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# Trend Evaluation in Failure Data of Mining Equipment for Reliability Assessment

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***Abstract:*** Reliability analysis of mining equipment has become essential for mining organizations for enhancing the availability of the machine and for achieving the established production targets. A large variety of equipments are involved in open cast mining viz., bulldozer, shovels, dumpers (tippers), draglines etc. Any breakdown in these equipments may result in unavailability of machine and loss of production. In order to avoid such instances, analyzing and enhancing the reliability of these equipment is necessary. Also, before conducting any reliability analysis, it is important to know and detect the trend in failure data of a system, which gives an idea for further analysis of the data. In this paper, statistical tests are used to detect the trends in the failure events of dumpers and also the underlying hypothesis have been tested using the same. For this, Laplace test and Crow/AMSAA was adopted to detect the possible trend in the failure data of dumpers used in open cast mining and conclusions were made based on the hypothesis obtained.

***Index Terms* – Reliability, Laplace test, Crow/AMSAA**

## I. INTRODUCTION

The failure of machineries and equipments used in complex sectors such as railways, aviation, mining etc, are unavoidable and may lead to adverse consequences which impact on production and safety of personnel/environment. It is very important to maintain these equipments and machineries in good condition to avoid breakdowns and to provide failure free services. Proper maintenance activities may considerably minimize the risk associated with failure by reducing the failure occurrences or consequences. Before conducting a maintenance activity, it is preferable to know and analyze the reliability of the system or equipment. Moreover, knowing the failure patterns by conducting trend analysis may give an idea for further analysis. Trend analysis also helps in identifying the suitable statistical approach for the failure data analysis and reliability assessment. The trend behavior of failure data of a system may change which depends on the maintenance strategies used.

In open cast mining, complex machineries are used which includes scrapers, dumpers, dozers, shovels, draglines, trucks etc. A dumper is an equipment designed for carrying bulk material, often employed in open pit mining and construction fields.. All the machineries except dumper will operate being at one place in the field. But the dumper has to travel from one place to another for loading and dumping. Also, from the field data it can be noted that dumpers are the only equipment having more breakdowns than any other machinery. This necessitates assessing reliability of dumpers working in open cast mining. Moreover, knowing the trend in failure events may trough some light for further reliability analysis. The objective of this paper is to determine whether and how the pattern of failures in dumpers is significantly changing with time.

## II. TREND ANALYSIS

Trend analysis is a significant task in reliability engineering while analyzing the failure data of repairable equipment. Before conducting reliability studies, it is essential to analyze the performance of a system with regard to their failure pattern. Trend analysis helps in identifying the pattern of failure events and paves a path for further statistical or reliability analysis. It is obvious that the inter-arrival time of failure events of repairable equipment may tend to decrease or increase due to overall effect of repairs. If the inter-arrival time of failure events are increasing, then it indicates that the trend is positive i.e., system is improving. If the inter-arrival time of failure events are decreasing, then it indicates that the trend is negative i.e., system is deteriorating. There is yet another trend i.e. neither increasing nor decreasing which may be termed as "No Trend". There are various graphical and analytical models available in the literature for detecting the trend. Most prominent graphical and analytical models for trend testing are described in the following sections.

### 2.1 Graphical Models

Simple graphical models can be used to determine the performance of a system. These techniques offer an easiest way of analyzing the failure patterns.

*i. Cumulative plot test*

This is the most powerful test and gives easy understanding because of its pictorial nature. To perform this test, first of all, the time between failures (TBFs) of the equipment is collected in chronological order. The cumulative time between failures (CTBF) are then calculated and plotted against the cumulative number of failures. By the presence of trend in TBFs, it means that whether the equipment or the item is deteriorating or improving with age. Figure no. 1 shows an ideal graph indicating improving, deteriorating and constant trend.

