Reliability and Maintainability Analysis of LHD Loader at Saoner Mines, Nagpur, India

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Abstract. In this era of intense economic competition as well as harsh and complicated environmental conditions, it is of utmost importance to achieve the high productivity and production of the mining equipment. This paper strives to analyze reliability and maintainability of Load, haul and dump (LHD) machine and to compute inherent availability of LHD machine in Saoner Mine Nagpur India. In this paper, renewal process is used for the modelling of the mechanical failures of the LHD. The validation of data whether it is independent and identically distributed (IID) is done by assessing the presence of trend and serial correlation with the help of graphical method. The parameters of various distributions were found by using Math Wave Easy Fit 5.6 professional software. Chi-square test has been applied for selecting the best fit distribution model. Further the study of the two parameter log normal distribution theory and its parameters is presented using log normal probability theory. The study reflects that analysis of reliability is a powerful tool for determining the intervals of maintenance.

1. Introduction
Load, haul and dump (LHD) machines are used for handling the muck of excavations of underground hard rock mining applications. The subcomponents of the system that makes the whole system can be either repairable or non-repairable. Some of the repairable machines that are extensively used in mining industry are trucks, shovels draglines etc. When it comes to repairable systems, reliability is commonly modeled using the five main models of stochastic processes that are the Renewal Process (RP), the Homogeneous Poisson Process, the Branch Poisson Process, the Superposed Renewal Process and the Poisson Process Not Homogeneous (NHPP). If a system in service can be repaired to function as “new as new” after each failure, the process of failure is called the renewal process [1]. Reliability is the probability that the product / machine performs its intended function adequately during a set period of time under the established operating environmental conditions. In other words, it is the quality of being trustworthy or consistently good performance. The purpose of this research is to reduce the sudden failures and failures of the LHD and to determine the time intervals for preventive maintenance.

2. Literature Review
A lot of work has been done previously in the field of Reliability, availability and maintainability (RAM) and this program has been proved a boon for an effective maintenance management. In the mining industry, the equipment that are used like draglines, shovels, loaders, haul trucks are of very complex nature and work in a very harsh environmental conditions. So the RAM study can be very helpful for the efficient working and maintenance of LHD loader. Some of the research papers that
have used Renewal Process (RP) and Non homogenous poisson process (NHPP) are illustrated in table 1.

**Table 1. Research papers**

| Reference | Year | Type of mining equipment | Failure Process Model |
|-----------|------|--------------------------|-----------------------|
| [2]       | 2014 | Trucks                   | RP                    |
| [3]       | 2008 | Crushing Plant           | RP,NHPP               |
| [4]       | 2016 | Dragline                 | RP                    |
| [5]       | 2009 | LHD                      | RP                    |
| [6]       | 2001 | Rear dump truck, LHD     | NHPP                  |
| [7]       | 2001 | Hydraulic Shovel          | RP,NHPP               |
| [8]       | 1995 | Hydraulic Excavator      | NHPP                  |
| [9]       | 2003 | Scoops and Trucks        | RP                    |
| [10]      | 2009 | Armoured Flexible Conveyor| RP                   |
| [11]      | 2004 | Electric Haul Truck      | RP                    |

3. Basic Methodology

Step by step procedure for the modeling of reliability is shown in Figure 1
4. Data Analysis

4.1 Data Collection

The first step of this project was the collection of failure data of the LHD machine. The failure data of LHD machine (811-682) was collected and arranged in the chronological order. The data was collected for 33 months ranging from October 2015 to June 2018. The time to repair (TTR) data was collected by adding the breakdown hours and maintenance hours in the respective month. The time between failures (TBF) data was the working hours itself in the respective month.

4.2 Assessing the presence of trend and serial correlation

After arranging the data in chronological order the next step was to check whether the data collected was independent and identically distributed (IID). It is known from the reliability literature that there are traditionally two methods available for checking the data whether it is identically distributed or not i.e. graphical method and analytical method. The Graphical Methods includes Nelson Aalen Plot Cumulative Failures vs. Time Plot, Scatter plot of Successive Service Lives. The Analytical Methods includes The Mann Test, The Laplace Test and The Lewis Robinson Test. The Military Handbook
The graphical method has been used in this study to check the presence of trend and serial correlation.

The presence of trend of data set was assessed by plotting the cumulative time to failures (TTRs) against a cumulative number of failures. It was observed that the failure data plots approximate straight line and thus from this linearity of the curve (Figure 2) this can be concluded that the there is no presence of trend in the data.

