

ASSESSMENT OF SURFACE MINER RELIABILITY: A CASE STUDY IN INDIAN COAL MINE

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ABSTRACT

Reliability assessment plays a vital role in enhancing the performance and operational efficiency of mining equipment. Accurate reliability analysis supports proactive maintenance planning, production scheduling, early fault detection, and overall risk management in mining systems. With increasing demand for productivity and cost-effectiveness, the evaluation of equipment reliability has become increasingly critical in modern opencast mining operations. This study investigates the operational reliability of a Surface Miner deployed in a coal mine located in central-eastern India. Failure data spanning a full calendar year (January to December) were collected and analyzed. Time between Failures (TBF) was calculated, and statistical modeling was performed using software Reliasoft Weibull++11 to determine the best-fit probability distribution. Distribution parameters were estimated using the Maximum Likelihood Estimation (MLE) technique. The reliability of the Surface Miner was evaluated over different operating intervals, revealing a steady decline—from 46.43% at 08 hours. These findings highlight the rapid degradation of reliability over time need for strategic reliability-centered maintenance. Further research is recommended to explore the influence of operational, environmental, and human factors on equipment reliability in surface mining content.

Keywords: Surface Miner reliability, Assessment in Surface Mining, Time between failures.

1. INTRODUCTION

In industrial production environments, ensuring machinery reliability is essential for sustaining operations, reducing unplanned downtime, and maintaining cost-effectiveness. This is especially important in the mining industry, where equipment breakdowns can result in significant production delays, heightened safety hazards, and increased operational expenses. Due to the intricate and large-scale nature of present-day mining activities, evaluating the reliability, maintainability, and availability of machinery has become a crucial aspect of performance assessment (Barabady & Kumar, 2005; 2008).

In earlier times, mining operations predominantly depended on manual labor and simple tools, which limited both efficiency and productivity (Furuly, 2012). With the rising global demand for minerals and the increasing complexity of ore deposits, the industry has progressively adopted mechanization and automation. These technological developments have greatly enhanced operational performance but have also introduced sophisticated and expensive equipment, thereby requiring detailed reliability assessments to guide maintenance planning and asset management.

Traditional surface mining techniques - such as drilling, blasting, and material transportation - often contribute to environmental problems like dust generation, fly rock, and ground vibrations. In response to these challenges, methods that eliminate the need for blasting, particularly the use of Surface Miners, have become more widely adopted. These machines allow for continuous rock cutting, minimize environmental disturbances, and improve cost efficiency, making them increasingly favorable in opencast coal mining operations (Prakash et al., 2013).

In the Indian context, there has been a noticeable shift towards opencast mining, with its share in overall coal production rising significantly since 2006–2007. As the deployment of Surface Miners expands, the likelihood of unexpected equipment failures and performance drops also increases. Therefore, assessing the reliability of

this machinery is crucial for enhancing operational availability, refining maintenance practices, and ensuring production goals are met.



Figure 1 Surface Miner in opencast

This study presents a reliability analysis of a Surface Miner operating in an opencast coalmine in western India. Failure data collected over a one-year period are used to model time between failures (TBF) and assess reliability trends. The results provide to inform reliability-centered maintenance (RCM) practices and support operational decision-making in surface mining content.

2.METHODS AND MATERIAL USED

2.1 Reliability Assessment Techniques

Reliability refers to the likelihood that a system, device, or component will carry out its intended function under specified conditions for a designated period (Birolini, 2017). It is closely associated with availability, which is generally understood as the systems or component's capability to operate at a given point or during a particular time frame. From a theoretical standpoint, reliability is a probabilistic and statistical measure used to analyze random variables, and is essentially defined as the probability of successful performance (Furuly, 2012). In this study, the reliability analysis of a surface miner has been carried out using Time Between Failures (TBF) data, as suggested by Sinha and Mukhopadhyay (2015). These data were sourced from the maintenance records of a mining operation where the surface miner is currently deployed. The TBF values were examined to assess whether they exhibit independence and identical distribution, which helps identify any existing trends or correlations in the dataset (Barabady and Kumar, 2008; Pandey et al., 2017). If no such patterns are found, the data can be classified as independent and identically distributed (i.i.d.) (Barabady and Kumar, 2008). Once the i.i.d. nature of the data is confirmed, the most suitable statistical distribution is identified. Subsequently, the parameters of this best-fit distribution are used to estimate the surface miner's reliability. The overall procedure for reliability estimation in this research is illustrated in Figure 2.

