# Reliability Analysis of Loader Equipment: A Case Study of a Galcheshmeh Travertine Quarry in Iran

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**ABSTRACT:** Unplanned equipment failures and their consequences have significant influence on the total operating cost of a mining system. Loader is one of the main machinery in quarry mines. From an economic point of view, more than 50 % of production costs in quarry mines are allocated to hauling and loading costs, so it is important to keep equipment in good condition. Reliability is a useful tool for evaluating the performance of this machine. In this research, the reliability analysis of loading equipment in Galcheshmeh travertine quarrying which consists of two loaders has been analyzed. In this study, two approaches were considered for analyze maintenance data, namely a basic maintenance approach and a reliability based approach. Trend and serial correlation test were applied to validate the assumption of independent and identically distribution (IID). For finding the best-fit distribution, different types of statistical distributions were tested by the Easyfit software. The developed model based on these data showed that the reliability of the loader No. 1 and Bo. 2 decreases to a zero value after approximately 477 hours and 309 hours of operation, respectively. To achieving the high reliability a review on maintenance program must be performed.

**KEYWORDS:** Reliability analysis, Maintenance, Failure, Probability distribution, Galcheshmeh travertine quarry

## 1. INTRODUCTION

Technological development has enabled the mining industry to deploy more complex and capital-intensive equipment to increase productivity, but inefficient operation and deficient maintenance often prevent utilization of its full capacity. Interest in the maintenance and operational reliability of all capital-intensive equipment has been stimulated by the current emphasis on reducing production costs. Reliability analysis techniques have been gradually accepted as standard tools for the planning and operation of automatic and complex mining systems since the mid-1980s (Kumar et al., 1989). The most important reliability studies were presented in Table 1.

## 2. BASIC CONCEPT AND APPROACH FOR RELIABILITY ANALYSIS

1. Mean Time To Repair (MTTR): The mean time required to repair a component, expressed as the total repair time divided by the total number of repairs.
2. Percentage of Total Repairs: The percentage of total repairs, expressed as the repair frequency of a system divided by total repair frequency for all systems.
3. Mean Time Between Failures (MTBF): The mean time of the failure distribution of a machine or component. For a constant failure rate it is expressed as the total operating time divided by the total number of repairs.
4. Availability: The percentage of time that a system is operating satisfactorily. It is represented by the following equation.

$$Availibity = \frac{MTBF}{MTBF + MTTR} \tag{1}$$

5. Reliability: The probability that a system or component will operate without failure under a given condition for a specified time period (Esmaeili et al., 2011).

$$R(t) = 1 - F(t) \tag{2}$$

Table 1. Summary of the literature review

| Date | Author | Title | Software used |
|---|---|---|---|
| 1989 | Kumar et al. | Reliability Investigation for a Fleet of Load Haul Dump Machines in a Swedish Mine | STATGRAPHICS |
| 1994 | Vagenas et al. | Analysis of truck maintenance characteristics in a Swedish open pit mine | - |
| 2000 | Nuziale & Vagenas | A software architecture for reliability analysis of mining equipment | RelSoft & Architecture |
| 2001 | Roy et al. | Maintainability and reliability of a fleet of shovels | - |
| 2008 | Barabady & Kumar | Reliability analysis of mining equipment: A case study of a crushing plant at Jajarm Bauxite Mine in Iran | Weibull++6 |
| 2011 | Esmaeili et al. | Reliability analysis of a fleet of loaders in SANGAN iron mine | Easy Fit |
| 2014 | Furuly et al. | Availability analysis of the main conveyor in the Svea Coal Mine in Norway | Weibull++7 |

## 3. CASE STUDY

Here we present a case study describing the reliability analysis of two Caterpillar loaders (988B No.1 and 988B No.2). These data collected over a time period of 9 months (from April 2015 to December 2015) for loader No.1 and a time period of 6 months (from June 2015 to November 2015) for loader No.2 by using hand written forms prepared by maintenance personal, daily report and maintenance cards. These maintenance cards include time to failure, the machine hour meter and the time to repairs.

Before analyzing the machine's characteristics and failure data, the machine should be classified into a number of systems and subsystems in order to categorize the types of failure occurring on the machine. These classifications will depend on the maintenance records kept by maintenance personnel, as well as the reasoning describing these records (Vagenas et al., 2003).

