A Study on Reliability Analysis of Haul Trucks

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Abstract: In this paper, we present the study of the two-parameter Weibull distribution theory and its parameters (shape β and scale α) using Weibull Probability Plotting. Using the failure data for haul trucks in operation at a marble quarry, we obtain the fatigue life equation by regression under different failure probabilities. Weibull distribution analysis for reliability and maintainability is showing a tendency of increasing failure rate, leaving room for decisions on reliability centered maintenance planning, machine improvements, optimal load and the need for review of data collection process.

Keywords : Reliability, Weibull distribution, Availability, Maintenance, Monitoring.

INTRODUCTION

Reliability is the probability that parts, components, products and systems will perform the functions for which they were designed without damage underspecified conditions, for a certain period of time and with a given confidence level. Although reliability is an independent notion, reliability and the concept of quality are closely related. The quality of a product represents all properties that make it suitable for the intended use; reliability is the ability to keep product quality throughout the operation. In other words, product quality reliability is extended in time [22].Reliability engineering techniques provide theoretical and practical methods that the likelihood and ability of the parts, components, equipment, products and systems to perform the functions for which they were designed and built, during predetermined time, under specified and known levels confidence, can be specified in advance, designed, tested, proven even under conditions in which they were stored, packaged, transported and then installed, commissioned, monitored and information submitted by all involved and interested. The reliability of machinery is essential, particularly in quarries, since the breakdown of any machine would cause an unpredictable loss or damage [14]. Therefore, it is obvious that the reliability of such equipment would have considerable impact, not only on production, but also machine life and potentially on human life. Prevention is better than cure. Instead of allowing the occurrence of failure and suffering from loss or damage of assets and environment, it is always worthwhile forestalling the occurrence. To operate in quarries with reduced number of failures, because of the harsh environment, the machines must be maintained to exhibit high reliability. The maintenance planning of equipment hence requires the orientation of reliability at every stage of its life. The present study is on effort in this direction that can provide some guidelines while planning the maintenance activities with an orientation to reliability. The most difficult part of this process is the acquisition of trustworthy data. It is known that no amount of precision n the statistical treatment of the data will enable sound judgments to be made based on invalid data.

1 Problem Formulation

Reliability is characterized by four concepts: probability, performance achieved, operating conditions and duration. Operational reliability is obtain parameter estimates that will help us to infer the reliabilities of the concerned machinery; and thus are able to compare them determined in real operating conditions. In some cases non-economic laboratory experiments, the main source of data collection, are not feasible. Experience in the field is recommending the selection of a group of beneficiaries, by category of use, operating conditions, etc. and systematic tracking performance of products through group reliability. This information is collected through direct reports of the interventions to address the nonconformities. Information processing is done by one of the methods available. Operational reliability is divided in two parts: functional and technological. Functional reliability is known as the operational safety concern matters relating to the operation of the system in terms of primary kinematics [2]. Technological reliability concerns with keeping within the limits of working parameters values. E.g. for a hydro pneumatic cylinder-piston engine, functional reliability is achieved during movements for which the engine was developed and designed; technological reliability means keeping the speed of travel, breaking times, force to the working body.

1.1 Reliability Indices

The basic reliability indices, as parameters which express reliability from a quantitative point of view, are being expressed by: the good operating probability, reliability function, $R(t)$; probability of deterioration, non-operation reliability function, $F(t)$; probable density of deteriorations, $f(t)$; intensity or rate of deterioration, $z(t)$; mean time of good operation, $MTBF$; mean time for repairing operations, MTR; rate of repairing operations, μ. Limit failure rate is the ratio of the probability that a device be damaged within the given time estimated $(t, t+dt)$ and the size of the sub-interval dt, since it tends to zero, provided that it is part of the devices that were in good condition early in the process. Any product lasts and

during its use, it is subjected to a process of attrition, a process that usually includes three periods (Fig.1), where upon it, someone must intervene effectively to restore performance to prolonged use, namely: - Initial period, when the number of faults that occur when running are relatively high, but decreasing; - Normal period (useful) life, when defects are reduced in number and random; -

