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CONSIDERATIONS ON THE RELIABILITY OF MACHINES AND EQUIPMENT USED IN THE OPEN PIT MINES

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Abstract: This paper presents a method intended to determine the main reliability indices for the machines and equipment employed in lignite quarries. The mining equipment used at Jilt quarry was monitored for a certain period and based on the data gained during that period we have drawn up Pareto charts that highlight the subassemblies of those installations which have to be considered with the view to increasing the main indices which allow to calculate the reliability of rotor excavators.

Keywords: reliability, reliability indices, Pareto chart, exponential distribution function of deterioration, rotor excavator, wastes dumping machines

1. INTRODUCTION

For a certain period of time, some aspects suck as reliability, maintenance, accessibility and capability have been dealt with in a separate manner, in different chapters of engineering sciences. A unitary approach which considers all these factors, in accordance with the working conditions of the technical systems has been accomplished in an interdisciplinary chapter of the technical sciences called safety theory in operation.

The concept of safety in operation is a new synthesis - type concept which allows a full analysis of the qualitative and of the quantitative parameters which characterize the behavior of an engineering system all through its period of operation.

The safety in operation of a machine or engineering system represent the extent to which these machines shall fulfill their tasks and depends on their

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accessibility, reliability, capability and maintainability.

The occurrence through which a machine ceases to fulfill the intended function is called fault or failure.

The operating cycle of the engineering systems involves acceleration, deceleration, reversal and stop; consequently, the component parts are being subjected to variable charges which may give birth to accidental faults due to some design, production or operating errors and to wear and tear of the equipment.

Generally speaking, the component parts of the engineering systems are subject to variable charges during their operation period and most of them display a random character which makes even difficult their reasonable sizing.

It might seem that their over sizing shall diminish the risk of deterioration because of overcharges, but this aspect shall increase both costs ant the weight of the component parts; a sizing following the mean values of the charges shall lead to an increment of the deterioration risk.

2. HOW TO DEFINE THE RELIABILITY INDICES

If considering reliability from a probabilistic point of view, one may say that nobody can determine for sure the moment when the deterioration occurs, so this very moment shall be consider as a probable parameter which shall be further connected to a safety range.

The concept of reliability encloses a statistical parameter, beside the probabilistic one. This aspect can be explained by the fact that the structure of reliability may be determined based on the data gained after monitoring the product in operation, when one gets a certain amount of information on faults which have been determined for a statistical population (sample).

As no physical, chemical or other processes which lead to the cessation of the said function of a product cannot be identified and used so that the moment when a certain fault occurs be established with some certainly, one shall use a statistical evaluation of the parameters that have been previously monitored.

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.

2.1. Reliability function

From a quantitative point of view, reliability has been defined as a probability for a product (technical system) to fulfill its intended function for a per-determined period of time and in certain given conditions.

According to this definition, the good operating probability $p(t)$, i.e. reliability

$R(t)$, shall be expressed by the following equation:

$$p(t) = R(t) = P(t > t_i), \tag{1}$$

where: t - random time variable (period of operation); t_i - upper limit stated for a good operation of the product.

Experimentally speaking with a view to getting an analytical form of the function, this means a monitoring of the behavior all though a certain period of time of a statistical population made of N_0 new identical products which operate in the same working conditions and which have been made with the help of the same technology, all meeting the same requirements. By considering that at $t = 0$, all the N_0 new products are capable to operate properly, then at t_i, located inside somewhere the interval $[t,\, t + \Delta t]$ only N products operate properly. Consequently, all through the period of time Δt, $\Delta N = N_0 - N$ shall be considered as those products with faults.

The rate of properly operating products, at the moment t_i, i.e. reliability $\hat{R}(t)$ is given by the ratio:

$$\hat{R}(t) = \frac{N}{N_0}. \tag{2}$$

The analytical form of the empiric reliability function shall be expressed as:

$$\hat{R}(t_i) = \frac{N_{t_i}}{N_0}, \tag{3}$$

where N_{t_i} - number of products (elements) in operation at the moment t_i.

Equation (3) shows the relative weight of items in operation, i.e. the weight of the products that haven't gone wrong until the end of the interval (i) which shall go wrong in the intervals to come.