In this paper preventive maintenance is applied as a subsystem in order to ensure a proper maintenance. Preventive maintenance defined as the actions performed in attempt to retain an item in a specified condition by providing systematic inspection, detection and prevention of incipient failure (Oyebisi 2000; Paraszczak and Perreault, 1994). Useful classification subsystem for a fleet of two loaders was presented in Table 2.

Table 2. Useful classification subsystem for loaders

| | Subsystem | Code |
|---|---|---|
| Loader No.1 | 1. Transmission | TRAN |
| | 2. Hydraulic | HYD |
| | 3. Others (Engine, Electrical, Structural, Bucket, Braking) | OTH |
| Loader No.2 | 1. Tire | TR |
| | 2. Others (Engine, Structural, Bucket) | OTH |

### 3.1. Data Collection, Sorting and Classification

Three basic steps have been performed before data analyzing for determining reliability Characteristics. These are data collection from different sources of data in mine equipment, sorting of the data required for analysis and data classification in the form required for the analysis (time between failures (TBF), time to repair (TTR), repair frequency, total breakdown hours, total working hours, total maintenance hours, etc.) (Barabady and Kumar, 2008).

We design our own tables in order to sort and arrange the data in a chronological order. The part of the data collected for loader No.1 and No.2 are given in Table 3 and 4, respectively.

Table 3. A part of failure data for reliability based analysis of loader No. 1

| No. | Systems repaired | TTR (hours) | Cumulative TTR | TBF (hours) | Cumulative TBF |
|---|---|---|---|---|---|
| 1 | OTH(Electrical) | 3 | 3 | 5 | 5 |
| 2 | HYD | 1 | 4 | 1 | 6 |
| 3 | HYD | 1 | 5 | 2 | 8 |
| 4 | TRAN | 2 | 7 | 5 | 13 |
| 5 | TRAN | 3 | 10 | 80 | 93 |
| 6 | TRAN | 6 | 16 | 20 | 113 |
| 7 | TRAN | 26 | 42 | 70 | 183 |
| 8 | TRAN | 40 | 82 | 140 | 323 |
| 9 | TRAN | 23 | 105 | 70 | 393 |
| 10 | TRAN | 24 | 129 | 60 | 453 |
| 11 | TRAN | 28 | 157 | 70 | 523 |
| 12 | HYD | 1 | 158 | 10 | 533 |
| 13 | OTH(Braking) | 5 | 163 | 9 | 542 |
| 14 | OTH(Bucket) | 20 | 183 | 50 | 592 |
| 15 | HYD | 1 | 184 | 2 | 594 |
| 16 | HYD | 1 | 185 | 12 | 606 |
| 17 | HYD | 5 | 190 | 6 | 612 |
| 18 | OTH(Structural) | 5 | 195 | 10 | 622 |
| 19 | OTH(Engine) | 10 | 205 | 60 | 682 |
| 20 | OTH(Electrical) | 6 | 211 | 30 | 712 |

Table 4. A part of failure data for reliability based analysis of loader No. 2

| No. | Systems repaired | TTR (hours) | Cumulative TTR | TBF (hours) | Cumulative TBF |
|---|---|---|---|---|---|
| 1 | OTH(Engine) | 3 | 3 | 30 | 30 |
| 2 | OTH(Bucket) | 19 | 22 | 20 | 50 |
| 3 | OTH(Structural) | 3 | 25 | 10 | 60 |
| 4 | TR | 18 | 43 | 60 | 120 |
| 5 | TR | 3 | 46 | 10 | 130 |
| 6 | OTH(Structural) | 19 | 65 | 50 | 180 |
| 7 | OTH(Bucket) | 31 | 96 | 80 | 260 |
| 8 | TR | 2.5 | 98.5 | 50 | 310 |
| 9 | TR | 3.5 | 102 | 60 | 370 |
| 10 | TR | 4 | 106 | 80 | 450 |

### 3.2. Analysis Using Graphical Methods

The next step was analyzed data by graphical methods in order to evaluate parameter such as repair frequency, time between failures (TBF), time to repair (TTR), total working hours and total repair time. The TBFs and TTRs for subsystems are calculated. Repair frequency, total repair time, percent of total repairs, minimum and maximum for each type of failure for two loaders provides in Table 5. The data from Table 5 may be better visualized in figures 1 and 2 for loader No. 1 and figures 3 and 4 for loader No. 2. Figure 1 displays the percent of total repairs and repair frequency versus type of failure. By studying Figure 2, it can be seen that the transmission and hydraulic are the most frequently occurring repairs for loader No. 1 and consume the most repair time. Also by studying Figure 3, it can be seen that the tire is the most frequently occurring repairs to loader No. 2 and consume the most repair time. Figures 2 and 4 have been provided a plot of repair frequency and repair time versus type of failure. These graphs provide a better view of failure trends of equipment. A summary of the operating time, total number of repairs, and total repair hours for two loaders provides in Table 6. In this table, availability is calculated by Equation 1.

