in opencast mine. It has significant role in opencast mine to improve the overall production and remove the overburden; performance of dragline depends on the reliability, availability and maintainability (RAM) of the subsystems.The regular or irregular occurrence of failures affects the performance of dragline and sudden failure of any component will stop the functioning which impacts on the huge loss in terms of production and financial. Also, it may be catastrophic for personnel who are working around or on it. The aim of this paper is to investigate the RAM of the critical components and subsystems of dragline using the failure and repair time data. The trend and serial correlation tests have been used to determine that dataare independent and identically distributed (IID) or not and the statistical techniques have been applied for RAM modelling. For improving the reliability of dragline, reliability-based preventive maintenance method has been used.

Keywords: *Reliability, availability, maintainability, statistical model, IID, dragline.*

1. Introduction

Mining industries are focusing on the reliability analysis to increase the productivity of technologically advanced mechanised and complex mining machinery to achieve the annual targets. These machines are combinations of different subsystems/ components which affect the reliability, availability and maintainability (RAM) of the subsystems (Low and Einstein 2013; Topal and Ramazan 2010). Ensuring a competent reliability level is of great importance for mining machinery, but due to complex in design, it is vital for the mining machinery to achieve the highest level of reliability and availability during operation. Inappropriate reliability estimation leads to several problems such as high maintenance costs, improper maintenance model and unsafe working conditions.

RAM is inherent characteristics of the system and it has a significant impact on the total life-cost of the machine. Reliability of the system depends on various situations like machine condition, level of automation, performance of workforce, organizational environment and external condition of environment (Avila 2015). These conditions affect the reliability of the machine from design level to operational level reliability. For improving the reliability or to maintain the certain level reliability, it is necessary to keep regular maintenance or renewal of the subsystem or component of system, but at the cost of financial implication.

In literature, there are so many methods which have been employed for the RAM analysis and can form a notable contribution to enhance the performance of the complex industrial and mining systems (U. Kumar 1990; Manzini, Riccardo. Regattieri, Alberto. Pham, Hoang. Ferrari 2013) and these methods have been carried out using the statistical analysis. Event tree, Fault tree analysis, reliability centred maintenance, fuzzy reliability; Markov modelling has some extensively used methods to estimate the RAM. Reliability was estimated on various large machines like shovel, heavy engineering machine and underground machines and these heavy machines depend on the large number of subsystem/ components which affect the reliability of system (Barabady and Kumar 2008). For maximum maintainability and availability, subsystems are connected in the series and each subsystem have to reliable and get the maximum productivity (Barabady 2005). To plan relevant maintenance exercise, it is necessary to get the proper information about the frequency of failures and performance of machine and it can be done using reliability estimation to keep the machine in operational condition. RAM analysis has been done on tunnel boring machine, earth pressure balance, tunnel boring machine to estimate the reliability and maintenance strategy to be followed with higher availability (Amini Khoshalan, Torabi, and Maleki 2015). Studies on major mining machines like shovel, (Samanta, Sarkar, and Mukherjee 2004), dumper engines (Kishorilal 2014), load-haul dump vehicles (Gustafson, Schunnesson, and Kumar 2015; Vayenas and Wu 2009) and rotary drilling machines (Javad Rahimdel et al. 2013) have shown that RAM analysis helped in improving their performance and also maintenance plan. There are various other methods to plan preventive maintenance using the

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reliability analysis of systems. These methods optimise the maintenance policy, spare parts availability to their operating and maintenance costs (Manzini, Riccardo. Regattieri, Alberto. Pham, Hoang. Ferrari 2013). In this study, failure/repair data has been used for the best fit among the standard distributions and corresponding parameters were identified in statistical model analysis. Further, RAM and hazard/failure rate has been calculated for the dragline. This can be potentially being useful tools to understand the current situation of the system/subsystems.

2. Modeling of RAM analysis of dragline

RAM analysis has significant role in improving the reliability of systems and subsystems of equipment by changing to the better maintenance plan and also reduce the maintenance costs, which help to secure the operation of machines. There is a basic definition of reliability, availability and maintainability.

2.1 Reliability

Ebeling (1997) has described reliability as the probability that a system/subsystem can a ccomplish a specific work under the specific conditions within the specific period of time. Therefore, it is essential to recognize the expected conditions that can be taken into consideration for system design (Dhillon 2013).

Reliability of any item can be expressed mathematically as

$$R(t) = \int_t^{\infty} f(t)dt \quad \text{... (1)}$$

Where, $R(t)$ is the reliability to be estimated at time t. f(t) is the probability density function of the failure.

The system has a single component, two or more than two components which may be connected with a series or parallel connection or maybe mixed connection. If the system is connected in a series combination then its reliability can be estimated as in equation 2.

$$R(t) = R_1 R_2 R_3 \dots\dots . R_n = \prod_{i=1}^{n} R_i \quad \text{... (2)}$$

Where R_i is the reliability of subsystems/components of the system.

For a parallel system, the system reliability can be estimated as in equation 3.

$$R(t) = 1 - F_{sys} = 1 - \prod_{i=1}^{n} [1 - R_i] \quad \text{... (3)}$$

2.2 Availability

Availability is the probability that a system performs its required function at a point of time when operating under a specific condition (Ebling C.E., 1997). Inherent availability is the most commonly used type of availability used in RAM analysis (Simon, Javad, and Abbas 2014).

Inherent availability of the systems/subsystem can be determined using equation 4.

$$A(T) = \frac{MTBF}{MTBF+MTTR} \quad \text{... (4)}$$

Where, MTTR and MTBF are the mean time between failure and mean time to repair respectively.