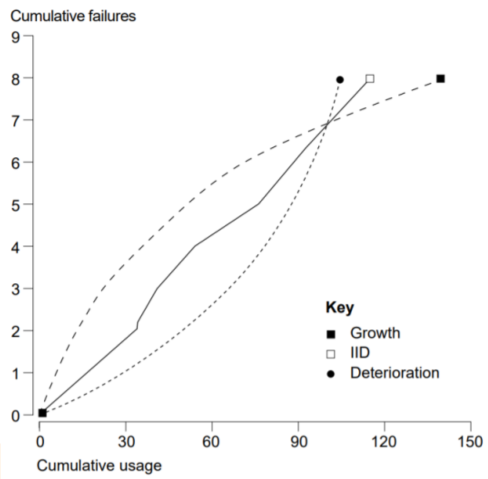


Figure 1: Cumulative plot test Graph

*ii. Eye ball analysis*

This is a simple analysis of testing presence of trend. In this we pass our eye through chronological TBFs and search for increase or decrease of the failure rate, i.e., if the TBFs are showing increasing failure magnitude towards the end, it shows decreasing failure rate. If the magnitude of TBFs decreases towards end, then it indicates increasing failure rate. If the magnitude of TBFs is approximately constant throughout the period, then it shows constant rate of failure.

Although, graphical models offers quick way of detecting the trend in failure data, it is sometimes required to validate these models quantitatively, especially for large set of data and for complex systems. Accuracy

### 2.2 Analytical Models

Analytical trend testing when compared to graphical techniques place more emphasis on testing significance. These techniques aim to find out whether the equipment reliability is improving, deteriorating or remains constant by studying the statistics of the failure periods. For repairable equipment, two types of reliability trend tests with null hypothesis ($H_0$) and alternative hypotheses ($H_a$) are as follows.

Trend Test 1: For Poisson process

$H_0$: HPP

$H_a$: NHPP

Trend Test 2: For renewal process

$H_0$: Renewal process

$H_a$: Non-renewal process

In a homogeneous Poisson process (HPP), the times between two consecutive failures are exponentially distributed with a constant rate. A non-homogeneous Poisson process (NHPP) is the generalization of the HPP in which the average rate of failure arrivals is allowed to vary with time

Table 1: Analytical trend tests and their test statistic

| Trend test | Test for | Test statistic |
|---|---|---|
| Laplace test | NHPP versus HPP | Normal |
| Crow/AMSSA | NHPP versus HPP | Chi-square |
| PCNT | Renew versus non-renew | Normal |
| Lewis–Robinson test | Renew versus non-renew | Normal |

A number of analytical models for trend testing can be found in Ascher and Feingold and Cox and Lewis. Also, a detailed discussion on trend tests was made in the work carried out by Wang and Coit (2005). The most extensive analytical models used in the literature are (a) Crow/AMSAA (b) Laplace test (c) Pair-wise comparison non-parametric test (PCNT) and (d) Lewis-Robinson test. The Laplace and Crow/AMSAA trend tests used to test NHPP versus HPP whereas Lewis-Robinson and PCNT trend tests are capable of testing renewal versus non-renewal processes. The test statistic for these method are summarized in table no. 1

**a. Crow/AMSSA**

The Crow/AMSAA trend test is based on the assumption that failure intensity in $u(t) = \lambda\beta t^{\beta-1}$ is appropriate for a repairable equipment. When $\beta = 1$, the failure intensity reduces to $u(t) = \lambda$, which means the failure process follows an HPP without a growth trend. If $\beta > 1$, the failure intensity increases with t, implying deterioration of reliability. If $\beta < 1$, the failure frequency reduces, indicating that the reliability of the system is improving. Therefore, the trend test involves whether the estimate of $\beta$ is significantly different from 1

According to Crow (2015), for a system under test, the maximum likelihood estimate (MLE) is

$$\hat{\beta} = \frac{N}{\sum_{i=1}^{N-1} ln\left(\frac{T_N}{T_i}\right)}$$

Where N = number of failures
$t_i$ = $i^{th}$ failure arrival time

The test statistics is $\frac{2N}{\hat{\beta}}$ which has a chi-squared distribution with degree 2n. Given 100(1− α)% confidence level, the rejection criteria of the null hypothesis is given by

$$\text{Reject } H_0 \text{ if } \frac{2N}{\hat{\beta}} < \chi^2{}_{2N,1-\frac{\alpha}{2}} \text{ or } \frac{2N}{\hat{\beta}} > \chi^2{}_{2N,\frac{\alpha}{2}}$$

**b. Laplace test**

Trend analysis through Laplace test can be used to assess the null hypotheses of HPP. This method provides a way for distinguishing between a constant rate at which failure are occurring and an increasing/decreasing rate of occurrence of such failures. Figure no. 2 shows the time series of failure events for repairable equipment.