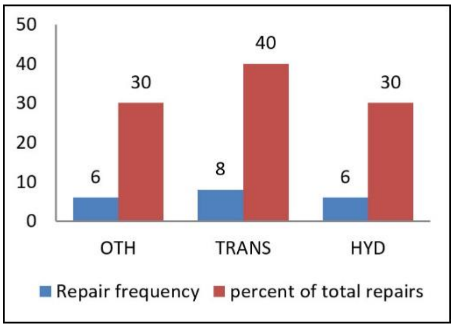


Figure 1. Repair frequency and percent of total repairs versus type of failure for loader No. 1

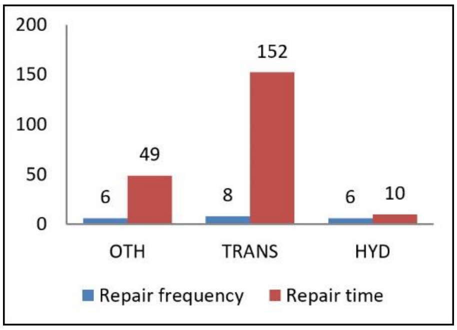


Figure 2. Repair time and repair frequency versus type of failure for loader No. 1

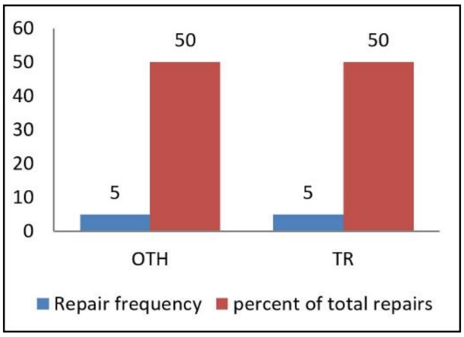


Figure 3. Repair frequency and percent of total repairs versus type of failure for loader No. 2

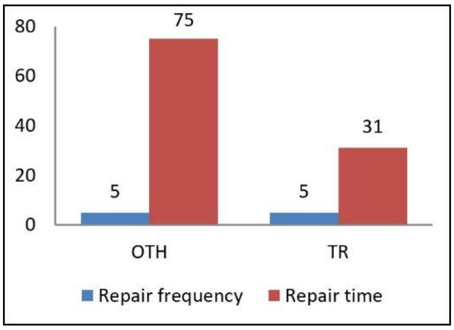


Figure 4. Repair time and repair frequency versus type of failure for loader No. 2

Table 5. An overall view of the maintenance characteristics for each type of failure

| | Type of Failure | TRAN | HYD | OTH | | TR | OTH |
|---|---|---|---|---|---|---|---|
| **Loader No. 1** | Repair frequency | 8 | 6 | 6 | **Loader No. 2** | 5 | 5 |
| | Repair time | 152 | 10 | 49 | | 31 | 75 |
| | Percent of total repairs | 40 | 30 | 30 | | 50 | 50 |
| | Min | 2 | 1 | 3 | | 2.5 | 3 |
| | Max | 40 | 5 | 30 | | 18 | 31 |
| | Avg | 19 | 1.7 | 8.2 | | 6.2 | 15 |

Table 6. The summary of failure characteristics of a fleet of two loaders

| | Loader No. 1 | Loader No. 2 |
|---|---|---|
| Operating Hours | 447 | 309 |
| Total Number of Repairs | 20 | 10 |
| Total Repair Hours | 211 | 106 |
| MTTR (Hours) | 10.55 | 10.6 |
| MTBF (Hours) | 23.9 | 30.9 |
| Availability | 69.3% | 74.5% |
| Fleet Availability (Average of availability of two loaders) | 71.89% | |

### 3.3. Trend Test and Serial Correlation

The next step after the collection, sorting and classification of data is the validation of the Independent and Identically Distributed (IID) nature of the TBF and TTR data of each subsystem. The computed values of the test statistic for the different subsystem failures and repairs' data are given in Table 3 and 4. A trend test involves plotting the cumulative failure number against the cumulative time between failures. Fig. 5 illustrates the trend test for loader No. 1 and No. 2. As can be seen in Fig. 5 trend test shows a straight line and it means that the data is free of trend.