2.3 Maintainability

Maintainability is the probability that a failed component or system is restored or repaired to a specified condition within a period when maintenance is performed by prescribed procedures (Ebling C.E., 1997). The probability to finish the repair at a time less than *t* can be defined as follows:

$$M(t) = \int_0^t m(t)dt \quad \text{... (5)}$$

Where $M(t)$ is a function of maintainability at time *t* and $m(t)$ is the probability density function of repair data.

3. Methodology

For the analysis of failures of the system/subsystems, the following steps have been adopted which has been graphically represented in Fig.1.

1. Data collection and validation: Data collection from field maintenance data, failure logbook data and also check to outliers, errors and any inconsistencies in the data
2. Study of failure data: To analyze the failure data to which types of the failure modes, distinguished the data in different failure types.
3. Test the trends in failure rate: Plot the number of failures against operating time to check the linear or curvature nature.
4. Description of failures: To analyze the failures rate either it is time constant or time-varying failure rate. To model the data as a renewal process (RP), a homogenous Poisson process (HPP), a non-homogeneous Poisson process (NHPP), or any other process and to estimate the values of model parameter. RAM can be described by applying this process to failure data of dragline.

3.1 Statistical analysis method

The statistical description of failure events illustrates the trend analysis, selection of best-fit distribution and estimation of model parameters for the time constant or time-dependent model. Thus, MTBF and MTTF have used to evaluate the reliability of repairable and non-repairable systems respectively (S. Kumar 2012). System or subsystems/ components failure occur due to non-operating behaviour under the specific conditions (Dhillon 2006). The major causes of mechanical failure of system/subsystems are improper design, material selection, manufacturing defects, improper installation, improper operation, wear out and gradual degradation in operation.

3.2 Data analysis

In the statistical analysis method, reliability and maintainability model depends on the TBF and TTR

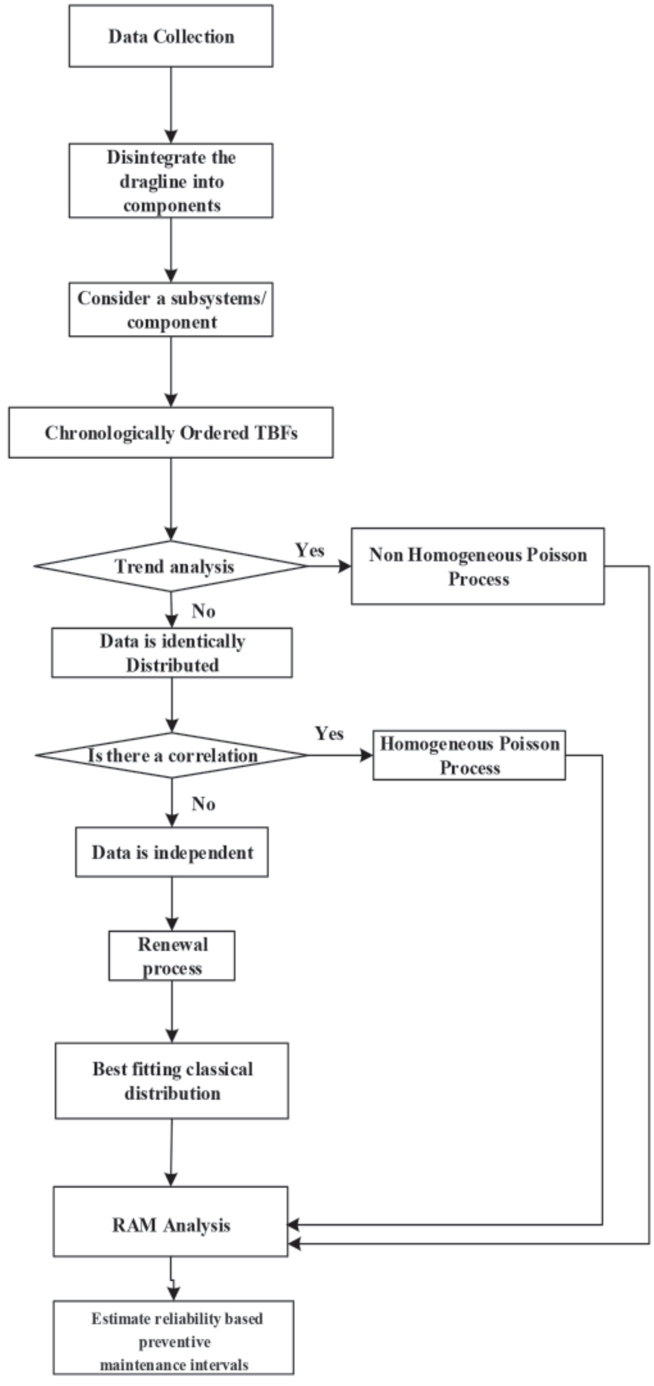


Fig.1 Procedure for analysis of the failure of repairable systems

respectively. If the failure data have IID nature, then it follows the RP otherwise NHPP. In the absence of trend and correlation, failure data follows the RP. Traditional process identifies the distribution function in the RP. Generally, the probability density functionin the renewal process is identified by Anderson-Darling, Kolmogorov-Smirnov, and Chi-Squared methods. In these methods, the least values will decide the best fit distribution for the systems/subsystems (Hoseinieetal. 2012).

4. Case study

The present case study has been carried out by considering a large opencast coal mine in India. For present study, two years (2013-2015) failure data has been collected to analyse the RAM of dragline. Table 1 shows the dragline subsystems with their specific component.