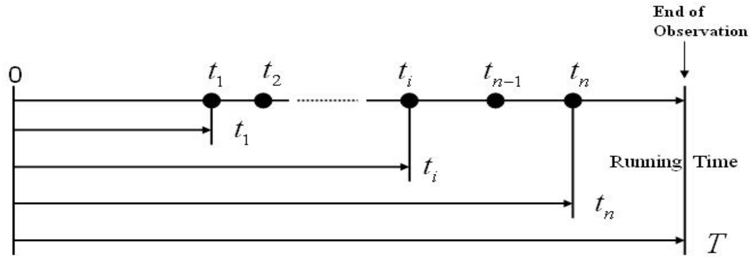


Figure 2: Failure arrival times

The test statistic of Laplace test can be calculated by

$$U_L = \sqrt{12n}\left(\frac{\sum_{i=1}^{n} t_i}{nt_n} - 0.5\right)$$

Where N = number of failures
$t_i$ = $i^{th}$ failure arrival time
$t_n$ = total time span
The rejection criterion is based on standard normal distribution assumption for $U_L$. It is given by,
Reject $H_0$ if $U_L > Z_{\alpha/2}$ or $U_L < - Z_{\alpha/2}$

## III. Field Investigation and Data Collection

The Present study is carried out at OCP-II, Ramagundam on dump trucks. A dump truck is repairable equipment used to carry the coal from the field to the conveyor area. A dumper in ideal state at maintenance shop is shown in the figure no 3. Trend analysis is performed using failure data of dumpers collected from the maintenance shop. Data collection is the primary task for any reliability analysis. Equipment failure data is collected from the maintenance register for the present study which contains type of failures, time between two successive failures, breakdown hours etc. Data errors and irregularities are removed and arranged in chronological order. Data pertaining to dumper no OC101 is shown in the table no 2.

Figure 3: Dump truck at maintenance shop at OCM

## IV. Trend Evaluation

The analytical trend tests discussed so far have been evaluated for the failure data of dumpers in this section. Information like number of failures, time between failures and cumulative time between failures have used for the analysis. Trend evaluation for the failure data of the dumpers is done using Crow/AMSAA and Laplace test. Total of 12 dumpers were considered for the study and calculated values for dumper no OC101 is shown in the table no 2.