2.2 Study Area and Data Collection

The failure data of surface miner for the period of one year has been collected from the mines situated in the

central- east part of the India. The summary of daily maintenance and repair work carried out for surface miner in the mines is recorded in a company logbook. The logbook summary of the machine provides the following information:-

- 1) Scheduled shift hours
- 2) Working hour with HMR readings
- 3) Idle hours
- 4) Maintenance hours
- 5) Breakdown hours
- 6) Reasons of breakdown
- 7) Production
- 8) Spares consumption

These data's provide us the time between failure data (TBF) of the surface miner. The Time between failures (TBF) is the time elapsed between two consecutive failures of a system during its normal system operation. The Time between failure (TBF) data for surface miner is shown in Table1.

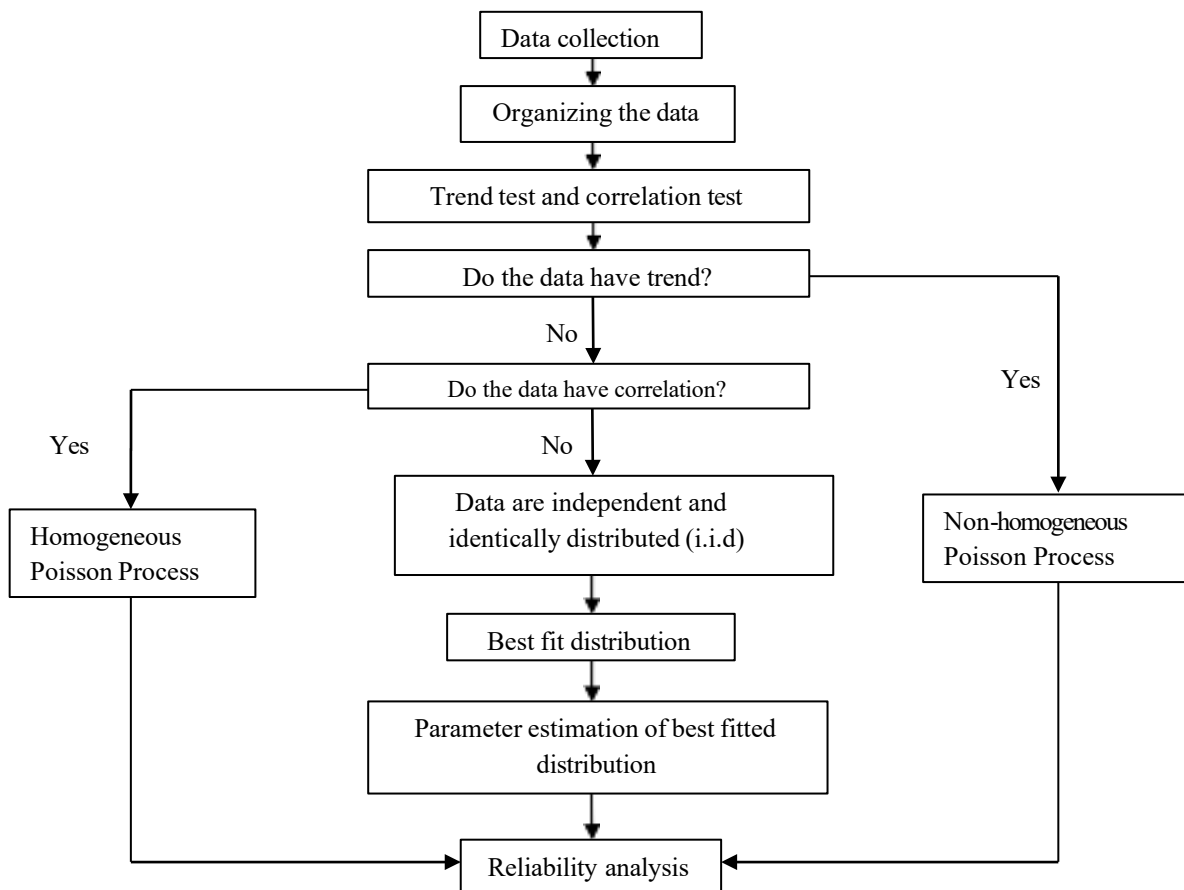


Figure 2 Process of data analysis (Ascher and Feingold, 1984)