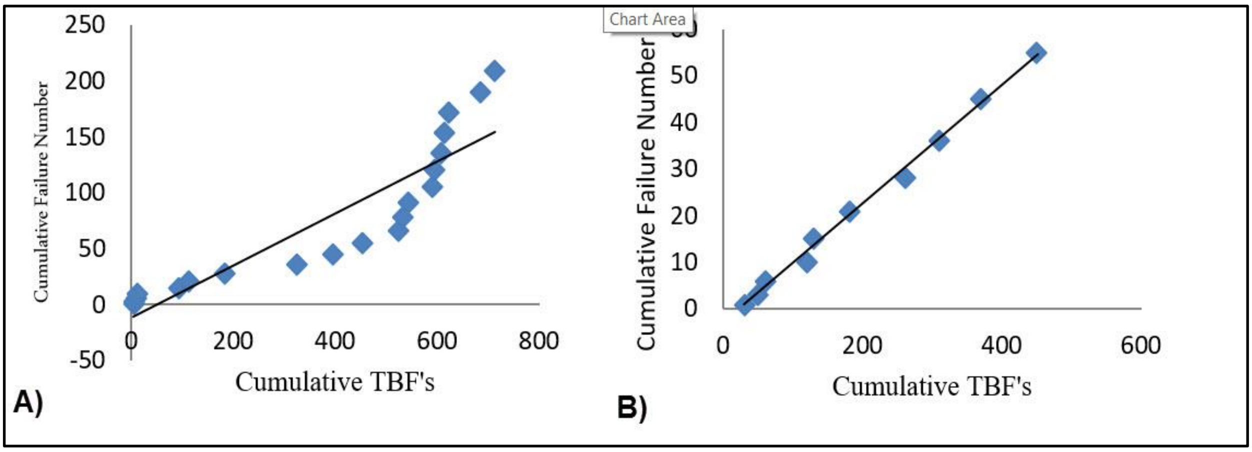


Figure 5. A) Trend plot for loader No. 1 and B) trend plot for loader No. 2

The serial correlation test is a plot of the data pairs (Xi, Xi–1) for i = 1, …, n, where n is the failure number. A scatter plots of the time between failures (TBF) for loader No. 1 and No.2 are displayed in Figure 6. They show that the points are scattered randomly throughout the plots. This indicates that the data is free of the correlations and can be assumed to be independent.

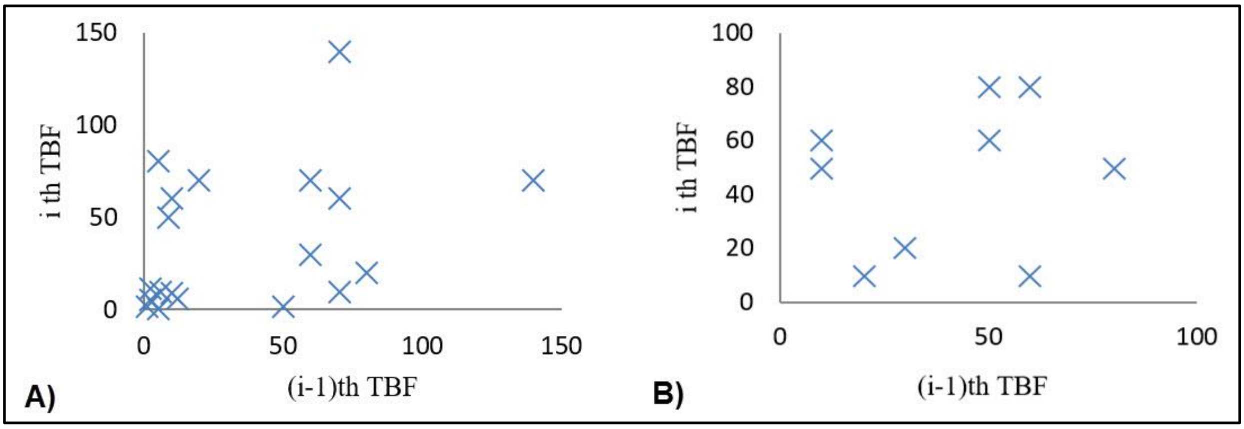


Figure 6. A) Scatter plot for test serial correlation for loader No. 1 and B) Scatter plot for test serial correlation for loader No. 2

Thus the assumption of independent and identically distributed (IID) data for all two loaders should be accepted and consequently the data can be fitted to theoretical probability distributions for reliability calculations.