The final period, when the number of failures due to wear or aging phenomena is growing. Looking from probabilistic perspective at the reliability problem [4], it can be said that time when a malfunction occurs cannot be establish with certainty, but only as a probability linked to a confidence interval.
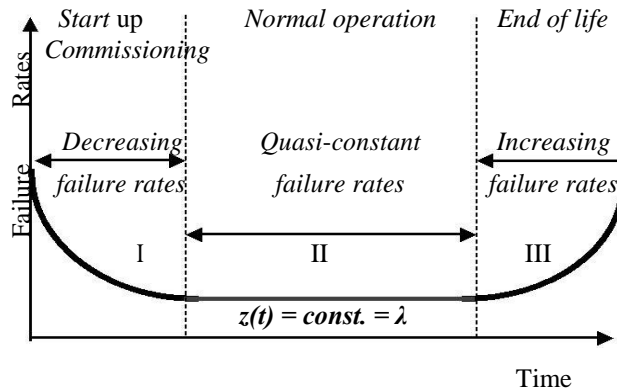

Fig.1

The evolution of failures on the entire life of a product. The concept of reliability has the statistical character in addition to the probabilistic. This is explained by the fact that the determination of reliability is based on data

obtained by measurements (laboratory), or through operational monitoring of the product, when obtain data on defects found on samples. As Reliability function [23] is recognized as survival function:

$$R(t) = P(T \geq t), \tag{1}$$

and has the following properties:

$R(t)$ is a continuous function of time, for each

$$t > 0, 0 \leq R(t) \leq 1, \tag{2}$$

where: T - random variable of running time up to the failure; t - time limit of the good working period.

$$R(t) = 1 \text{ for } t = 0, \tag{3}$$

At the initial moment, when system starts to operate, it surely works.

$$\text{Lim } R(t) = 0, \tag{4}$$

after a period of time, sufficient likelihood of better functioning decreases after a certain law, until it reaches zero.

$$\text{For } t_1 < t_2 \text{ results } R(t_1) > R(t_2), \tag{5}$$

so it's a decreasing function. The probability that a system will not fail in the time interval $[a, b]$ is:

$$P(a < T < b) = R(a) - R(b) \tag{6}$$

1.2 Weibull Distribution

Sometimes there are physical arguments based on the probabilistic failure mode which tends to justify the choice of model. The models are used only because of its empirical success in real data failure sheet. We choose the calculation of reliability by Weibull model. Weibull model is a very flexible method for modeling data sets containing values greater than zero, such as failure data. Weibull

analysis can make predictions about the life of a product, compare the reliability of competing products, can establish policies to guarantee statistical or proactively manage stocks of spare parts [3]. Weibull analysis is primarily a graphical technique although it can be done analytically. One graphical technique is Weibull

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Probability Plotting [16]; other graphical methods are Maximum Likelihood Estimation or Hazard Plotting. Weibull distribution is characterized by three parameters:

- α (alpha), shape parameter; shows the stretching on the time axis of the Weibull distribution law.

- β (beta), scale parameter or characteristic life;changes the shape of variations of reliability curves.

- γ (gamma), location parameter or min. life.

The Weibull distribution density function [5],[11],[18] is given by the probability PDF:

$$f(t, \beta, \alpha, \gamma) = \frac{\beta}{\alpha} \left(\frac{t - \gamma}{\alpha} \right)^{\beta - 1} e^{-\left(\frac{t - \gamma}{\alpha} \right)^{\beta}} \qquad (7)$$

With: $\beta > 0, \alpha > 0, t \geq 0, \gamma \geq 0$

The cumulative Weibull distribution function [15], [20], [9] is given by the cumulative distribution,CDF:

$$F(t) = 1 - e^{-\left(\frac{t - \gamma}{\alpha} \right)^{\beta}} \qquad (8)$$

Where: β (beta) is the shape parameter, α (alpha) is

the scale parameter, γ (gamma) is the location parameter. Formulas and properties [12], [6]:

Reliability: $\qquad R(t) = e^{-\left(\frac{t}{\alpha} \right)^{\beta}} \qquad (9)$

Failure rate: $\quad h(t) = \frac{\beta}{t} \left(\frac{t}{\alpha} \right)^{\beta - 1} \qquad (10)$

Properties:

- Mean Rank: $\alpha.\Gamma\left(1 + \frac{1}{\beta} \right) \qquad (11)$

- Median Rank: $\alpha.(\ln 2)^{\frac{1}{\beta}} \qquad (12)$

- Variation:

$$\alpha^2.\Gamma\left(1 + \frac{2}{\beta} \right) - \left[\alpha.\Gamma\left(1 + \frac{1}{\beta} \right) \right]^2 \qquad (13)$$

Where: Γ (gamma), gamma function with value of

Γ(*N*) for the entire *N*.

Γ(N) = (N-1)! $\qquad (14)$

From equation (10) we determine time before failure, TBF:

$$t = \alpha.(- \ln R(t))^{\frac{1}{\beta}} \qquad (15)$$

To determine the relation between the CDF and

the two parameters (β, α), we take the double

logarithmic transformation of the CDF.

Considering γ=0, we have:

$$F(t) = 1 - e^{-\left(\frac{t}{\alpha} \right)^{\beta}} \qquad (16)$$

$$F(t) = 1 - e^{-\left(\frac{t}{\alpha} \right)^{\beta}} \qquad (17)$$

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$$\ln\left(\frac{1}{1-F(t)}\right) = -\left(\frac{t}{\alpha}\right)^{\beta} \qquad (18)$$

$$\ln\left[\ln\left(\frac{1}{1-F(t)}\right)\right] = \beta \ln t - \beta \ln \alpha \qquad (19)$$

Equation (20) is an equation of a straightline. To plot $F(t)$ versus t, we follow three steps:

      a) Rank estimates in an ascending order To estimate $F(tn)$, one method of calculation formula is applied (Table 1). Where: N=TotalRank, is total number of data points; n=Rank, is the rank number of the given nonconformity.

Methods for estimating $F(tn)$

Method	F(tn)	
Mean Rank	$\dfrac{n}{N+1}$	(20)
Median Rank	$\dfrac{n-0.3}{n+0.4}$	(21)
Symmetrical CDF	$\dfrac{n-0.5}{N}$	(22)

In our calculation, having a sample size less than 100, will consider the Median Rank method (Bernard's approximation), formula (22).

      b) Estimate $F(tn)$ of the nth failure

      c) Plot $F(tn)$ versus t

Cumulative Weibull distribution function $F(t)$ can be rearranged in a form to which we apply the linear regression. The rearranged $F(t)$:

$$y(t) = \ln\left[\ln\left(\frac{1}{1-F(t)}\right)\right] = -shape.\ln(scale) + shape.\ln(t) \qquad (23)$$

$$y = \text{intercept} + \text{slope}.t \qquad (24)$$

$y(t)$ is a linear function of $\ln(t)$ having $slope=\beta$ and $intercept=-\beta ln\alpha$, the basis for the linearization of the Weibull CDF (Fig.2). It has been shown [1], [23] that shape factor drops directly out of the regression equation, whilst the scale factor has to be derived from the intercept:

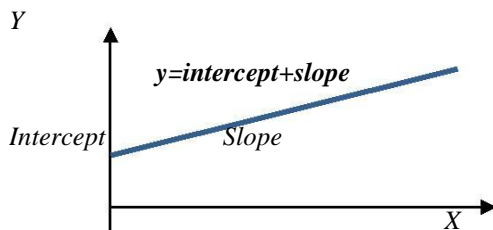$$\text{scale} = \exp\left(-\frac{\text{int}\,ercept}{shape}\right) \qquad (25)$$