Table 1 Time between Failures (TBF) Data

S. No.	TBF(Hours)	S. No.	TBF(Hours)	S. No.	TBF(Hours)	S. No.	TBF(Hours)
1	3	61	6	121	18	181	6
2	5	62	10	122	47	182	5
3	14	63	4	123	23	183	6
4	7	64	30	124	31	184	215
5	1	65	46	125	7	185	7
6	30	66	31	126	19	186	5
7	39	67	22	127	78	187	1
8	39	68	93	128	4	188	38
9	221	69	358	129	6	189	22
10	4	70	49	130	6	190	20
11	4	71	52	131	4	191	31
12	3	72	22.5	132	118	192	5
13	14	73	4	133	5	193	29
14	45	74	23	134	60	194	28
15	13	75	31	135	4	195	20
16	4	76	6.5	136	62	196	78
17	4	77	22	137	1	197	70
18	63	78	4	138	1	198	45
19	25	79	38	139	2	199	3
20	23	80	7	140	5	200	102
21	23	81	15	141	1	201	15
22	21	82	7	142	1	202	2
23	22	83	63	143	3	203	42
24	4	84	1	144	6	204	83
25	6	85	18	145	1	205	22
26	5	86	13	146	23	206	12
27	23	87	63	147	12	207	7
28	6	88	190	148	54	208	69
29	6	89	142	149	21	209	14
30	20	90	7	150	19	210	6
31	23	91	75	151	30	211	6
32	22	92	30	152	3	212	14
33	20	93	46	153	1	213	6
34	29	94	207	154	95	214	4
35	15	95	53	155	5	215	51

36	5	96	5	156	166	216	50
37	7	97	13	157	7	217	6
38	5	98	7	158	13	218	14
39	51	99	20	159	55	219	6
40	11	100	20	160	39	220	6
41	46	101	13	161	46	221	21
42	15	102	148	162	5	222	4
43	7	103	5	163	4	223	5
44	31	104	4	164	3	224	5
45	13	105	12	165	2	225	22
46	6	106	5	166	4	226	14.5
47	2	107	14	167	2	227	46
48	4	108	70	168	3	228	3
49	68	109	6	169	4	229	6
50	87	110	3	170	14	230	5
51	47	111	7	171	6	231	3
52	6	112	37	172	6	232	13
53	12	113	5	173	5	233	6
54	4	114	6	174	5	234	36
55	33	115	94	175	5	235	21
56	263	116	13	176	6	236	7
57	143	117	6	177	5	237	11
58	126	118	6	178	5	238	7
59	21	119	6	179	5	239	7
60	22	120	4	180	5	240	26

2.3 Data Analysis

2.3.1 Trend and Correlation Analysis

In the trend and correlation analysis, the Time Between Failure (TBF) data examined to determine the identical and independent (i.i.d) characteristics. The graph was plotted between cumulative time between failures and the cumulative failure numbers to determine that whether a trend is present in the data set or not. A straight line indicates there is no trend in the data (kumar et al, 1989). In the serial correlation test, the $(i-1)^{\text{th}}$ TBF is plotted against the i^{th} TBF. If the data set points are randomly scattered dividing any clear pattern, it implies that data set free from serial correlation, which again implies that the data points are independent of each other (Ascher and Feingold,1984). The TBF data of surface miner is tested for the i.i.d characteristics, which is shown in Figure 3(a) and 3(b). The plots follows approximately linear pattern ($R^2= 0.9762$), which show that there is no trend in the data-set (Figure 3a). The Figure 3(b) depicts that there is no correlation exist between the TBF data, hence it can be concluded that the data follows i.i.d characteristics. After finding i.i.d characteristics, the best distribution is determined and subsequently the parameters are estimated from the best-fit distribution to evaluate reliability of the surface miner.

