Methods for Study the Reliability of Vehicles Used in Ornamental Rock Quarries

Dascar Secara Camelia Monia, Nan Silviu Marin, Dascar Emil

***Abstract*—**The productivity of an open pit mine relies on a very effective and reliable transportation system. For a marble quarry, it is critical that haul trucks are maintained efficiently to have a high availability. Many authors have studied records and associated statistics in regards to failure data. Normal distribution has been used to describe the failures of the individual machine components of a complex system, but different variables and machine particularities, wear or other constrains, determine a real life data following a dynamic large distribution. The objective of this paper is to present two techniques of estimation based on record statistics for the two-parameter Weibull distribution theory and its parameters (shape β and scale α) and the Exponential Method with the survival time parameters. Finally, a real dataset of the failure data for haul trucks in operation at a marble quarry is used to illustrate by fitting the Weibull and Exponential distributions to the data, calculate the relevant parameters and obtain the fatigue life equation by regression under different failure probabilities. The distribution analysis in terms of reliability and durability shows a trend of increasing failure rate, opening the opportunity for setting a decision plan on reliability centered maintenance planning activities, possible improvements, respect the optimal load/speed, and the need to revise the maintenance data collection process.

***Keywords*—**Exponential distribution, Prevention, Reliability, Weibull distribution.

I. Introduction

RELIABILITY is the probability that parts, components, products and systems will perform the functions for which they were designed without damage under specified 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 [25].

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 [17]. 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. Failure must be precisely defined in practice. For dealings between producers and consumers, it is essential that the definition of a failure be agreed upon in advance to minimize disputes. For many products, failure is catastrophic, and it is clear when failure occurs. For some products, performance slowly degrades, and there is no clear end of life. One can then define that a failure occurs when performance degrades below a specified value [18].

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.

A great deal of research has been done on estimating the parameters of the Weibull distribution using classical methods, a very good summary of this work can be found in McCool [12]. Many authors have studied other distribution methods to better analyze records and associated statistics on different fields, among others are Jula et al.[8], Mann et al.[11], Hoseinie et al.[7], Toader et al.[15], Hall [6].

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 in the statistical treatment of the data will enable sound judgments to be made based on invalid data.

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II. Problem Formulation

Reliability is characterized by four concepts: probability, performance achieved, operating conditions and duration. Operational reliability is 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 [4]. 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.

A. *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, *MTTR*; the 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 [9], 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.

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 [26] [8] is recognized as survival function:

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

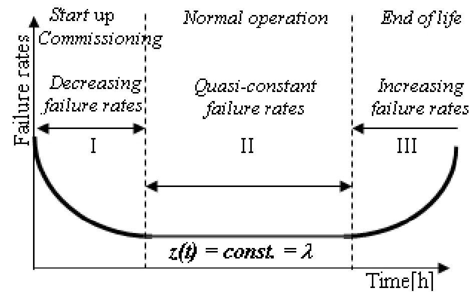

Fig.1 The evolution of failures on the entire life of a product

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 sureley works.

$$\lim R(t) = 0 \tag{4}$$

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:

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

Reliability block diagram (RBD) - A device or system is described as a collection of parts or components. The system operates successfully if all its components operate successfully (do not fail), but it may also operate if a subset of components has failed. RBD is a diagrammatic method for showing how component reliability contributes to the success or failure of a complex system. RBD is also known as a dependence diagram (DD).

B. *Graphic Systems*

Matrix of defects shows the number of failures recorded on each component of the system at equal time intervals. The number of failures shall sum horizontally, for each component during the experiment. The corresponding histogram is built as a matrix, which is Pareto chart of the system. Pareto chart is in the form of a histogram showing the number of defects registered to a time "t" of each of the components of a system.

Pareto chart allows highlighting the component with the lowest reliability in a system. Complex Pareto charts rises in successive steps to highlight simple elements with the highest rate of falls. The goal is to find Pareto analysis of subsystems that affect overall system failure, characterizing the frequency of subsystems failures and ranking system for each subsystem failure.