Table 1: Draglines divided into different subsystems with their code

Subsystems	Code	Components
Bucket and accessories	BCKT	Bucket teeth, adapter, spender rod pin,
Dragging subsystem	DRG	Drag rope, drag socket, drag pulley
Ragging	RAG	Dump rope, dump socket, dump pulley
Motor and generators	MTG	Swing motor, drag motor, hoist motor, generators, exciter etc.
Hoist	HST	Hoist rope, hoistpulley, hoist socket
Walking/movement	WLK	Rotating rail track, eccentric arm,
Others	OTH	Compressor, electric cables and other secondary use of machinery
Structural subsystem	STR	Boom, A-frame

4.1 The specification of studied dragline

Basic specification of dragline is bucket capacity: 24m^3, boom length: 96m, weight of dragline: 2000 tonne, boom angle: 30^o, operating radius: 88m, drum diameter: 2.59m dump height: 39.6m, hoist, hoist rope diameter: 2×60mm, digging depth: 53.3m drag drum diameter: 2.59m, hoist drum diameter: 2×70mm, base diameter: 15.25m, shoe length: 17m, shoe length: 17m, shoe width: 2.8m, walking speed: 0.24km/h, maximum suspended area: 183m^3, average ground bearing pressure: 0.95kg/cm^2. Bucket specification is: weight 32 tonne, capacity: 24m^3, width: 4.88m, number of teeth: 5 body material: alloy steel.

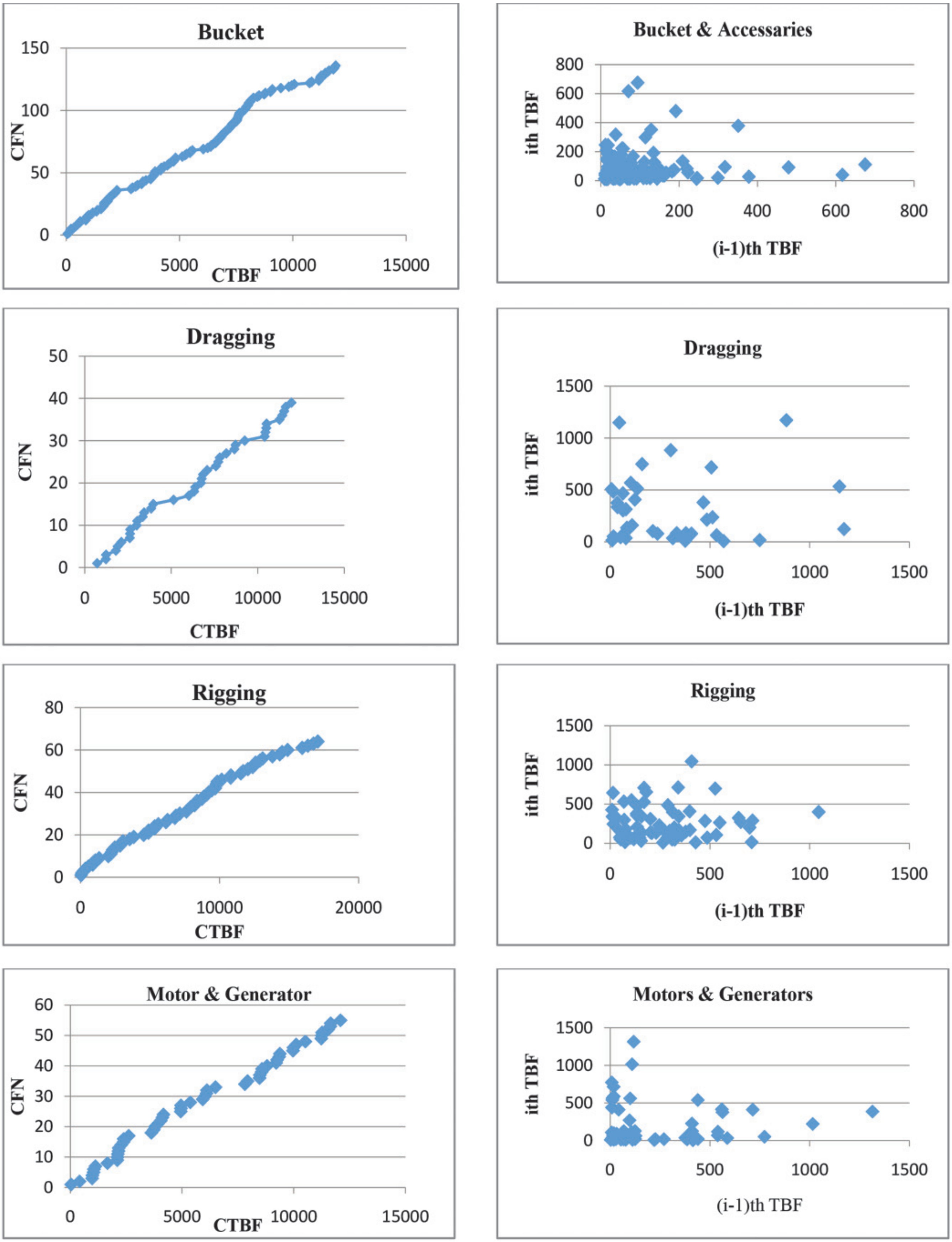
Failure data is the primary step to estimate the reliability analysis of repairable or non-repairable systems with the record book. For data collection, record book would have various sources like operational record book, maintenance logbook; daily maintenance reports. For reliability modelling, these data have been used. To investigate the RAM analysis, dragline systems were divided into several subsystems.

Each subsystem has repairable or non-repairable components. At the time of regularly scheduled maintenance, repairable components would be repaired and some of the components cannot be repaired during the regular schedule maintenance would be replaced by the new one, is known as non-repairable components..