2.2. Non-operation reliability function

This index shows the probability of deterioration for a product which should operate properly within a pre-determined t_i period of time, and in certain given conditions. It is expressed by the following equation:

$$F(t) = P(t \le t_i). \tag{4}$$

Between the reliability and the non-operation reliability function there is the following equation:

$$F(t) = 1 - R(t). \tag{5}$$

The analytical form of the empiric non-operation reliability function shall be expressed as:

$$\hat{F}(t_i) = \frac{N_0 - N_{t_i}}{N_0}. \tag{6}$$

2.3. Probable density of deteriorations

By derivate the non-operation reliability function in relation to time, one can get a new function called probable density of deteriorations, *f*(*t*) which is the frequency function or the density of distribution. It shows the relative incidence of deteriorations within the time interval *dt*:

$$f(t) = \frac{dF(t)}{dt} = -\frac{dR(t)}{dt}. \tag{7}$$

By using the fine increments and considering the equation (6), the equation which expresses the probability concentration of deteriorations is:

$$\hat{f}(t) = \frac{d\hat{F}(t)}{dt} = \frac{\dfrac{N_0 - N}{N_0} - \dfrac{N_0 - (N + \Delta N)}{N_0}}{\Delta t} = \frac{\Delta N}{N_0}\frac{1}{\Delta t}, \tag{8}$$

The analytical form of the empiric function for the idea of probable density is:

$$\hat{f}(t_i) = \frac{\Delta N_i}{N_0 \cdot \Delta t_i}, \tag{9}$$

where, $\Delta N_i = N_{t_{i-1}} - N_{t_i}$ and N_{t_i} and $N_{t_{i-1}}$ represent the number of elements in operation at the moments t_i and t_{i-1} and Δt_i is the length of the interval that has been considered.

Intensity or rate of deterioration

The expression *z*(*t*) *dt* represents the probability that an equipment which in good state at the moment *t* goes wrong within the interval (*t*, *t* + *dt*). By definition, *z*(*t*) *dt* is the density of the conditioned probability. The condition is that a good device at the moment *t* shall be defective at the moment *t* + *dt*.

Intensity or rate of deterioration shall be determined with the help of the following equation:

$$z(t)=\frac{f(t)}{R(t)}=\frac{-\dfrac{dR(t)}{dt}}{R(t)}. \tag{10}$$

If solving the differential equation with the consideration of the limit condition, at final one can get the general equation of reliability:

$$R(t)=e^{-\int_0^t z(\tau)d\tau}. \tag{11}$$

The limit condition means that at the moment $t = 0$, i.e. at the very moment when the reliability study is being started, all the products are capable of operation, which means that $R(0) = 1$.

The experimental determination of the rate of deterioration for a time interval Δt_i, in relation to the absolute incidence of failures within the time interval considered shall be made with the help of the following equation:

$$\hat{z}(t_i)=\frac{\hat{f}(t_i)}{\hat{R}(t_i)}=\frac{\Delta N_i}{N_{t_i}\cdot\Delta t_i}. \tag{12}$$

2.5. Mean time of good operation

This index shows the average operating period until the moment of deterioration, for the case of those components which cannot be repaired or the period elapsed between two consecutive failures for the components which can be repaired.

The value of this parameter is given by the mean times of operation that takes the following form for a continuous distribution at limit:

$$m=MTBF=\int_0^\infty R(t)dt=\int_0^\infty [1-F(t)]dt=\int_0^\infty t\,f(t)dt=\int_0^\infty e^{-\int_0^t z(\tau)d\tau}dt, \tag{13}$$

where *MTBF* mean time of good operation.

For the case of a batch made of N_0 products, each of these products displays a certain period of operation, t_{f_i}. In this situation, the mean period of good operation shall be determined based on the discrete values, as an arithmetic average value of all the periods of good operation $t_{f_1}, t_{f_2},..., t_{f_{N0}}$:

$$M\hat{T}BF=\frac{\sum_{i=1}^{N_0} t_{f_i}}{N_0}. \tag{14}$$

The mean time of good operation can also be calculated as a weighted average value by taking into consideration the number of failures occurred within the interval (*i*).

$$\hat{MTBF} = \frac{\sum_{i=1}^{N_0} t_{f_i} \cdot \Delta N_i}{\sum_{i=1}^{N_0} \Delta N_i} = \frac{\sum_{i=1}^{N_0} t_{f_i} \cdot \Delta N_i}{N_0}. \qquad (15)$$

2.6. Mean time for repairing operations

The average period assigned for repairing operations, *MTR*, gives information on the number of hours spent for repairing purposes. Most of the times it shall be expressed as *hours*/*repairing* session.