Fig.2 Linearization of the Weibull CDF

1.3 Mean Time Before Failure (MTBF)

      After a system is repaired, it does not have the same performance characteristics as a new one, because not always the repair of defective components is perfect, the system has suffered overheating components, or broken parts were not well repaired. The best estimate of the total MTBF for Weibull distribution [15], [16] is given by:

$$MTBF = \alpha . \Gamma\left(1 + \frac{1}{\beta}\right) + \gamma \qquad (26)$$

MTBF parameter value estimated using this statistical method often cannot be calculated because of incomplete field data. In most cases, this time decreases randomly with age, which demonstrates that there is a series of random factors that make the average cycle time to decrease. If all system faults can be rectified, implying a long service life of the system, the estimated average cycle time becomes constant, obviously taking into account the age of the system.

2 The Work Metodology

In this subsection, we provide a data set assumed to be distributed with Weibull law (see [13], pp. 83,100).

This is known as steady state condition. Uptime and disruption may change depending on system's age:

$$MTBF = \frac{T}{N} \qquad (27)$$

Where: T is total working time of the system;

N is total number of faults.

MTBF parameter value estimated using this methodology must be corrected in order to reach a value as close to reality as possible, requiring a certain level of confidence. Correction factors can be achieved using the confidence interval method.

The data sets (Table 1) were recorded in a time period of 15 months for a number of 12 haul trucks in use at an open pit, marble quarry [9]:

Table1

#	TTR	CTTR	CAUSE	TBF	CTBF
1	28	28	Engine	870	870
2	32	60	Gear box	1530	2400
3	18	78	Transmission	3360	5760
4	16	94	Others-exhaust	976	6736
5	33	127	Engine	1590	8326
6	26	153	Breaks	558	8884
7	24	177	Suspension	902	9786
8	16	193	Gear box	782	10568
9	19	212	Transmission	1628	12196
10	18	230	Transmission	1560	13756
11	28	258	Breaks	42	13798
12	16	274	Steering	880	14678
13	12	286	Others-frame	208	14886
14	16	302	Transmission	97	14983
15	29	331	Breaks	688	15671
16	16	347	Engine	750	16421
17	24	371	Gear box	801	17222
18	28	399	Breaks	202	17424
19	20	419	Breaks	910	18334
20	9	428	Suspension	44	18378
21	9	437	Steering	186	18564
22	22	459	Transmission	600	19164
23	27	486	Breaks	500	19664
24	18	504	Suspension	70	19734
25	20	524	Suspension	440	20174
26	14	538	Others-frame	396	20570
27	30	568	Breaks	212	20782
28	12	580	Transmission	184	20966
29	9	589	Gear box	122	21088
30	23	612	Engine	88	21176
31	12	624	Others-frame	420	21596
32	11	635	Steering	77	21673
33	19	654	Suspension	886	22559
34	7	661	Transmission	784	23343
35	19	680	Gear box	160	23503

2.1 Application methods for calculating reliability - Weibull

Calculating only the MTBF to represent the system reliability could lead to misleading and unnecessary spares expenses, or not enough spares to continue work effectively. Failures are not normally distributed; MTBF does not provide information about the changing nature of failure rates over time. The high value of the mean time to repair subassemblies, namely the mean intensity or repair rate, is explained by the difficulty of corrective maintenance work, given the large masses and working gauges. To provide reasonable accurate failure analysis and failure forecasts with a limited number of samples, we have chosen Weibull method because it provides a performance analysis using a simple and useful graphical plot of the failure data.

2.1.1 Preparing to analyze

Weibull analysis requires some preparatory calculations: MedianRank column is an estimate of the proportion of the population that fails until the time listed in column TBF (Time Before Failure). To generate the graph of the corresponding regression, Weibull Analysis needs to generate median ranks as median values on the Y axis values, ranks obtained with the method of calculating Median Ranks, formula (22), where n=1,2, ... 35; N=35 (total number of failures), Table 2.The advantage of this method is that data corresponding to *ln(ln(1/(1-MedianRank)))* is graphical awarded in a straight line. By performing a simple linear regression we obtained estimated parameters which allow inferences on TBF values. To do this, in next step we used Excel add-in Analysis ToolPak to calculate the parameters (Table2) required to estimate Weibull parameters:

Table 2

TBF	rank	median rank	1/(1-median rank)	ln(ln(1/(1-median rank)))	ln(TBF)
870	1	0.020	1.020	-3.913	6.768
2400	2	0.048	1.050	-3.012	7.783
5760	3	0.076	1.083	-2.534	8.659
6736	4	0.105	1.117	-2.204	8.815
8326	5	0.133	1.153	-1.949	9.027
8884	6	0.161	1.192	-1.740	9.092
9786	7	0.189	1.233	-1.562	9.189
10568	8	0.218	1.278	-1.405	9.266
12196	9	0.246	1.326	-1.266	9.409
13756	10	0.274	1.377	-1.139	9.529
13798	11	0.302	1.433	-1.022	9.532
14678	12	0.331	1.494	-0.913	9.594
14886	13	0.359	1.559	-0.811	9.608
14983	14	0.387	1.631	-0.715	9.615
15671	15	0.415	1.710	-0.623	9.660
16421	16	0.444	1.797	-0.534	9.706
17222	17	0.472	1.893	-0.449	9.754
17424	18	0.500	2.000	-0.367	9.766
18334	19	0.528	2.120	-0.286	9.817
18378	20	0.556	2.255	-0.207	9.819
18564	21	0.585	2.408	-0.129	9.829
19164	22	0.613	2.584	-0.052	9.861
19664	23	0.641	2.787	0.025	9.887
19734	24	0.669	3.026	0.102	9.890
20174	25	0.698	3.308	0.179	9.912
20570	26	0.726	3.649	0.258	9.932
20782	27	0.754	4.069	0.339	9.942
20966	28	0.782	4.597	0.422	9.951
21088	29	0.811	5.284	0.510	9.956
21176	30	0.839	6.211	0.602	9.961
21596	31	0.867	7.532	0.703	9.980
21673	32	0.895	9.568	0.815	9.984
22559	33	0.924	13.111	0.945	10.024
23343	34	0.952	20.824	1.111	10.058
23503	35	0.980	50.571	1.367	10.065

2.1.2 Estimation of Weibull parameters

Weibull cumulative distribution function can be transformed so that it appears as a straight line. Using Excel Data Analysis [25], with ToolPack Analysis kit, we generated a new set of data represented in Table 3.

Table 3

Observation	Predicted ln(ln(1/(1-median rank)))	Residuals
1	-5.05612	1.142705
2	-3.40395	0.392375
3	-1.97853	-0.55553
4	-1.72367	-0.48002
5	-1.37863	-0.57014
6	-1.27301	-0.46674
7	-1.11556	-0.44597
8	-0.99039	-0.41496
9	-0.75711	-0.50857
10	-0.56113	-0.57761
11	-0.55617	-0.46574
12	-0.4555	-0.4577
13	-0.43259	-0.37856
14	-0.42202	-0.29256
15	-0.34892	-0.27362
16	-0.2728	-0.26147
17	-0.19526	-0.25386
18	-0.17627	-0.19024
19	-0.09338	-0.19256
20	-0.08948	-0.11748
21	-0.07308	-0.05604
22	-0.02129	-0.03072
23	0.020643	0.004157
24	0.026429	0.075336
25	0.062333	0.117041
26	0.093983	0.164207
27	0.110678	0.228212
28	0.12503	0.297286
29	0.134477	0.37511
30	0.141257	0.461005
31	0.173234	0.529442
32	0.179029	0.635618
33	0.244266	0.700986
34	0.299889	0.810679
35	0.311011	1.055944

2.1.3 Fitting a line to the data

With data calculated in Table 3, next step was to generate the graphical representation for the two entries which determine the reliability curve:
- Predicted ln(ln(1/(1-n)))
- Residuals