5. Results and discussions (RAM analysis)

5.1 Reliability

In this investigation, dragline is divided into eight major



(Fig.2 Continued...)

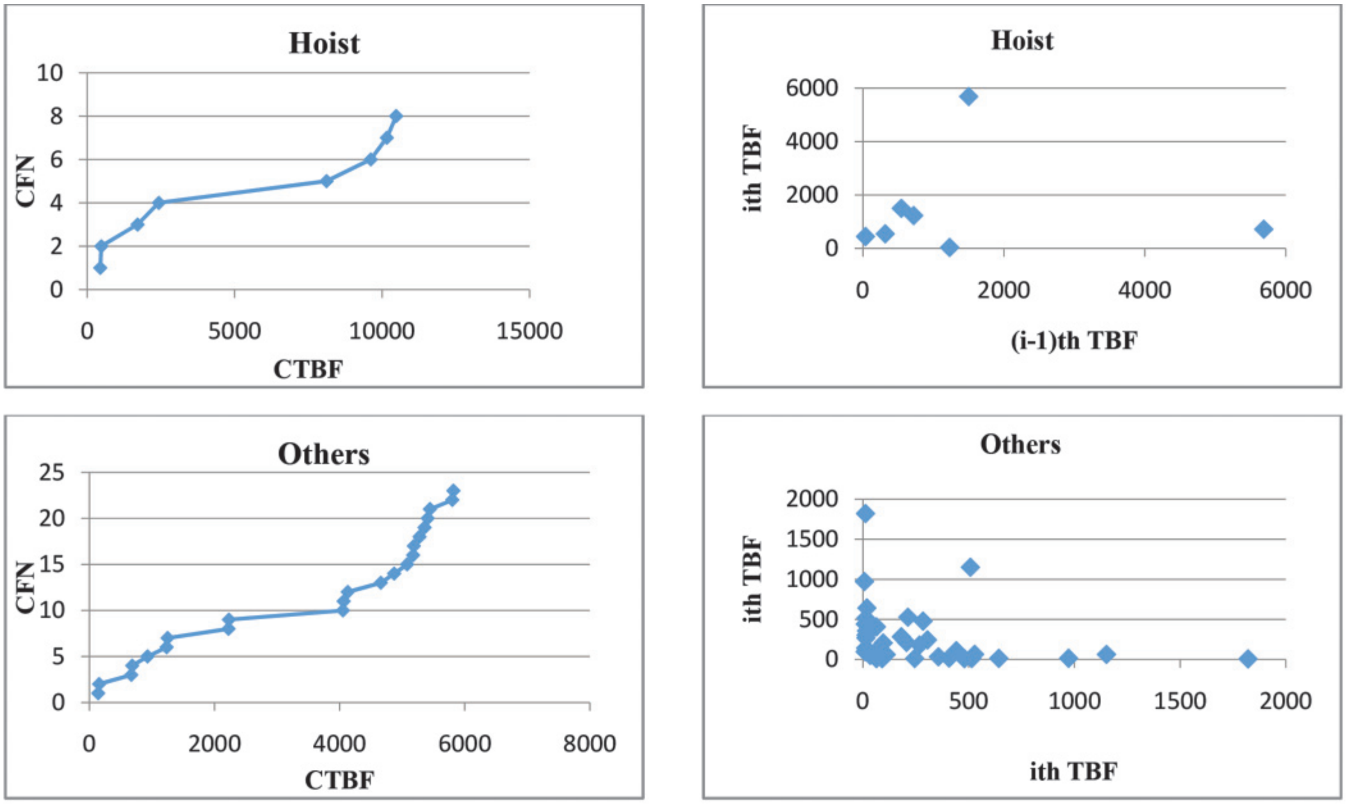


Fig.2 Trend and correlation tests diagram for TBF data of dragline

subsystems named as: rigging, dragging, bucket and accessories, hoisting, movement/walking mechanism, boom and others. All the subsystems have different types of components and having different frequency of failures. Using TBF data of dragline, the trend and correlation for reliability estimation has been carried out which decides that trend test follows the traditional or NHPP methods (Fig.2). If trend test is a straight line then it implies that reliability should follow the conventional parametric distribution process for estimating the reliability and trend shows the curvature in the graph and it should follow the NHPP distribution.

In Table 2, the results of the goodness of fit test for all the subsystems of the dragline have been given and it was found that weibull distribution best fits in all of the subsystems. The failure probability density is defined as

$$f(t) = \frac{\beta}{\eta}\left(\frac{\beta}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad \text{... (6)}$$

Where, $f(t)$ is the failure probability distribution function.

Thus, reliability of the subsystem has followed the weibull distribution.

$$R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad \text{... (7)}$$

Where, β, η are the shape and scale parameters, respectively.

The TBF data shows the presence of trends in trend test (Fig.3) for OTH subsystem of the dragline. Thus, this subsystem should be analysed by NHPP model. NHPP model is used for reliability modelling of other subsystems of the dragline.