This period shall be calculated with the help of the following equation:

$$\hat{MTR} = \frac{\sum_{i=1}^{n} t_i}{n} \qquad (16)$$

where: t_i - period of time necessary to accomplish the operation *i* of maintenance; *n* - total number of operations of maintenance.

2.7. Rate of repairing operations

This index shows how often a product is being repaired, i.e. the density of conditioned probability for finishing a repairing operation within a definite period of time (t, $t + \Delta t$), supposing that the product was being repaired within the period of time (0, t). It is usually expressed as repairing *session*/*hour*.

It is defined as the inverse value of the mean time necessary for repairing purposes:

$$\hat{\mu} = \frac{1}{\hat{MTR}}. \qquad (17)$$

3. PARETO CHARTS USED TO ANALYZE THE OPERATION OF THE EQUIPMENT FOUND IN QUARRIES

3.1. Generals

It is very important that any analysis on the reliability of equipment underlines the occurrence of certain types of failures come up during operating period. In this manner one can easily determine which items shall have to be improved, which failures occur mostly on the same product and even the existing connections between different types of failures.

As a rule Pareto charts are being used to show all these information. So, a Pareto chart is a graphic image where the type of the failure occurred on the product, in a decreasing sequence of the weight held of the total failures is put on the abscises axis and the weight of failures expressed as absolute or relative rate (in percentage) is put on the ordinate axis.

Pareto charts show that 20% of causes can explain 80% of failures and that 80% of failures emerge from 20% of causes. These figures shall focus attention on these particular causes and neglect, for the moment being, those causes which are less important.

Pareto charts are useful tools that allow establishing efficiently the types of problems occurred. These charts allow a classification of failures depending on their importance. The greatest benefit of these charts is that you can easily see which failures are the most important ones compared to the situation when you use a table or a data sheet.

Pareto charts give a quantity or percentage type distribution of failures occurred during the manufacturing or operating stage for a certain length of time, in a decreasing sequence of the weight of occurrence.

Such a chart allows an analysis of incidence of all types of failures and, consequently it gives the highest priority for the most serious problems. Subsequently there shall be determined the measures necessary to settle the problems and to eliminate failures, depending on their importance, weight and rate of incidence. This is the reason why one can say that the production of Pareto charts represent the first stage in the process of improvement.

3.2. Analyzing the operation of rotor excavators

Considering the aspects said above, there has been produced a Pareto charts which underlines the rate of failures occurred on EsRc-1400 excavators at Jilt Mining Unit. All the 13 excavators in operation were monitored between 20.06.2005 and 02.05.2006.

The types, the incidence and the total number of failures occurred in this period have all been summed up in table 1.

Table 1. **Data summation sheet for the production of Pareto chart**

Code	Subassemblies with faults	Incidence of faults	Total number of faults
A	Driving system of the bucket wheel	~~////~~ ~~////~~ ~~////~~	15
B	Conveyance system	~~////~~ ~~////~~ ///	13
C	BRS	~~////~~ ~~////~~ ~~////~~	15
D	Belts system	~~////~~	5
E	Other subassemblies	////	4
	Total		52

Table 2 shows the faulty subassemblies, the total number of faults, the weight of these faults for each subassembly; Figures 1 and 2 shows Pareto charts in relation to the absolute and cumulated incidence of faults.

Table 2. **Data necessary for the production of Pareto charts**

Code	**Subassemblies with faults**	**No of faults**	**Total cumulated faults**	**Percentage of total**	**Percentage of the cumulated faults**
A	Driving system of the bucket wheel	15	15	28,85	28,85
C	BRS	15	30	28,85	57,69
B	Conveyance system	13	43	25,00	82,69
D	Belts system	5	48	9,62	92,31
E	Other subassemblies	4	52	7,69	100
	Total	52	-	100	-