### 3.4. Reliability Estimation

The next step is to assess the goodness-of-fit of a probability distribution model to the failures. One of the most widely used non parametric test for assessing the goodness-of-fit of repair times and time between failures is the Kolmogorov-Smirnov (K-S) test (Paraszczak and Perreault, 1994; Kumar and Vagenas, 1993). The K-S test examines for differences between the theoretical distribution and the observed cumulative distribution. This test can easily be performed by a probability distribution fitting software package. The data for the two loaders were tested for goodness-of-fit. Five distribution methods such as Weibull 2 parameter, Weibull 3 parameter, Exponential 1parameter, Exponential 2 parameter and Lognormal were fitted to the time between failures (TBF) data. Table 7 and 8 illustrates the results of these tests for the TBF data using the Easy-Fit software. This software assesses the goodness-of-fit of a probability distribution to the data by theoretical probability distributions.

Table 7. Goodness of fit for determination of best fit distribution for the TBF data of loader No. 1

| **K-S test (goodness-of-fit)** | | | | | | **Best fit** | **Parameters** |
|---|---|---|---|---|---|---|---|
| Sub-system | Weibull2 parameter | Log normal | Exponential 2 parameter | Weibull3 parameter | Exponential 1 parameter | | |
| TRAN | 0.3283 | 0.3495 | 0.3539 | 0.3865 | 0.3562 | Weibull2 parameter | α = 0.81718<br>β = 71.788 |
| HYD | 0.2083 | 0.2549 | 0.3007 | 0.3231 | 0.1951 | Exponential 1parameter | λ = 0.18182 |
| OTH | 0.2141 | 0.2458 | 0.2994 | 0.2549 | 0.1936 | Exponential 1parameter | λ =0.03659 |
| Machine | 0.1736 | 0.1818 | 0.2276 | 0.1642 | 0.2138 | Weibull3 parameter | α = 0.61645<br>β = 26.969<br>γ = 1.0 |

The next step after determination of the best fit distribution is reliability estimation of the entire machine and their subsystems using the reliability function of the fitted distribution (Equation 2). The required functions provided in Table 9 and then the reliability of the two loaders was calculated (Table 10). Figures 7 and 8 display the results of the reliability estimation for the operation hours of each subsystem of loader No. 1 and No. 2, respectively.

Table 8. Goodness of fit for determination of best fit distribution for the TBF data of loader No. 2

| **K-S test (goodness-of-fit)** | | | | | | **Best fit** | **Parameters** |
|---|---|---|---|---|---|---|---|
| Sub-system | Weibull2 parameter | Log normal | Exponential 2 parameter | Weibull3 parameter | Exponential 1parameter | | |
| TR | 0.3658 | 0.3993 | 0.4321 | 0.4773 | 0.4321 | Weibull2 parameter | α = 0.85043 |
| | | | | | | | β = 61.87 |
| OTH | 0.2095 | 0.1619 | 0.2 | 0.1771 | 0.2313 | Lognormal | σ =0.72032 |
| | | | | | | | μ = 3.3987 |
| Machine | 0.2394 | 0.2713 | 0.2811 | 0.3452 | 0.2708 | Weibull2 parameter | α = 1.2046 |
| | | | | | | | β = 49.178 |

Table 9. Required functions for reliability analysis

| **Distribution** | **Density function** | **Distribution function** |
|---|---|---|
| Weibull2 Parameter | $f(x)=\frac{\alpha}{\beta}(\frac{x}{\beta})^{\alpha-1}\exp(-(\frac{x}{\beta}))^{\alpha}$ | $F(x)=1-\exp(-(\frac{x}{\beta}))^{\alpha}$ |
| Weibull3 Parameter | $f(x)=\frac{\alpha}{\beta}(\frac{x-\gamma}{\beta})^{\alpha-1}\exp(-(\frac{x-\gamma}{\beta}))^{\alpha}$ | $F(x)=1-\exp(-(\frac{x-\gamma}{\beta}))^{\alpha}$ |
| Exponential 2 parameter | $f(x)=\lambda\exp(-\lambda(x-y))$ | $F(x)=1-\exp(-\lambda(x-y))$ |
| Lognormal 2 parameter | $f(x)=\frac{\exp(-\frac{1}{2}(\frac{\ln(x)-\mu}{\sigma})^{2})}{x\sigma\sqrt{2\pi}}$ | $F(x)=\Phi(\frac{\ln(x)-\mu}{\sigma})$ |
| Exponential 1 parameter | $f(x)=\lambda\exp(-\lambda x)$ | $F(x)=1-\exp(-\lambda x)$ |