Pareto Chart is a priority failure analysis showing overall subsystem. Then fault numbers are added together vertically, to the intervals [1]. At the bottom of the matrix it builds a histogram showing the evolution of the number of failure time intervals Δt of the entire system. Since the probability density function:

$$f(t)=\frac{n(\Delta t)}{N_0\cdot\Delta t} \tag{7}$$

N_0 and Δt are constant, the histogram is representing the histogram of *f(t)* but at a different scale.

C. Weibull Distribution

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 is given by the probability [8], [13], [6]:

PDF: $$f(t,\beta,\alpha,\gamma)=\frac{\beta}{\alpha}\left(\frac{t-\gamma}{\alpha}\right)^{\beta-1}e^{-\left(\frac{t-\gamma}{\alpha}\right)^{\beta}} \tag{8}$$

with: $\beta>0,\alpha>0,t\geq0,\gamma\geq0$

The cumulative Weibull distribution function is given by the cumulative distribution, [19], [2], [11]:

CDF: $$F(t)=1-e^{-\left(\frac{t-\gamma}{\alpha}\right)^{\beta}} \tag{9}$$

where: β (beta) is the shape parameter, α(alpha) the scale parameter, γ(gamma) the location parameter.

Formulas and properties [16], [20]:

Reliability: $$R(t)=e^{-\left(\frac{t}{\alpha}\right)^{\beta}} \tag{10}$$

Hazard function: $$h(t)=\frac{\beta}{t}\left(\frac{t}{\alpha}\right)^{\beta-1} \tag{11}$$

Mean Rank: $$\alpha\cdot\Gamma\left(1+\frac{1}{\beta}\right) \tag{12}$$

Median Rank: $$\alpha\cdot(\ln 2)^{\frac{1}{\beta}} \tag{13}$$

Variance: $$\alpha^2\cdot\Gamma\left(1+\frac{2}{\beta}\right)-\left[\alpha\cdot\Gamma\left(1+\frac{1}{\beta}\right)\right]^2 \tag{14}$$

where: Γ (gamma), gamma function with value of Γ(*N*) for the entire *N*.

$$\Gamma(N) = (N-1)! \tag{15}$$

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

$$t=\alpha\cdot(-\ln R(t))^{\frac{1}{\beta}} \tag{16}$$

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:

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

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

$$\ln\left(\frac{1}{1-F(t)}\right)=-\left(\frac{t}{\alpha}\right)^{\beta} \tag{19}$$

$$n\left[\ln\left(\frac{1}{1-F(t)}\right)\right]=\beta\ln t-\beta\ln\alpha \tag{20}$$

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

a) Rank F(tn) estimates in an ascending order - 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 *$F(t_n)$:*

Mean Rank	*n/N+1*	(21)
Median Rank	*(n-0.3)/(n+0.4)*	(22)
Symmetrical CDF	*(n-0.5)/N*	(23)

Having a sample size less than 100, will consider the Median

Table.1 Confidence level [19]

# of defects	Confidence level							
	60%		80%		90%		95%	
	MTBF min	MTBF max	MTBF min	MTBF max	MTBF min	MTBF max	MTBF min	MTBF max
25	0.829	12063	0.764	13267	0.716	14383	0.677	15452
30	0.844	11848	0.783	12915	0.737	13893	0.701	14822

Rank method (Bernard's approximation) equation (22), [28].

b) Estimate *$F(t_n)$* of the n^{th} failure

c) Plot *$F(t_n)$* 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)*:

$$y(t)=\ln\left[\ln\left(\frac{1}{1-F(t)}\right)\right]=-shape\cdot\ln(scale)+shape\cdot\ln(t) \tag{24}$$

$$y = intercept + slope\cdot t \tag{25}$$

y(t) is a linear function of ln*(t)* having *slope=β* and *intercept=–βlnα*, the basis for the linearization of the Weibull CDF (Fig.2). It has been shown that shape factor drops directly out of the regression equation, whilst the scale factor has to be derived from the intercept [3], [12]:

$$scale = exp(-intercept/shape) \tag{26}$$

Weibull 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

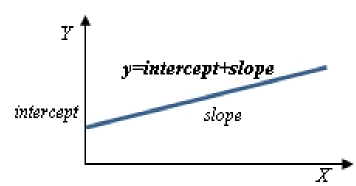

Fig.2 Linearization of the Weibull CDF

estimate of the total MTBF for Weibull distribution [27], [19] is given by:

$$MTBF=\alpha\cdot\Gamma\left(1+\frac{1}{\beta}\right)+\gamma \tag{27}$$

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

$$MTBF = \frac{T}{N} \tag{28}$$

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.