The intensity function of NHPP is

$$\lambda(t) = \left({}^{\beta}/_{\alpha} \right) ({}^{t}/_{\alpha})^{\beta-1} \quad \text{... (8)}$$

Where β = shape parameter and α = scale parameter

The parameters can be computed as follows

$$\alpha = {}^{T_n}\Big/_{(n)^{1/\beta}}, \beta = \frac{n}{\sum_{i=1}^{n} \ln\left(\frac{T_n}{T_i}\right)} \quad \text{... (9)}$$

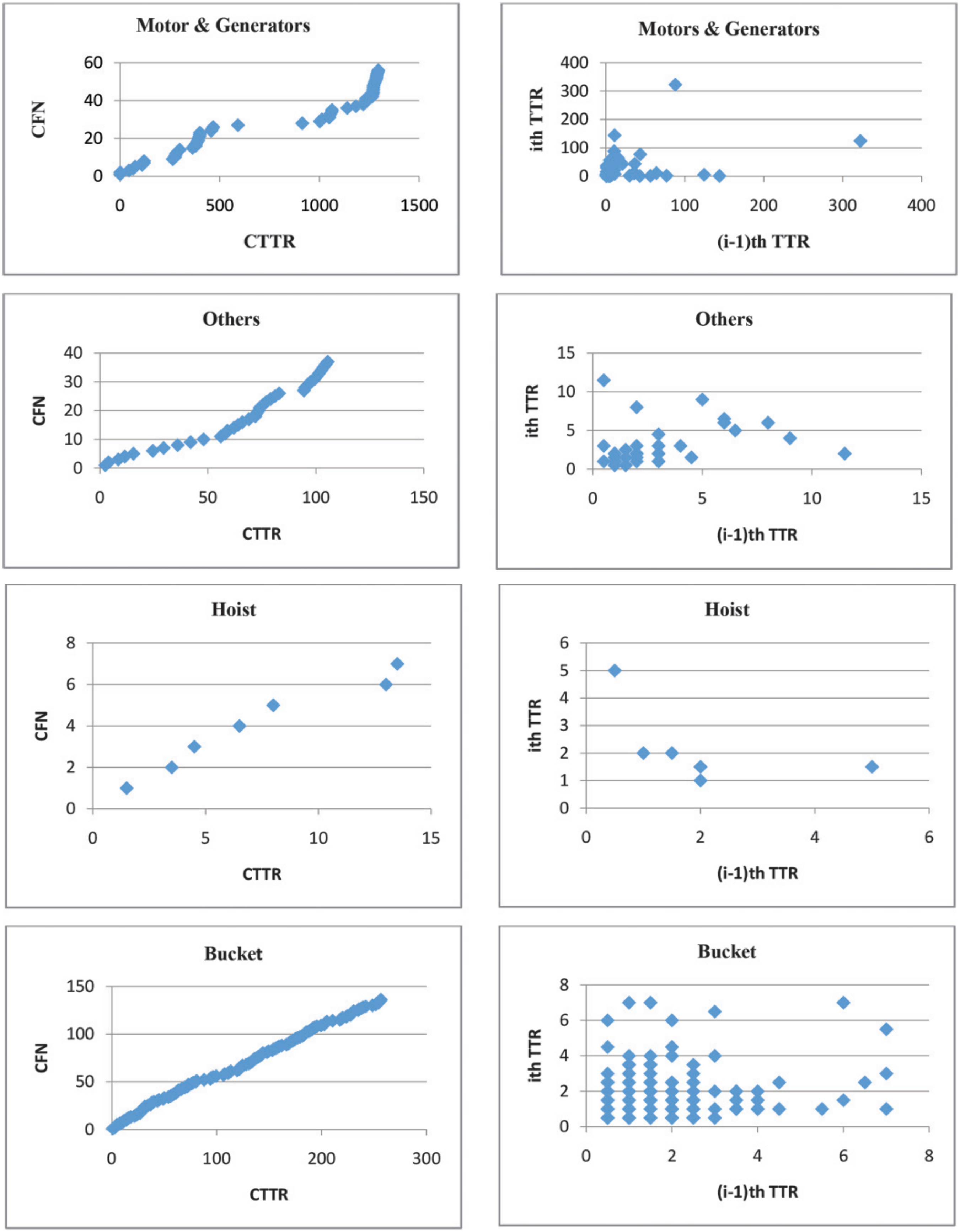
Where n = number of occurrence of failure

T_n = total running time

T_i = running time at the occurrence of failure number. Table 2 gives result of analysis of TBF data of dragline $i = 1, 2, 3... n$

The above parameters for OTH subsystem of dragline 1 were estimated using failure data and are shown in Table 2.

From the Table 2, goodness of best fit for parametric distribution of every subsystem has been identified, and K-S test was used to specify the distribution. After the best fit distribution, parameters were estimated for these distributions. Table 3 also shows the estimated parameters for



(Fig.3 Continued...)