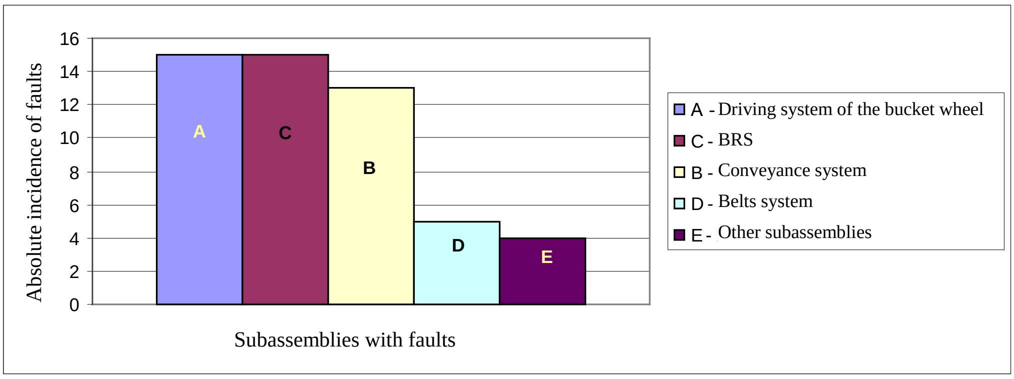

Fig.1. Pareto chart depending on the absolute incidence of faults for rotor excavators

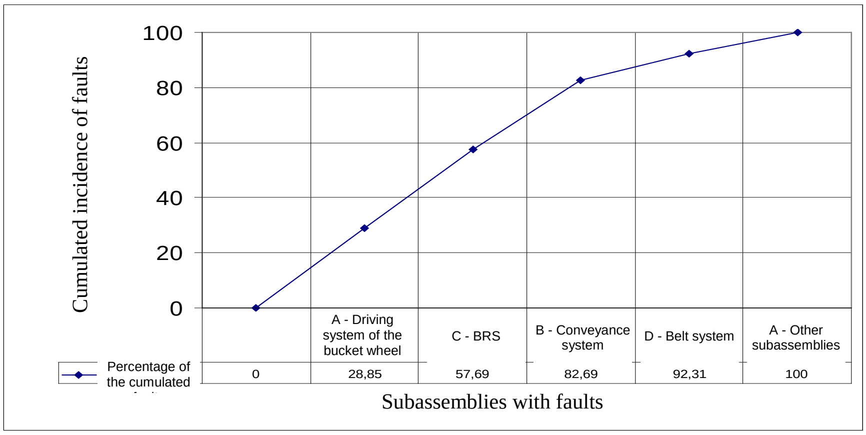

Fig. 2. Pareto chart depending on the cumulated incidence of faults for rotor excavators

So, according to the above charts, it results that 82.61% of faults occur due to the deterioration of three subassemblies: the driving system of the bucket wheel (28.85%), the BRS (28.85%) and the conveyance system (25%).

Consequently, for increasing the utilization rate of these excavators, the three said above subassemblies shall have to be updated.

3.3. Analyzing the operation of waste dumping machines

Following the same methodology, there has been produced Pareto chart which underlines the incidence of failures occurred, on the waste dumping machines and on the related circuits at Jilt Mining Unit. All the 6 waste dumping machines together with the related circuits in operation were monitored between 20.06.2005 and 02.05.2006.

The types of failures, their incidence together with the total number of failures occurred in this period have been summed up in table 3.

Table 3. **Data summation sheet for the production of Pareto diagram**

Code	Subassemblies with faults	Incidence of faults	Total number of faults
A	Conveying drum	~~////~~ ////	9
B	Driving system of conveyors	//	2
C	Driving system of the conveyor belt	//	2
D	Conveying system	~~////~~ /	6
	Total		19

Table 4 shows the faulty subassemblies, the total number of faults as well the weight of these faults for each subassembly. Fig. 3 and 4 show Pareto charts in relation to the absolute and cumulated incidence of faults.

Table 4. **Data necessary for the production of Pareto charts**

Code	Subassemblies with faults	No of faults	Total cumulated faults	Percentage of total	Percentage of the cumulated faults
A	Conveying drum	9	9	47,37	47,37
D	Conveying system	6	15	31,58	78,95
B	Driving system of conveyors	2	17	10,53	89,48
C	Driving system of the conveyor belt	2	19	10,53	100
	Total	19	-	100	-

So, according to the above charts, it result that 78.95% of faults occur due to the deterioration conveyors (47.37%) and the conveying system (31.58%). Consequently, with the view to increasing the utilization rate of the waste dumping machines, first of all it is necessary to make some changes on the construction of these subassemblies.