Table 2: Failure numbers and failure arrival time for dumper no. OC101

| Failure number (N) | $t_i$ | $\sum t_i$ | $T_n/t_i$ | $\ln(t_n/t_i)$ |
|---|---|---|---|---|
| 1 | 624 | 624 | 50.65385 | 3.925015 |
| 2 | 672 | 1296 | 47.03571 | 3.850907 |
| 3 | 1656 | 2952 | 19.08696 | 2.949005 |
| 4 | 2376 | 5328 | 13.30303 | 2.587992 |
| 5 | 3432 | 8760 | 9.20979 | 2.220267 |
| 6 | 3528 | 12288 | 8.959184 | 2.192679 |
| 7 | 3552 | 15840 | 8.898649 | 2.185899 |
| 8 | 6192 | 22032 | 5.104651 | 1.630152 |
| 9 | 6312 | 28344 | 5.007605 | 1.610958 |
| 10 | 6648 | 34992 | 4.754513 | 1.559094 |
| 11 | 6912 | 41904 | 4.572917 | 1.520151 |
| 12 | 7608 | 49512 | 4.154574 | 1.42421 |
| 13 | 8088 | 57600 | 3.908012 | 1.363029 |
| 14 | 9912 | 67512 | 3.188862 | 1.159664 |
| 15 | 10512 | 78024 | 3.006849 | 1.100893 |
| 16 | 11088 | 89112 | 2.850649 | 1.047547 |
| 17 | 12384 | 101496 | 2.552326 | 0.937005 |
| 18 | 13416 | 114912 | 2.355993 | 0.856962 |
| 19 | 13560 | 128472 | 2.330973 | 0.846286 |
| 20 | 13632 | 142104 | 2.318662 | 0.84099 |
| 21 | 13680 | 155784 | 2.310526 | 0.837475 |
| 22 | 13728 | 169512 | 2.302448 | 0.833973 |
| 23 | 14136 | 183648 | 2.235993 | 0.804686 |
| 24 | 14520 | 198168 | 2.17686 | 0.777883 |
| 25 | 14856 | 213024 | 2.127625 | 0.755006 |
| 26 | 16872 | 229896 | 1.8734 | 0.627755 |
| 27 | 17016 | 246912 | 1.857546 | 0.619256 |
| 28 | 17616 | 264528 | 1.794278 | 0.584603 |
| 29 | 17664 | 282192 | 1.789402 | 0.581882 |
| 30 | 17736 | 299928 | 1.782138 | 0.577814 |
| 31 | 18288 | 318216 | 1.728346 | 0.547165 |
| 32 | 18312 | 336528 | 1.726081 | 0.545854 |
| 33 | 19728 | 356256 | 1.60219 | 0.471371 |
| 34 | 22200 | 378456 | 1.423784 | 0.353318 |
| 35 | 23016 | 401472 | 1.373306 | 0.317221 |
| 36 | 23640 | 425112 | 1.337056 | 0.29047 |
| 37 | 26448 | 451560 | 1.1951 | 0.17823 |
| 38 | 26544 | 478104 | 1.190778 | 0.174607 |
| 39 | 26664 | 504768 | 1.185419 | 0.170096 |
| 40 | 26760 | 531528 | 1.181166 | 0.166502 |
| 41 | 27696 | 559224 | 1.141248 | 0.132122 |
| 42 | 27768 | 586992 | 1.138289 | 0.129526 |
| 43 | 27888 | 614880 | 1.133391 | 0.125214 |
| 44 | 28224 | 643104 | 1.119898 | 0.113238 |
| 45 | 28920 | 672024 | 1.092946 | 0.088877 |
| 46 | 29280 | 701304 | 1.079508 | 0.076506 |
| 47 | 29520 | 730824 | 1.070732 | 0.068342 |
| 48 | 30648 | 761472 | 1.031323 | 0.030843 |
| 49 | 30888 | 792360 | 1.02331 | 0.023042 |
| 50 | 31608 | 823968 | 1 | 0 |
| | | | $\sum_{i=1}^{N} \ln\left(\frac{Tn}{Ti}\right) =$ | 46.8118 |

**Crow/AMSAA**

Substitute $t_i$ for $i$ = 1, 2,…, 50 into the below equation along with $n$ =50 and $t_N$ = 31608 hours.
The MLE of β is given below:

$$\beta = \frac{N}{\sum_{i=1}^{N} ln\left(\frac{T_N}{T_i}\right)} = \frac{50}{46.8118} = 1.0681$$

Table 3: β values in Crow/AMSAA test for different dumpers

| Dumper code | N | $\sum_{i=1}^{N} \ln(\frac{Tn}{Ti})$ | β | 2N/β | $\chi^2_{2N,97.5\%}$ left | $\chi^2_{2N,2.5\%}$right | Remark |
|---|---|---|---|---|---|---|---|
| OC101 | 50 | 46.8118 | 1.0681 | 93.624 | 73.364 | 128.4185 | HPP |
| OC102 | 43 | 24.65343 | 1.744179 | 49.307 | 61.675 | 112.3285 | NHPP |
| OC103 | 34 | 9.9678 | 3.4109 | 19.936 | 46.2752 | 91.5055 | NHPP |
| OC104 | 38 | 13.3509 | 2.8462 | 26.702 | 52.9305 | 100.826 | NHPP |
| OC105 | 38 | 20.7756 | 1.829 | 41.55 | 52.9305 | 100.826 | NHPP |
| OC106 | 34 | 9.0238 | 3.767 | 18.05 | 46.2752 | 91.5055 | NHPP |
| OC107 | 28 | 13.3810 | 2.0925 | 26.762 | 36.419 | 77.359 | NHPP |
| OC108 | 23 | 9.922 | 2.3810 | 19.319 | 28.395 | 65.381 | NHPP |
| OC109 | 25 | 9.6907 | 2.5797 | 19.382 | 31.7563 | 70.2122 | NHPP |
| OC110 | 30 | 13.783 | 2.176 | 27.573 | 39.6908 | 82.1102 | NHPP |
| OC111 | 25 | 7.8117 | 3.2003 | 15.623 | 31.7563 | 70.2122 | NHPP |
| OC112 | 20 | 7.1986 | 2.7782 | 14.398 | 23.6668 | 58.1057 | NHPP |