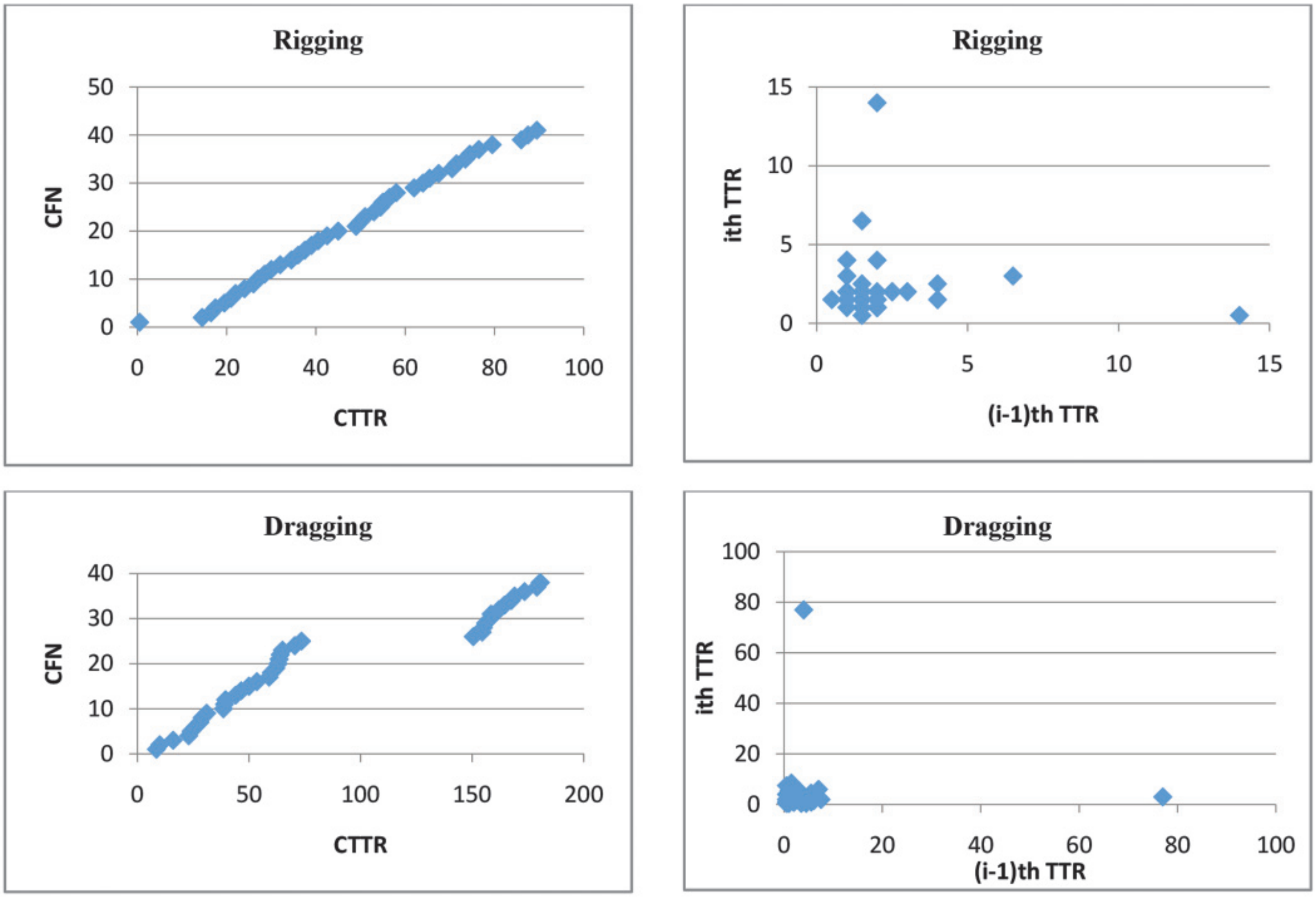


Fig.3 Trend and correlation test of TTR data for dragline

all subsystems. The reliability behaviour of the system can be predicted using the model parameters. The theoretical reliability for all the subsystems has been estimated using equations 7 and 8, and as shown in Fig.4. The Fig.4 shows that among all subsystems, BCKT has lowest reliability while HST is the most reliable subsystem.

5.2 Availability

The availability of every subsystem is calculated by using equation 4. The corresponding value of MTBF and MTTR for each subsystem with the number of failures is shown in Table 4.

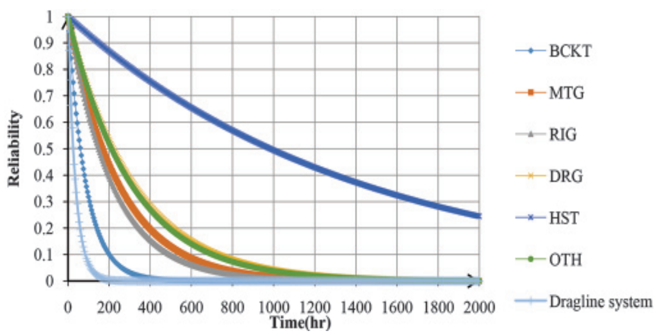


Fig.4 The reliability plots of each subsystem of the dragline

The MTTF of Weibull distribution is calculated by the following equation

$$MTTF = \beta * \Gamma(1 + \frac{1}{\eta}) \quad \text{... (10)}$$

The MTTR of Weibull distribution is calculated by

$$MTTR = \beta * \Gamma(1 + \frac{1}{\eta}) \quad \text{... (11)}$$

Table 4 shows the availability of subsystems of dragline and the results show that subsystems are available more than the dragline. System availability of dragline system is 85.45%. All the subsystems are connected in series combination. Thus, system availability of dragline system is $A_s(t) = \prod_{i=1}^{n} A_i(t)$.

Where n are independent components in series.

5.3 Maintainability

In maintainability analysis, TTR data has been used in a similar process as TBF data. Weibull distribution was used in most of the subsystems reliability analysis. The results of goodness of best fit has been given in Table 3 which shows that some subsystems follow Weibull distribution and some subsystems follow the NHPP distribution. The failure repair time of the dragline is about 50 hrs with 90% probability while

Table 2: Result of analysis of TBF data of dragline machines

System/ subsystems	Exponential	Weibull		Normal		Lognormal		K-S test Dmax				Best fit distribution
		β	η	Mean	S.D.	Mean	S.D.	Exp	Normal	Lognormal	Weibull	
Bucket &Accessaries	87.4	1.01	88.2	87.4	104.8	86.3	108.1	0.1158	0.23	0.110	0.110	Weibull
Motor & Generators	219.9	0.74	181.5	219.9	281.7	281.3	880.05	0.2158	0.28	0.122	0.118	Wiebull
Rigging	266.6	1.2	258.2	266.6	214.6	307.4	434.2	0.1115	0.12	0.109	0.054	weibull
Dragging	306.3	0.93	297.1	306.1	306.3	398.4	866.5	0.1304	0.17	0.1425	0.0999	Weibull
Hoist	1309.6	0.83	1178.1	1309.6	1832.4	1774.6	4785.7	0.202	0.33	0.197	0.169	weibull