Data plotted on X-axes, *ln(TBF),* and Y-axes, ln(ln(1/(1-n))), has been further adjusted to create the linear distribution:- predicted ln(ln(1/(1-n)))
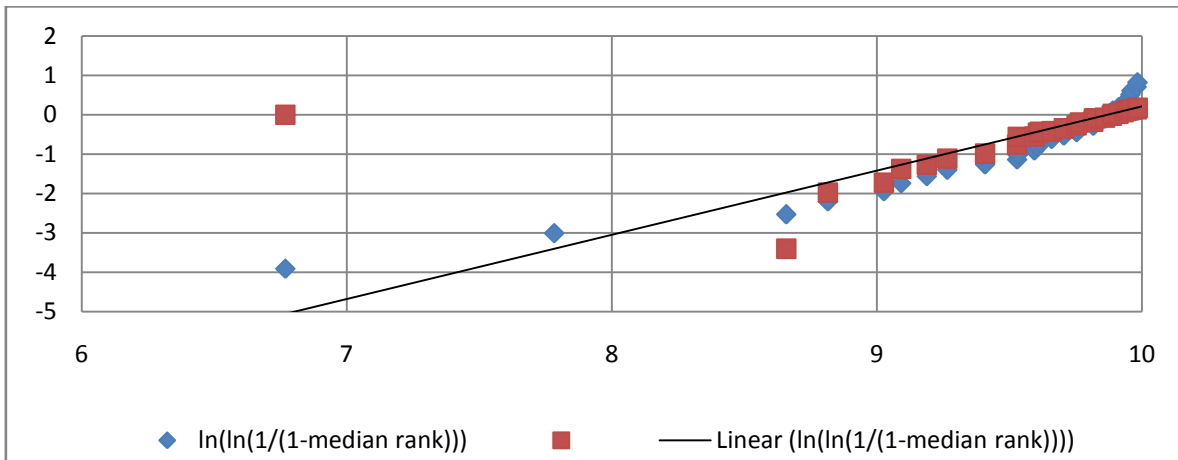

Fig.5

Predicted line Survival probability and reliability were determined by selecting 20 intervals of 1,000 hours *(X)* together with Microsoft Office Excel formula:

$$\text{WEIBULL}(X, \alpha, \beta, TRUE) \qquad (28)$$

The results were entered into Table 4

Table-4

TBF	Reliability	TBF	Reliability
0	1.000	26000	0.201
1000	0.992	27000	0.182
2000	0.975	28000	0.164
3000	0.953	29000	0.147
4000	0.926	30000	0.132
5000	0.895	31000	0.118
6000	0.861	32000	0.106
7000	0.826	33000	0.094
8000	0.788	34000	0.084
9000	0.750	35000	0.074
10000	0.711	36000	0.066
11000	0.671	37000	0.058
12000	0.632	38000	0.051
13000	0.593	39000	0.045
14000	0.555	40000	0.040
15000	0.518	41000	0.035
16000	0.481	42000	0.030
17000	0.447	43000	0.027
18000	0.413	44000	0.023
19000	0.381	45000	0.020
20000	0.350	46000	0.018
21000	0.321	47000	0.02
22000	0.294	48000	0.01
23000	0.268	49000	0.01
24000	0.244	50000	0.01
25000	0.222	-	-

2.1.4 TBF for a certain reliability level

Sometimes we need time before failure for a certain reliability level, given through the requirements. We Performed the calculations using formula (15).