D. *Exponential Method*

1-parameter form of the exponential distribution is commonly used for components or systems exhibiting a constant failure rate. A model for the distribution of its lifespan can be any probability density function (PDF), f(t), defined in time interval from t = 0 to t = infinity. Cumulative distribution function CDF, F(t), is a useful model as it gives the probability that a randomly selected unit will fail during time t, [19] [18].

Exponential Model - The exponential model is widely used for two reasons:

- most systems spend most of their useful life in constant repair portion of the "bathtub curve" graph;
- it is easy to plan tests, estimate MTBF and calculate the confidence intervals.

The key equations for the exponential function are shown below:

PDF: $$f(t,\lambda) = \lambda e^{-\lambda t} \tag{29}$$

CDF: $$F(t) = 1 - e^{-\lambda t} \tag{30}$$

Reliability: $$R(t) = e^{-\lambda t} \tag{31}$$

Failure/Hazard Rate: $$h(t) = \lambda \tag{32}$$

Mean Rank: $$1/\lambda \tag{33}$$

Median Rank: $$\ln 2/\lambda \cong 0.693/\lambda \tag{34}$$

Variance: $$1/\lambda^2 \tag{35}$$

Mean Time To Fail (MTTF) - The failure rate reduces to the constant λ for any time. Another name for the exponential mean is the Mean Time To Fail or MTTF and we have:

$$MTTF = 1/\lambda \tag{36}$$

The cumulative hazard function for the exponential is the integral of the failure rate or H(t):

$$H(t) = \lambda t \tag{37}$$

Exponential Mean Time Between Failures MTBF, [9] [23]:

$$MTBF = T_{WORKING\_TIME} / N_{FAILURES} \tag{38}$$

Relation between MTBF (Mean Time Between Failures), MTTF (Mean Time to Failures) and MTTR (System Mean Time to Repair):

$$MTBF = MTTF + MTTR \tag{39}$$

$$MTTR = T_{DOWN\_TIME} / N_{FAILURES} \tag{40}$$

The rate of repairing operation, μ: $\mu = 1/MTTR$ (41)

Confidence level selected is calculated with a simple equation:

$$100(1 - \alpha) \tag{42}$$

The values calculated with equation (42) for various confidence levels selected: *95% => α=0.05; 90% => α=0.1; 80% => α=0.2; 60% => α=0.4;*

III. THE WORK METODOLOGY

In this subsection, we provide a failure data set in the form of Time between Failures (TBFs) and Time To Repair (TTRs), which is assumed to be distributed with Weibull law (see [16], pp. 83, 100). The data sets (table 2) were recorded in a time period of 1 year for a number of 8 haul trucks in use at an open pit, marble quarry [7].

Reliability block diagram (Fig.3) – blocks are arranged in series configuration with each critical subsystem [24].

Reliability model (Fig.4) – it is important that data is collected with consistency using a field data collection process [29].

A. *Pareto Analysis*

The frequency of failures of each component or subsystem can be determined using the Pareto principle, or 80-20 rule [3], which states that for many events, 80 % of the effect was caused by 20% of the cause.

#	TTR	CTTR	Cause	TBF	CTBF
1	14	14	Engine	430	430
2	31	45	Gear box	770	1200
3	9	54	Transmission	1690	2890
4	8	62	Others-exhaust	488	3378
5	32	94	Engine	800	4178
6	13	107	Brakes	1784	5962
7	12	119	Suspension	456	6418
8	16	135	Gear box	886	7304
9	7	142	Transmission	1328	8632
10	9	151	Transmission	1460	10092
11	11	162	Brakes	16	10108
12	8	170	Steering	920	11028
13	4	174	Others-frame	218	11246
14	8	182	Transmission	77	11323
15	11	193	Brakes	680	12003
16	41	234	Engine	1650	13653
17	26	260	Gear box	501	14154
18	13	273	Brakes	1150	15304
19	14	287	Brakes	1000	16304
20	10	297	Suspension	88	16392
21	7	304	Steering	156	16548
22	7	311	Transmission	800	17348
23	14	325	Brakes	420	17768
24	12	337	Suspension	60	17828
25	10	347	Suspension	340	18168
26	8	355	Others-frame	196	18364