**Laplace Test**

Substitute $t_i$ for $i$ = 1, 2,…, 50 into the below equation along with $n$ =50, $\sum t_{50}$ = 823968 hours and $t_n$=31608.

$$U_L = \sqrt{12n}\left(\frac{\sum_{i=1}^{n} t_i}{nt_n} - 0.5\right)$$

Table 4: Laplace test values for different values

| Dumper code | N | ∑t | T | $U_L$ | Remark |
|---|---|---|---|---|---|
| OC101 | 50 | 823968 | 31608 | 0.5233 | HPP |
| OC102 | 43 | 775848 | 29688 | 2.4477 | NHPP |
| OC103 | 34 | 1062144 | 40608 | 5.435 | NHPP |
| OC104 | 38 | 901368 | 32472 | 4.9217 | NHPP |
| OC105 | 38 | 746496 | 31176 | 5.570 | NHPP |
| OC106 | 34 | 868800 | 32232 | 5.914 | NHPP |
| OC107 | 28 | 531360 | 28296 | 3.128 | NHPP |
| OC108 | 23 | 443808 | 27912 | 3.178 | NHPP |
| OC109 | 25 | 508656 | 27528 | 4.142 | NHPP |
| OC110 | 30 | 573888 | 28248 | 3.362 | NHPP |
| OC111 | 25 | 506376 | 26688 | 4.4852 | NHPP |
| OC112 | 20 | 398184 | 27144 | 3.617 | NHPP |

## V. Results and Discussions

Analytical trend tests were applied for 12 dumpers working in open cast mining to detect possible trend. Laplace test and Crow/AMSAA were used to analyze the trend behavior in 97.5% confidence interval and the results are shown in the table no 5. It is observed that, in Laplace test all the dumpers except OC101 are yielding alternate hypothesis indicating non-homogeneous poison process. In Crow/AMSAA trend test, three dumpers (OC101, 102, 108) are accepting alternative hypothesis where as remaining dumpers rejecting alternative hypothesis indicating non-homogeneous poison process.

Table 5: Test results for different dumper

| DUMPER | LAPLACE | CROW/AMSAA |
|---|---|---|
| OC101 | Accept Ho | Accept H0 |
| OC102 | Reject Ho | Accept Ho |
| OC103 | Reject Ho | Reject H0 |
| OC104 | Reject Ho | Reject H0 |
| OC105 | Reject Ho | Reject H0 |
| OC106 | Reject Ho | Reject H0 |
| OC107 | Reject Ho | Reject H0 |
| OC108 | Reject Ho | Accept Ho |
| OC109 | Reject Ho | Reject H0 |
| OC110 | Reject Ho | Reject H0 |
| OC111 | Reject Ho | Reject H0 |
| OC112 | Reject Ho | Reject H0 |

## VI. Conclusion

The failure data of any repairable equipment can be analyzed statistically in order to assess the reliability. Moreover, analysis of failure events through statistical trend tests shows some direction for further reliability analysis. In this paper, two important reliability trend tests namely Laplace trend test and Crow/AMSAA were discussed and evaluated for the dumpers working in open cast mining. The condition of shortening or extending of inter-arrival time of failures can be tested using these trend tests. Relevant data like number of failures, failure arrival time and total time span have been taken and substituted in the formulae. All the dumpers except dumper no OC101 are rejecting null hypothesis in Laplace test where as in Crow/AMSAA three dumpers are accepting null hypothesis and remaining are rejecting null hypothesis. It can be concluded that, 11 dumpers are showing trend in their failure data, where as dumper no. OC101 is not showing any trend in its failure events.

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