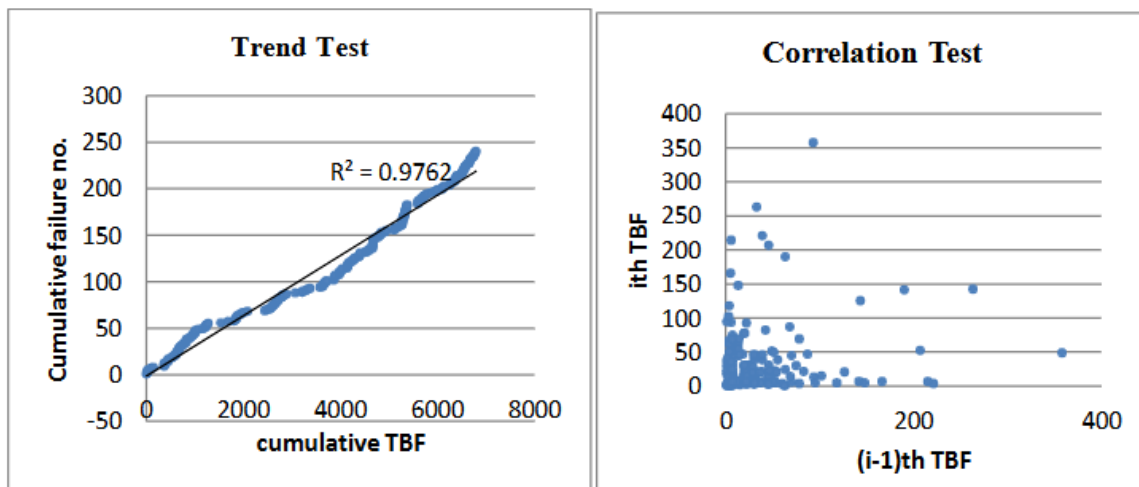


Figure 3 (a) Trend Test

Figure 3 (b) Correlation Test

2.3.2 Best fit distribution and reliability analysis

Reliability analysis of the collected failure data was conducted using ReliaSoft Weibull++11 software. The life data analysis feature in Weibull++ enables fitting appropriate statistical distributions to failure time data, thereby helping to evaluate a system's reliability over time and predict its future performance. As previously discussed, the logbook contains information on breakdown hours, idle time, maintenance periods, and operational hours of the surface miner. This information is used to derive the Time Between Failures (TBF) data for the equipment. Various probability distributions are applied to the TBF data, and statistical methods are employed to identify the distribution that best fits the data. To confirm the suitability of the chosen distribution, the Chi-square goodness-of-fit test is utilized. The parameters of the selected distribution are then estimated using the Maximum Likelihood Estimation (MLE) technique. With the best-fitting model established, it becomes possible to assess failure probabilities, reliability, and future performance, all within defined confidence intervals.

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The Time between failure (TBF) data of surface mine are fitted for different distribution. The types of distribution which are fitted for TBF data are-

- 1P-Exponential Distribution
- 2P-Exponential Distribution
- Normal Distribution
- Lognormal Distribution
- 2P-Weibull Distribution
- Gamma Distribution

Chi-square test is used to find the best-fit distribution for a sample data comes from a population with a specific distribution. The principle behind goodness-of-fit tests is to see how far the chosen distribution is matched with the actual data set, or in other words, how well the chosen distribution represents the actual distribution. Among the all distributions mentioned in Table 2 the lognormal distribution is the best fit distribution because it gives the lowest value i.e. 31.635.

Table 2 Results of Chi-Square Test

Distributions type	1P-Exponential	2P-Exponential	Normal distribution	Lognormal Distribution	2P weibull distribution	Gamma distribution
statistics	70.701	77.067	83.978	31.635	158.0	115.55
Ranking	2	3	4	1	6	5

The parameters for the best-fitting lognormal distribution were determined using the Maximum Likelihood Estimation (MLE) technique. MLE is a widely accepted statistical approach that identifies the parameter values which maximize the likelihood function (Hurlin, 2013). In this study, the lognormal distribution was employed to assess the failure characteristics of a surface miner, enabling estimation of failure probabilities over time and evaluation of the equipment's reliability. The analysis involved generating several plots, including the probability density function, the unreliability curve (lognormal probability plot), the failure rate over time, and the reliability curve. These are illustrated in Figures 4(a), 4(b), 4(c), and 4(d), respectively.