Table 5

Reliability	TBF
0.01	49590
0.10	32401
0.50	15503
0.90	4876
0.99	1152

3 Generate the survival chart

Using data from Table 4, the reliability chart is:
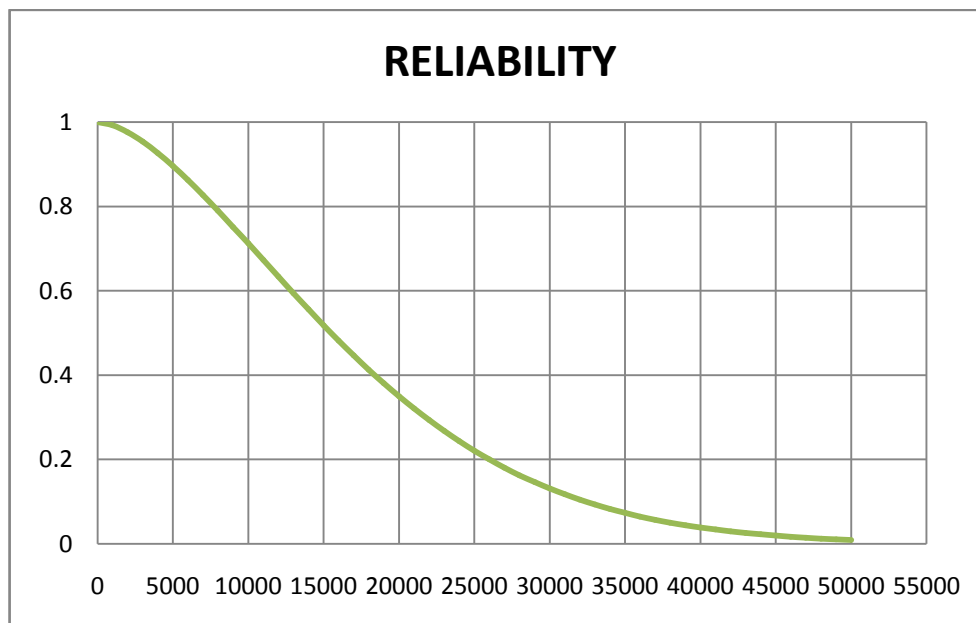
Fig.6 Survival graph, $\beta=1.62$

4 CONCLUSION

We conclude that the restrained to a relative small number of equipments investigated (12 haul trucks). The accuracy of the data collected is depending on the people concerned with maintenance activities, the collection in a systematic and organized way of failure/repair reports the equipment performance depends on its age and other factors. It is critical to record failure/repair data in such manner that can be used by the management team for spare parts provision, maintenance planning, ordering new equipment, or taking corrective actions about factors that have an influence on the equipment reliability (load, speed, roads, etc). Performance of a quarry not only depends upon production equipment like drills/cutters/excavators/ loaders but very much affected by the availability and utilization of service equipment. An integrated study of availability of all the equipment in a quarry can definitely improve the productivity through enhanced utilization of production equipment based on their availability. Weibull shape parameter β indicates if the failure rate is increasing, constant or decreasing [10]. In our study we found β > 1.0 indicating an increase in the rate of failures. This is typical to products presenting the phenomenon of wear. In this study Weibull model shows that for a confidence level of 99 %, TBF has a value of at least 4876 hours. To increase the reliability it is absolutely necessary to address, the major nonconformities on each subsystem: brakes,

transmission, suspension, engine, gearbox, running system. Along with that, it is necessary to review the data collection process. Repairs of major systems may take several days and often requires removing other components to carry out the work. Effective identification, planning, scheduling and execution can significantly reduce the impact of these failures. Eliminating failures primarily through a valid predictive maintenance would have the greatest positive impact. Another main cause of failure is a combination of truck speed, payload and road conditions. If any of these three cases is eliminated, the problem is minimized. A review of load conditions and truck speed are needed, also an evaluation of the road conditions which are a major cause of equipment downtime because of damages to the brakes and suspension.