For the validation of the data to be free from serial correlation, the (i-1)th value of TTRs were plotted against ith value of TTR. It was observed that the plotted points are randomly scattered (Figure 3) and thus this absence of any kind of pattern confirms that there is no presence of serial correlation in the data.

Similarly the time between failures (TBF) data set was checked for the presence of trend and serial correlation and it was concluded from Figure 4 and Figure 5 that there is no presence of trend and serial correlation in the data respectively.
4.3 Determining best fit probability distribution

The data sets of both TTR and TBF were found to be free from trend and serial correlation. So the condition for applying the renewal approach has been fulfilled. Therefore we can now determine the probability distribution that is best fitted to both TTF as well as TBF data sets. The parameters of the distributions were estimated by using Math Wave Easy Fit 5.6 Professional software for both TTR and TBF data sets and the selection of the best fit distribution for both TTR and TBF was done by applying Chi-square Test as shown in shown in table 2 and table 3 respectively.

**Table 2.** Parameters of distribution of TTR data.

| Distribution     | Statistics | Rank |
|------------------|------------|------|
| EXPONENTIAL      | 19.518     | 7    |
| EXPONENTIAL (2P) | 2.4201     | 6    |
| LOGNORMAL        | 0.54907    | 4    |
| LOGNORMAL (3P)   | 0.30056    | 3    |
| NORMAL           | 0.76517    | 5    |
| WEIBULL          | 0.15381    | 1    |
| WEIBULL (3P)     | 0.19457    | 2    |

**Table 3.** Parameters of distribution of TBF data.

| Distribution     | Statistics | Rank |
|------------------|------------|------|
| EXPONENTIAL      | 17.778     | 7    |
| EXPONENTIAL (2P) | 4.2806     | 6    |
| LOGNORMAL        | 0.32275    | 1    |
| LOGNORMAL (3P)   | 0.38981    | 3    |
| NORMAL           | 3.6232     | 5    |
| WEIBULL          | 1.9361     | 4    |
| WEIBULL (3P)     | 0.36603    | 2    |
From the above tables it was concluded that the best fit distribution for the TTR data is Weibull distribution and for the TBF data the best fit distribution model is lognormal distribution. For Weibull distribution the scale parameter \( \alpha \) and shape parameter \( \beta \) were found to be 3.1146 and 73.395 respectively. For lognormal distribution the mean \( \mu \) and standard deviation \( \sigma \) were found to be 5.4429 and 0.35528.

4.4 Determining best fit probability distribution

With the help of best distribution fits of both TTR and TBF, reliability and maintainability estimates of LHD machine have been made for different time intervals. It can be clearly seen from graph that as the time interval increases the reliability decreases (Figure 6). However maintainability increases with the increase in time interval (Figure 7).

Table 4 and Table 5 shows reliability level and maintainability level respectively for different time intervals.

**Table 4. Reliability of LHD at different time intervals.**

| Reliability Level | Time Intervals (HRs) |
|-------------------|----------------------|
| 0.99              | 80                   |
| 0.95              | 130                  |
| 0.92              | 140                  |
| 0.85              | 160                  |
| 0.75              | 180                  |
| 0.7               | 190                  |
| 0.5               | 230                  |
| 0.3               | 260                  |

**Table 5. Maintainability of LHD at different time intervals.**

| Maintainability Level | Time Intervals (HRs) |
|-----------------------|----------------------|
| 0.13                  | 10                   |
As seen from the table 4, the probability of not failing the machine is almost 1 initially when the machine is new and to get the reliability of 85% and 75%, the preventive maintenance must be carried out before 160 hours and 180 hours respectively. Also from table 5 it is seen that the maintainability (the ease with which a machine can be maintained) is increasing with time. The maintainability level at 30 hours of time interval is 0.51 means that there is 51% chance, that any failure in the machine will be repaired within 30 hours. At 160 hours of operation the maintainability level is 90%.

5. Conclusion

LHD is very useful for handling the muck of excavation in the mines. It is very effective machine for coal handling. Reliability and Maintainability analysis provided effective and optimum use of the machine. In this paper, different type of distribution for finding the best fitment of the probability distribution are checked. Weibull distribution is best fitment for TTR data and lognormal distribution is for TBF data. Thereafter, reliability and maintainability of LHD at different time intervals were calculated.

- Maintenance activities at every 6th day or 7th day would be satisfactory and quite feasible for practical implementation to get reliability between 75% and 85%.
- The study shows that the health of the machine and the maintenance intervals can be suitably known with the help of reliability analysis to avoid any impending failure of the equipment.
- Also in order to meet the production target of coal mine and for effective maintenance scheduling, reliability analysis of each and every mining equipment should be done separately.

6. References

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