In Figure 4(a), the horizontal axis represents time in hours, while the vertical axis indicates the probability density. The graph displays a positively skewed, asymmetrical distribution, with the highest probability concentrated near the origin. The cumulative probability rises rapidly, exceeding 0.048, before decreasing exponentially. Figure 4(b) illustrates the unreliability curve, where the x-axis shows time (in hours) and the y-axis represents the probability of failure, defined as $100 - R(t)$. This graph demonstrates a steady increase in unreliability over time.

Figure 4(c) presents the failure rate as a function of time. The x-axis denotes time in hours, and the y-axis shows the failure rate. The plot reveals that the failure rate increases sharply during the initial hours of operation, reaches a peak, and then gradually declines.

In Figure 4(d), the reliability of the system is plotted against time. The x-axis again represents time in hours, while the y-axis corresponds to reliability. The graph exhibits a continuous decline in reliability as time progresses, eventually approaching zero and becoming asymptotic to the time axis. This indicates that the reliability of the surface miner decreases over time and ultimately approaches zero.

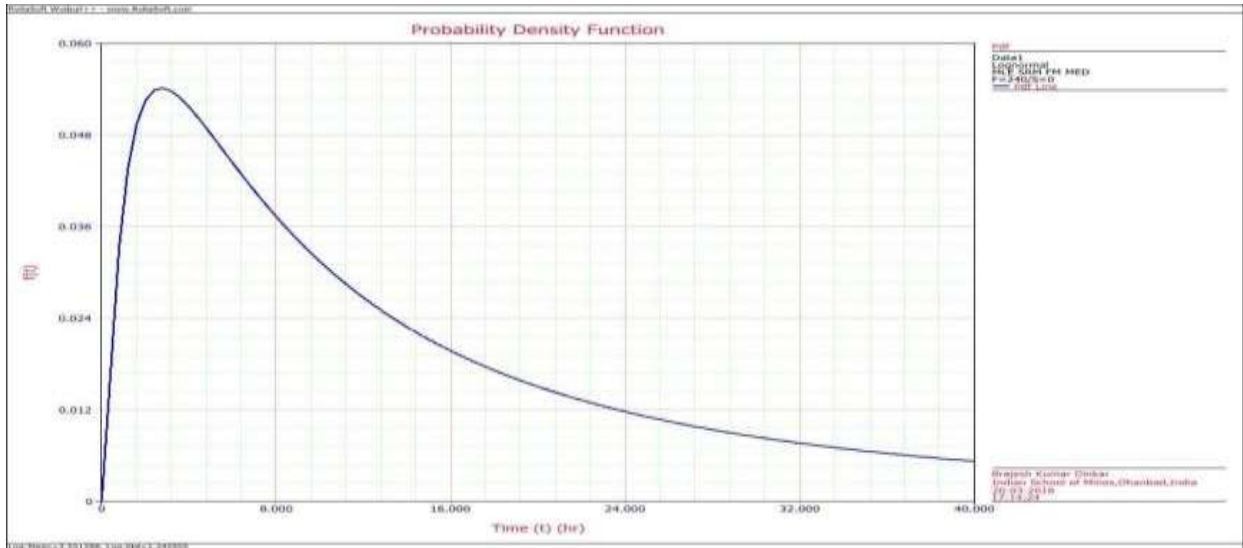


Figure 4(a) Probability Density Function

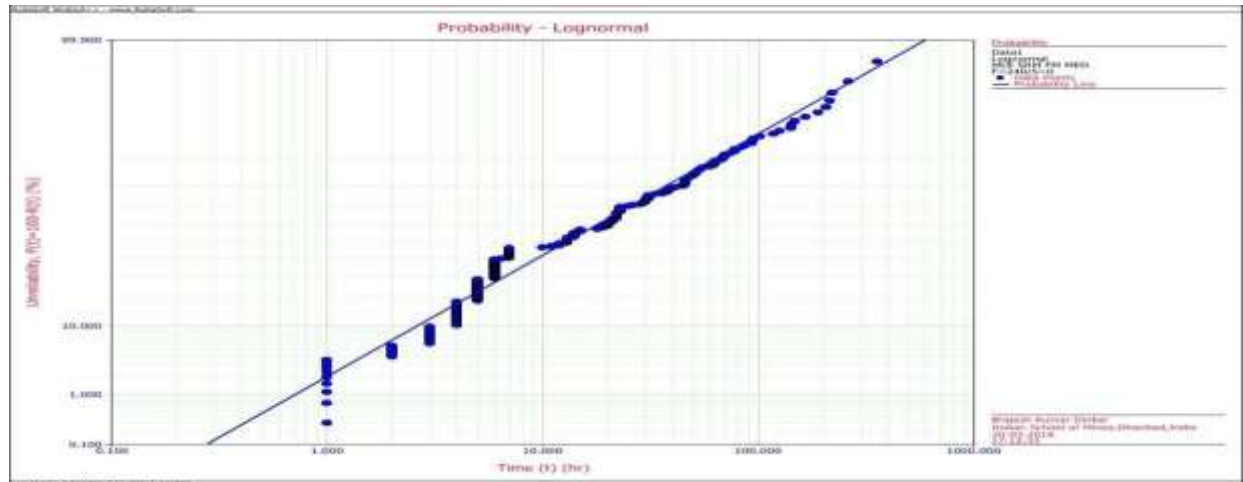


Figure 4(b) Probability Lognormal



Figure 4(c) Failure rate vs time



Figure 4(d) Reliability vs time

3. RESULTS AND DISCUSSION

The Time Between Failures (TBF) data for the Surface Miner were found to be independent and identically distributed (i.i.d.), indicating consistency in the statistical behavior of failure intervals. A Chi-Square Goodness-of-Fit test confirmed that the lognormal distribution best represents the TBF dataset.

Reliability values were estimated for the Surface Miner over six discrete operational intervals: 10, 20, 30, 40, 50, and 150 hours. As presented in Table 3, the reliability exhibits a consistently decreasing trend with time. Specifically, the reliability was observed to be 57.93% at 10 hours, which declined to 36.03% at 20 hours, and further to 24.70% at 30 hours. At 40 and 50 hours, the reliability dropped to 17.99% and 13.67%, respectively. Notably, after 150 hours, the reliability reduced significantly to 2.39%, and approached near-zero (0.96%) after 235 operational hours.