Table 2 Data collected

Pareto Analysis shows the number of failures recorded for each component of the system at equal time intervals. The number of failures is summed horizontally for each component during the experiment. On the right side of the matrix the

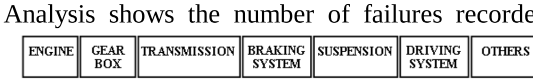

Fig.3 Reliability block [14]

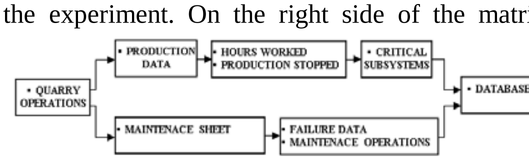

Fig.4 Data collection process

corresponding histogram is built, which is the Pareto chart of the system.

Then, fault numbers are added together vertically for each time interval. At the bottom of the matrix is built a histogram showing the evolution of the number of failures in time intervals Δt for the entire system.

Since the probability density function $f(t)=n(\Delta t)/N_0\Delta t$ and $N0$, Δt are constant, it represents the histogram of f(t) but at a different scale (Fig.5):

Trend analysis (Fig.6) of the system does not show any trend, the method proves that the system deteriorates [27].

System reliability is an indicator of the condition of the equipment's overall performance; reliability analysis was done using each subsystem failure then chart is analyzed to select the most important components affecting the system.

B. Application methods for calculating reliability – Weibull analysis

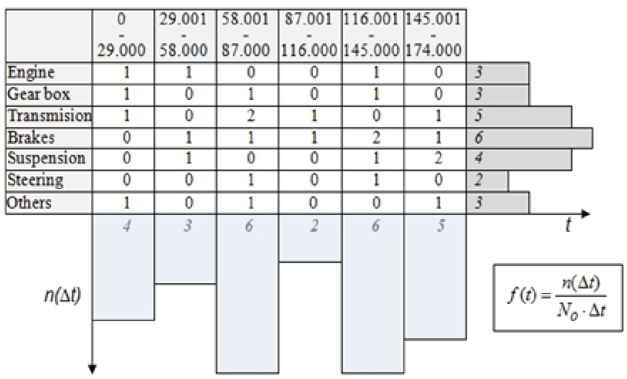

Fig.5 Reliability block [14]

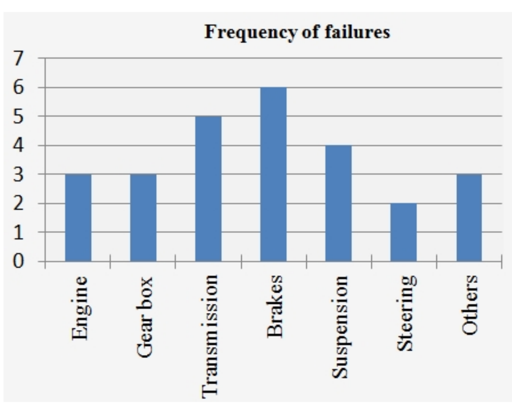

Fig.6 Pareto chart on the absolute incidence of faults

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 precise performance analysis using a graphical plot of the failure data.

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, alpha ranks obtained with the method of calculating Median Ranks, formula (22), where n=1,2, ... 26; N=26 (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, using Excel add-in Analysis Tool Pack we obtained estimated parameters which allow inferences on TBF values.

Estimation of Weibull parameters - Weibull cumulative distribution function can be transformed so that it appears as a straight line. Using Excel Data Analysis [5], with ToolPack Analysis kit, we generated a new set of data.