REFERENCES

[1] Brighton Webs, Statistics for energy and the environment, http://www.brightonwebs. co.uk/distributions/weibull2.aspx.
[2] Burlacu G., ş.a., Fiabilitate, mentenabilitate şi disponibilitate, EdituraMatrix, Bucureşti, 2011.
[3] Chandra Mouli, Subbarao Chamarthi, Ravi Chandra G, Anil Kumar V, Reliability Modeling and Performance Analysis of Dumper Systems in Mining by KME Method,International Journal of Current Engineering and Technology, 2014.
[4] Dumitru Jula, Gabriel Praporgescu, Sorin Mihăilescu, NicolaeCornaciu, Ion Deaconu, Considerations on the Reliability of Machines and Equipment used in the Open Pit Mines, Annals of the University of Petroşani,Mechanical Engineering, 8 (2006), 155-172.
[5] Dumitru Jula, Iosif Dumitrescu, Fiabilitatea Sistemelor de Transport,Petrosani, Iunie 2009.
[6] A.Ramesh Kumar , V.Krishnan, A Study of Bulldozers in Reliability Analysis, International Journal of Innovative Research in Science, Engineering and Technology,vol.5,Issue 9,September 2016.
[7] Eman Widijanto, Operational Reliability of an Open Pit Mine, Santiago De Chile, Oct. 2010.
[8] Grebennikov Alexandre, Explicit General Ray, Method for Solution of Coefficient Inverse Problems for Heat Transfer, Proceedings of the7th IASME / WSEAS International Conference on Thermal Engineering and Environment (HTE '09), Moscow, Russia August 20-22,2009, pp. 135-139.
[9] Hoseinie S.H., Ataei, M., Khalokakaie R., Kumar, U., Reliability and maintainability analysis of electrical system of drum shearers. 2011 Journal of Coal Science & Engineering(China), Vol.17, No.2, pp. 192–197.
[10] Mann N. R., Schafer R. E., and Singpurwalla N. D., Methods for statistical analysis of reliability and life data, 1974, John Wiley andSons, New York.
[11] Mohammad A. Al-Fawzan,, Methods for Estimating the Parameters of the Weibull Distribution, King Abdulaziz City for Science and Technology, May 2000.
[12] Munteanu Toader, Gurguiatu Gelu, Balanuta Ciprian, Fiabilitate si Calitate in Energie Electrica, Note de Curs, Galati University Press, 2009.
[13] Murthy D. N. P., Xie M. and Jiang R. (2004). Weibull Models, John Wiley, New York.
[14] Nan Marin Silviu, Capacitatea sistemelor de transport, Editura Universitas Petroşani, 2000.
[15] Nevin Uzgoren, Sermin Elevli, Birol ElevliI, ÖnderUysal,Reliability Analysis of Draglines Mechanical Failures, Eksploatacja I Niezawodnosc NR 4/2010.
[16] NIST, U.S. Commerce Department, NIST/SEMATECH e-Handbook of Statistical Methods, Assessing Product Reliability, 2013.
[17] Pratama Aditya Tirta , Armand Omar Moeis, Farizal, Effort on Reliability and Availability improvement of Excavator Hitachi EX-2500 at Open-Pit Coal Mine Areas by Using Importance Measure, Proceeding, International Seminar on Industrial Engineering an Management, August 2011.
[18] Robert Hall, Analysis of Mobile Equipment Maintenance Data in an Underground Mine, Quenn's University, Ontario 1997.
[19] Sihong Peng and Nick Vayenas, Maintainability Analysis of Underground Mining Equipment, Using Genetic Algorithms: Case Studies with an LHD Vehicle, Hindawi Publishing Corporation, Journal of Mining, Volume 2014, Article ID 528414, 10 pages, http://dx.doi.org/10.1155/2014/528414.
[20] The Journal of the Reliability Analysis Center,, Second Quarter, 2005, https://src.alionscience.com/pdf/2Q2005.pdf.
[21] Titu I. Bajenescu, Fiabilitatea sistemelor tehnice, 2011, ISBN: 973-685-624-0.
[22] Tudor A. ş.a., Durabilitatea şi fiabilitatea transmisiilor mecanice, Editura Tehnica, Bucureşti, 1988.
[23] Universitatea Politenica Bucuresti, Facultatea Inginerie Mecanica si Mecatronica, Fiabilitatea Sistemelor Mecanice, curs, 2007, http://www.omtr.pub.ro/didactic/fsm.
[24] Using the Weibull Distribution: Reliability, Modeling and Inference, First Edition. John I. McCool, 2012, John Willey & Sons, 2012.
[25] William W. Dorner, Quality Digest, Using Microsoft Excel for Weibull Analysis, 1999.