Table 3 Reliability of Surface Miner

Time in hour	10	20	30	40	50	150	235
Probability of failure (%)	42.068	63.9711	75.3013	82.0042	86.3266	96.6107	99.0373
Reliability (%)	57.932	36.0289	24.6987	17.9958	13.673	2.389	0.9627

These results clearly indicate a negative correlation between operational time and reliability. The most substantial decline occurs within the first 50 hours, emphasizing the need for proactive maintenance strategies. The near-zero reliability observed after extended use (235 hours) implies that unscheduled downtime becomes highly probable if preventive measures are not adopted.

The findings are consistent with prior studies that also reported degradation in equipment reliability over time (Pandey et al., 2018; Barabady & Kumar, 2008; Demirel et al., 2014; Touama & Basha, 2013). This reinforces the importance of timely maintenance scheduling—neither too premature nor excessively delayed—to sustain equipment efficiency.

Furthermore, this study aligns with earlier research indicating that variations in operating and environmental conditions significantly influence equipment reliability (Demirel et al., 2014; Pandey et al., 2018). A thorough reassessment of the existing maintenance program is recommended to achieve sustained reliability and operational safety.

4. LIMITATION OF THE STUDY

The scope and constraints of the present study are limited to estimating the reliability of the surface miner during different hours of operation. It was observed that the machine's reliability exhibits a declining trend over time. Although the reliability of a surface miner can be influenced by various site-specific factors such as geological conditions, material type, mining methods, mechanical aspects, and the operator's skill, these influences have not been incorporated into the current analysis. Therefore, the findings should be interpreted within the context of this defined scope.

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