Beta (or Shape Parameter) = CoefTBF = 1.42

Alpha(Ch. Life) = EXP(-CoefIntercept/CoefTBF) = 13,126

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-axis, ln(TBF), and Y-axis, ln(ln(1/(1-n))), has been further adjusted to create the linear distribution (Fig.7): Linear -> ln(ln(1/(1-n))) Survival probability and reliability were determined by selecting 20 intervals of 1,000 hours (X) together with MO Excel formula:

$$WEIBULL(X,\alpha,\beta,TRUE) \quad (29)$$

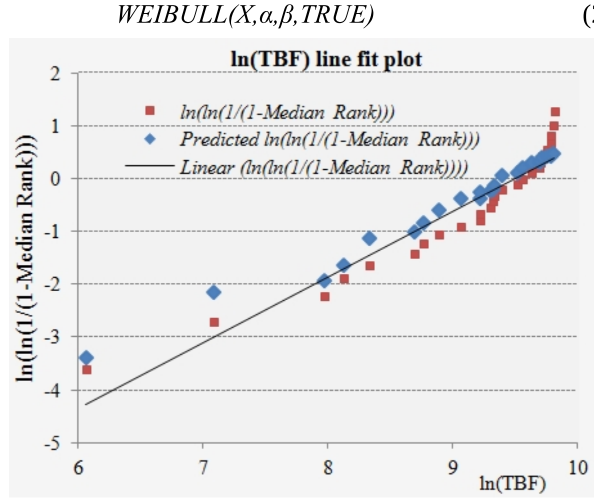

Fig.7 Predicted line

TBF for a certain reliability level - Sometimes we need time before failure for a certain reliability level, given through the requirements (Table 3), using formula (16).

Reliability	TBF
0.01	38,432
0.10	23,601
0.50	10,143
0.90	2,696
0.99	516

Table 3 TBF for certain Reliability

Generate the survival chart - Using data from Table 5, the reliability chart calculated is shown on Fig.8, with Y-axis Survival Probability, and X-axis Time Before Failure:

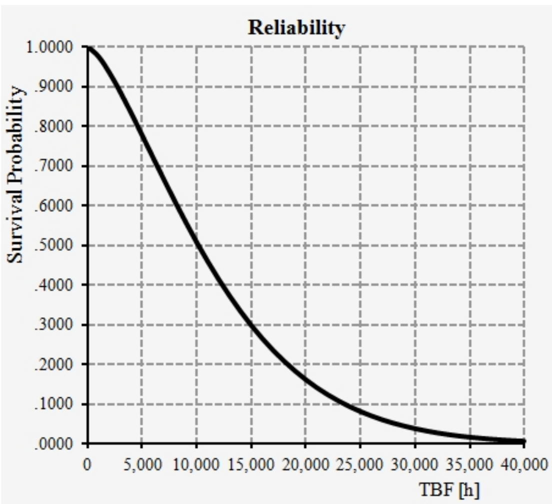

Fig.8 Survival graph, $\beta=1.42$

C. Application methods for calculating reliability – Exponential Model

Calculate Mean Time Before Failure for one vehicle - using relation (38): $MTBF=88.28$ *[h]*. For a confidence level of 90%, the most widely industry used, which corresponds to a coefficient α=0.1, the values of *MTBF* min and max are:

- minimum value, for a number of 26 defects and a correction coefficient 0.830992 (tabel 1): $MTBF_{min}=63.58$ *[h]*
- maximum value, for a number of 26 defects and a correction coefficient 1.210616 (tabel 1): $MTBF_{max}=126.1$ *[h]*

Calculate the failure rate, λ – For the same confidence level of 90% the extreme values of the failure rate, $\lambda=1/MTBF$: $\lambda_{max}=0.01572$*[defects/h]*; $\lambda_{min}=0.00793$*[defects/h]*.
Our calculations show that, with a probability of 90%, the estimated mean time is found inside operating ranges 63-126 hours, and the failure rate inside interval 0.01572-0.00793 defects/hour.

Calculate the probability density function of faults occurrence - For the exponential distribution law, on the basis of relation (29) we determined the range of values that expresses the variation in density of the probability of failure occurrence with respect to time, *f1(t)* and *f2(t)*. These values are calculated for the two margin values of the failure rate: $f(t,\lambda)=\lambda_{max}\exp(-\lambda_{max}t)$, $f(t,\lambda)=\lambda_{min}\exp(-\lambda_{min}t)$, Fig.9.