Table 10. Reliability estimation for two loaders

| **Loaders** | **Best fit** | **Parameter** | **Reliability estimation** | **Operation hours** |
|---|---|---|---|---|
| Loader No. 1 | Weibull3 parameter | α = 0.61645 | $2.8 \times 10^{-3}$ | 477 |
| | | β = 26.969 | | |
| | | γ = 1.0 | | |
| Loader No. 2 | Weibull2 parameter | α = 1.2046 | $1.06 \times 10^{-4}$ | 309 |
| | | β = 49.178 | | |

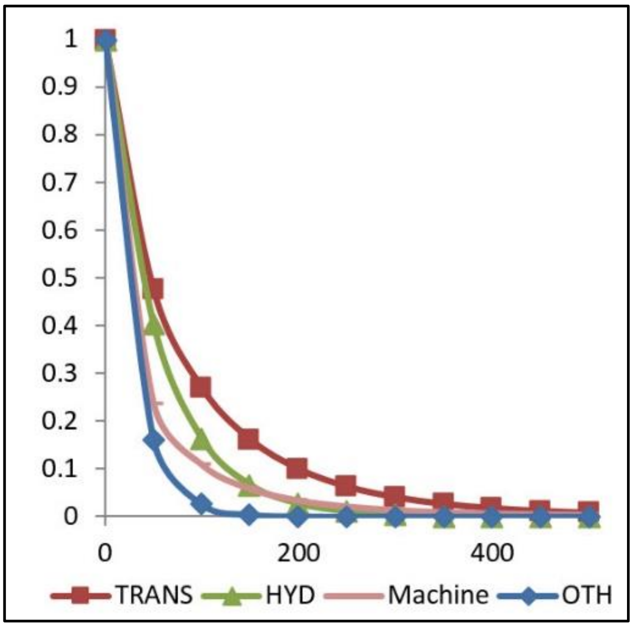


Figure 7. A plot for reliability estimation of loader No. 1

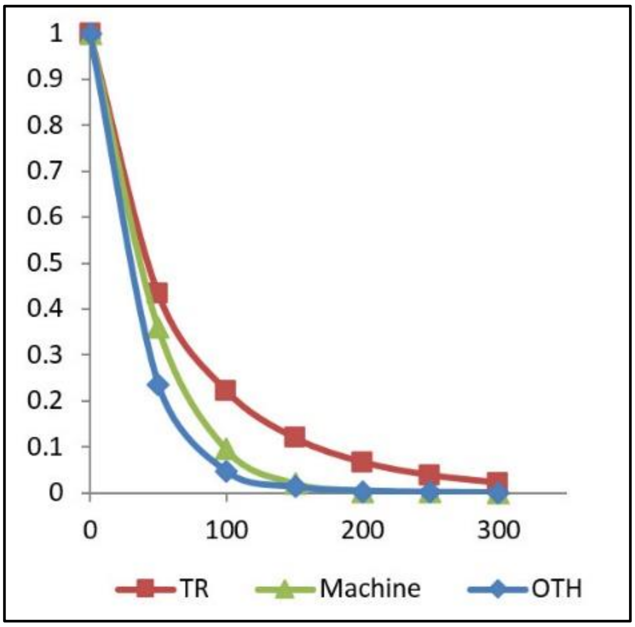


Figure 8. A plot for reliability estimation of loader No. 2

## 4. CONCLUSIONS

Reliability and maintainability of mining industry is more in focus than ever, and the mining systems are becoming more complex and the equipment more expensive to repair or modify. In this paper, the case study shows that the transmission and hydraulic in the loader No. 1, the tire in the loader No. 2, are the most frequency occurring repairs and consume the most repair times. These subsystems are critical from a reliability point of view. The Weibull distribution provided the best fit distribution, in the most cases, to the time between failures data of two loaders. Then, the loaders No. 1 and No. 2 reliability for the operation hours have been predicted, $2.8\times10^{-3}$, $1.06\times10^{-4}$ respectively. The reason of the low reliability of loaders can be expressed closed to end of working life. This study shows that the reliability analysis is very useful for deciding maintenance intervals.

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