Others Concave downward trend plot, NHPP, Powe law process, Paramters β=0.9776, α=253.4562

Table 3: Result of analysis of TRR data ofdragline machines

System/ subsystems	Exponential	Weibull		Normal		Lognormal		K-S test Dmax				Best fit distribution
		β	η	Mean	S.D.	Mean	S.D.	Exp	Normal	Lognormal	Weibull	
Bucket &Accessaries	1.88	1.42	2.092	1.886	1.455	1.895	1.586	0.2328	0.185	0.134	0.121	Weibull
Hoist	1.92	1.56	2.61	1.928	1.455	1.999	1.601	0.2618	0.3375	0.2193	0.2707	Lognormal
Rigging	2.18	1.33	2.41	2.183	2.16	2.095	1.36	0.3187	0.2643	0.3385	0.2185	Weibull

Motors and generators concave downward trend plot, NHPP, powe law process, paramters β=0.9673, α=20.193
Others concave upward trend plot, NHPP, powe law process, paramters β=1.4, α=8.0023
Dragging concave downward trend plot, NHPP, powe law process, paramters β=0.943, α=3.820194

the repair time for the BKT, RIG, HST, DRG, OTH and MTRG are 5, 10, 15 and 50 hrs respectively (Fig.5). Furthermore, it is clear from Fig.5 that motors and generators have less maintainability than each subsystem and maintainability of bucket and accessories, hoist and rigging subsystems are approximately equal or nearby. It can be implemented to the higher frequency and quality inspections to increase the reliability of the system (Berrade et al. 2013), but this process will lead economical losses. Therefore, reliability-based maintenance (RBM) can be used to balance between maintenance cost-minimizing and system value maximising (Marais 2013). The main purpose of maintenance is to increase or maintain the existing reliability of the system and subsystems at present level. Preventive maintenance (PM) would be helpful in it. PM is the routine maintenance method to preventing failure threats and inspection of system or subsystem before failure which help to reduce the down time of repairs. PM schedule is based on time duration, in that time duration; maintenance would be good to prevent the failure of system. PM schedule is based on weekly, monthly, quarterly or yearly basis. It uses lubrication to inspection of wearing part to identify the hidden failure and repair it. In statistical method, to enhance the reliability of overall system, each subsystem has need to take separate preventive maintenance schedule which will enhance the reliability of the subsystems. The maintenance intervals for each subsystem of the dragline was computed and determined the reliability at different levels as shown in Table 5 through the relevant reliability functions. Table 5 represents reliability maintenance intervals for each subsystem of the dragline.

To plan a PM programme, 90% reliability was chosen and thus, based on the selected reliability level, reliability based PM of subsystems is shown in Table 5. Bucket and accessories has lowest hrs on 90% reliability while at 90% reliability, HST has taking maximum time to sustain. Dragging subsystem, motors and generators and rigging, others subsystem need more frequently maintenance interval in the dragline.

Table 4: Availability of sub-systems of dragline

Subsystem	Number of failures	MTBF (hr)	MTTR (hr)	Availability (%)	Unavailability (%)
BCKT	136	87.44	1.886	97.88	2.12
DRG	39	306.4	4.75	98.59	1.41
RIG	64	266.64	2.183	99.18	0.82
MTRG	55	219.95	23.55	90.32	9.68
HST	8	1309.62	1.928	99.85	0.15
OTH	38	275.18	2.77	99	1

Table 5: Reliability based preventive maintenance interval for dragline susbsystems

Reliability level(%)	BKT	RIG	DRG	MTRG	HST	OTH
90	9.2h	22.67h	33.65h	25.84h	149.5h	27.31h
80	19.48h	48h	71.28h	54.73h	316.73h	57.85h
70	31.14h	76.74h	113.94h	87.48h	506.26h	92.47h
60	44.6h	109.9h	163.18h	125.3h	725.06h	132.43h
50	60.53h	149.1h	221.43h	170h	983.85h	179.7h

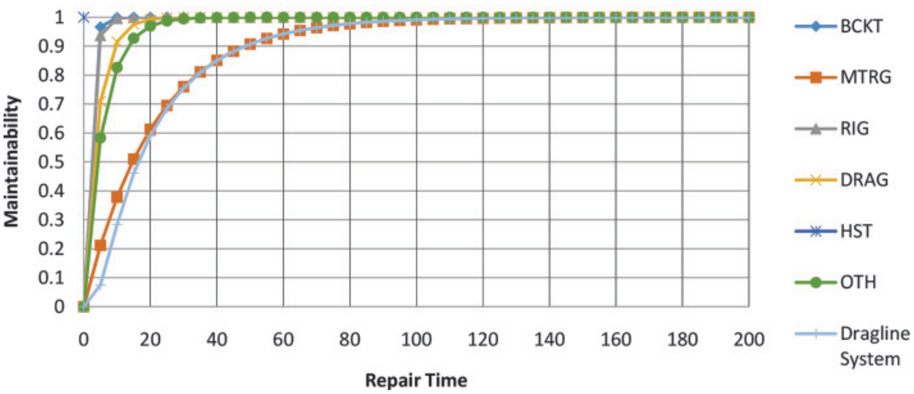


Fig.5 The maintainability plots of each subsystem of the dragline

This study illustrates that RAM analysis has important role for deciding the maintenance intervals of dragline. The calculated availability of subsystems can be helpful for the utilization, time planning and cost control in dragline system. For better utilization factor of dragline, it can be recommended that downtime due to operator skill and maintenance personnel etc can be considered.