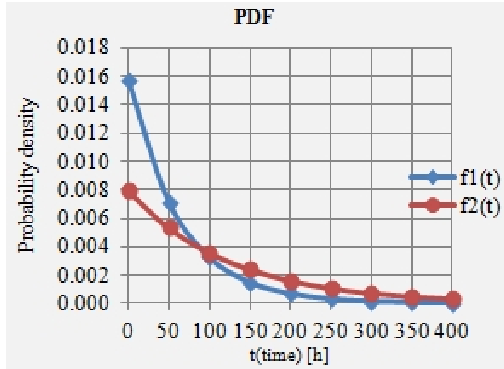

Fig.9 Probability density function

Calculate cumulative distribution F(t) - using the equations $F(t)=1-\exp(-\lambda_{max}t)$ and $F(t)=1-\exp(-\lambda_{min}t)$, Fig.10.

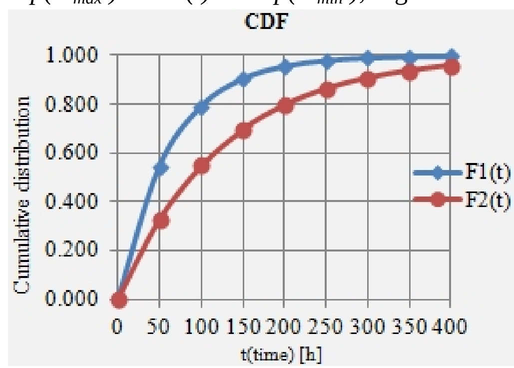

Fig.10 Cumulative distribution function

Calculate survival or reliability function R(t) - using the equations $R(t)=\exp(-\lambda_{max}t)$ and $R(t)=\exp(-\lambda_{min}t)$, Fig.11.

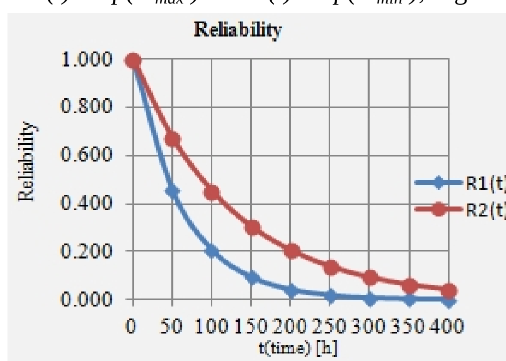

Fig.11 Reliability curve

From this chart we concluded that the value of reliability of the fleet is large, e.g. for a running time of 50 hours, the probability of not having defects (reliability) is between 46 and 68%, this time being a time of actual work, not a calendaristic time. We disregarded the times spent to fix the defects of other equipments in the system, the times related to the technological disruptions, organizational deficiencies. Also, we have not considered current repairs and maintenance related times.

Calculate the average repair time (MTTR) and adjusting the processing rate (μ) - The total downtime for all trucks as a result of the 26 faults that have occurred in the period under review, is 355 hours. Using equations (40) and (41), $MTTR=13.65$ *[h]*; $\mu=0.073$ *[rep/h]*. The calculated values of the mean time to repair the subassemblies, relatively high, is explained by the difficulty of corrective maintenance work, given the large masses and gauges to be handled.

IV. Conclusion

This study is restrained to a relative small number of equipments investigated (8 haul trucks). Performance of a quarry not only depends upon production equipment but very much affected by the availability and utilization of service equipment. The accuracy of the data collected dependins 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).

Weibull shape parameter β indicates if the failure rate is increasing, constant or decreasing [13], [10]. In our study we found $\beta > 1.0$ 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 2,696 hours. To increase the reliability it is absolutely necessary to address, using the analysis performed with Pareto charts, 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 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. An integrated part of the maintenance program is to remove old components, worn or those that have reached the end of their useful life, and replace them with components that meet the standards of durability and reliability. A key element of success is monitoring program, the collection of routines that facilitate early detection of changes in the functionality of the equipment and systems.

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