6. Conclusions

RAM should be the essential part of the dragline system for increasing the availability and proper maintenance to improve the utilization of the dragline system in opencast mining projects. To improve the RAM of dragline, it is necessary to remove the failure causes at every steps of the life cycle such as design plan, construction of machine, operation and maintenance. RAM analysis of dragline shows that the TBF data have generally weibull distribution and some components follow the NHPP distribution while TTR data have weibull and lognormal distribution with NHPP distribution. Fig.5 of maintainability plot shows that the BCKT and RIG subsystems have been repaired in a less than an hour. There is 90% probability that the preventive maintenance of dragline system will complete within 50 hours. The availability of the dragline system is 85.45% due to high repair time of motor and generator. It can be increased with the proper maintenance interval; at every 24h, it is necessary to do the preventive maintenance to reduce the repair time of motors and generator.

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References

1. Amini Khoshalan, H., Torabi S. R., and Maleki D. (2015): "RAM Analysis of Hydraulic System of Earth Pressure Balance Tunnel Boring Machine." *Indian Journal of Science and Technology* 8(28).
2. Ávila, S. F. (2015): "Reliability Analysis for Socio-Technical System, Case Propene Pumping." Engineering Failure Analysis 56: 177–84.
3. Barabady, Javad. (2005): "Reliability and Maintainability Analysis of Crushing Plants in Jajarm Bauxite Mine of Iran." Proceedings - Annual Reliability and Maintainability Symposium: 109–15.
4. Barabady, Javad, and Uday Kumar. (2008): "Reliability Analysis of Mining Equipment: A Case Study of a Crushing Plant at Jajarm Bauxite Mine in Iran."

Reliability Engineering and System Safety 93(4): 647–53.

5. Berrade, M. D., P. A. Scarf, C. A.V. Cavalcante, and R. A. Dwight. (2013): "Imperfect Inspection and Replacement of a System with a Defective State: A Cost and Reliability Analysis." Reliability Engineering and System Safety 120: 80–87. http://dx.doi.org/10.1016/j.ress. 2013.02.024.

6. Dhillon, B.S. (2006): 4 *IEEE Power and Energy Magazine Aging, Maintenance, and Reliability.*

7. Dillon B.S. (2013): 53 Journal of Chemical Information and Modelling Mining Equipment Reliability, Maitainability and Safety.

8. Ebeling, Charles E. (1997): "Intro to Reliability & Maintainability Engineering.Pdf." : 486.

9. Gustafson, Anna, Håkan Schunnesson, and Uday Kumar. (2015): "Reliability Analysis and Comparison between Automatic and Manual Load Haul Dump Machines." *Quality and Reliability Engineering International* 31(3): 523–31.

10. Hoseinie, Seyed Hadi et al. (2012): "Reliability Analysis of Drum Shearer Machine at Mechanized Longwall Mines." *Journal of Quality in Maintenance Engineering* 18(1): 98–119.

11. Javad Rahimdel, Mohammad, Mohammad Ataei, Reza Khalokakaei, and Seyed Hadi. (2013): "International Journal of Mining Science and Technology Reliability-Based Maintenance Scheduling of Hydraulic System of Rotary Drilling Machines." *International Journal of Mining Science and Technology* 23(5): 771–75. http://dx.doi.org/10.1016/j.ijmst.2013.08.023.

12. Kishorilal, Dinkar Brajeshkumar. (2014): "Reliability analysis of overhauled engines of dumpers ." 594: 1756–60.

13. Kumar, Sanjeev. (2012): "Performance Analysis and Optimization of Best-." 16(10): 1648-51.

14. Kumar, Uday. (1990): "Reliability Analysis of Load-Haul-Dump Machines.": 63.

15. Low, B. K., and H. H. Einstein. (2013): "Reliability Analysis of Roof Wedges and Rockbolt Forces in Tunnels." Tunnelling and Underground Space Technology 38: 1–10. http://dx.doi.org/10.1016/j.tust.2013.04.006.

16. Manzini, Riccardo. Regattieri, Alberto. Pham, Hoang. Ferrari, Emilio. (2013): 53 *Journal of Chemical Information and Modeling Maintenance for Industrial Systems.*

17. Marais, Karen B. (2013): "Value Maximizing Maintenance Policies under General Repair." Reliability Engineering and System Safety 119: 76–87. http://dx.doi.org/10.1016/j.ress. 2013.05.015.

18. Samanta, B., B. Sarkar, and S. K. Mukherjee. (2004): "Reliability Modelling and Performance Analyses of an LHD System in Mining." *Journal of The South African Institute of Mining and Metallurgy* 104(1): 1–8.

19. Simon, Furuly, Barabady Javad, and Barabadi Abbas. (2014): "Availability Analysis of the Main Conveyor in the Svea Coal Mine in Norway." *International Journal of Mining Science and Technology* 24(5): 587–91. http://dx.doi.org/10.1016/j.ijmst.2014.07.004.

20. Topal, Erkan, and Salih Ramazan. (2010): "A New MIP Model for Mine Equipment Scheduling by Minimizing Maintenance Cost." *European Journal of Operational Research* 207(2): 1065–71. http://dx.doi.org/10.1016/j.ejor.2010.05.037.

21. Vayenas, Nick, and Xiangxi Wu. (2009): "Maintenance and Reliability Analysis of a Fleet of Load-Haul-Dump Vehicles in an Underground Hard Rock Mine." *International Journal of Mining, Reclamation and Environment* 23(3): 227-38.

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