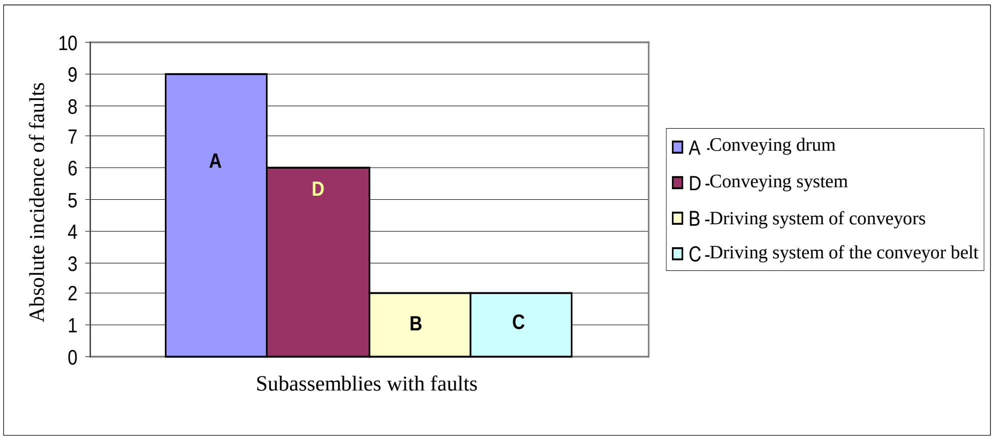

Fig. 3. Pareto chart on the absolute incidence of faults for waste dumping machines

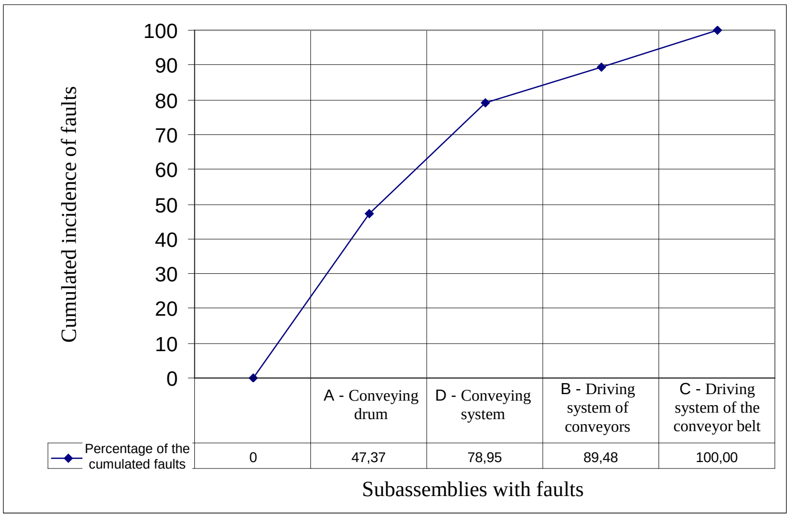

Fig. 4. Pareto diagram on the cumulated incidence of faults for waste dumping machines

4. RELIABILITY OF THE MINING SYSTEM

4.1. Considerations on the reliability of machines and equipments used in quarries

In spite of the fact that there are some studies regarding the reliability of the equipment used in the Romanian quarries, they are not enough and the information they cover are quite poor. And this is because:

- there are a lot of types of machines and equipment which operate in different conditions. So, it is quite difficult to ascertain the operating reliability of the equipment used in quarries because a lot of information are needed which have to be further processed;

- there are no information systems or system used to record or to keep up the track of failures occurred on each type of equipment, especially of the operating periods until the first failure occurs or of the periods elapsed between two consecutive failures. Additionally, some problems have come up in the attempt to gather data on reliability, maintenance and maintainability because the specific aspects are not so well-known;
- there are a lot of reasons why the equipment goes wrong, including the manner they are being used, this aspect makes even harder to determine the distribution type of faults;
- there is no bibliography on the reliability of equipment used in lignite quarries so certain methods and final results cannot be checked out or compared. So, there is being used information from other domains with a tradition in this spirit, with a solid knowledge but with the consideration of the particular aspects displayed by the equipment used in quarries.

The studies on reliability intend to establish the reliability indices of certain machines, equipment or installations used in lignite quarries, the weight of different types of failures, as well the indices regarding maintainability and accessibility. So, if those parts of a machine which display a high rate of failures and low reliability indices are being known, then it are possible to take technical and organization measures with the view to increasing reliability; these measures also refer to those who operate the machines and equipment used in quarries.

It is intended to determine the real laws governing the period for increasing of reliability then the rate of deterioration chart $\lambda(t)$ or the density chart on the probability of failures $f(t)$ shall be drawn up based on the data gained during the operating process.

If it is necessary to determine only the reliability of the element or of the system, the empirical distribution is being approximated with the help of theoretical distribution.

Theoretically, as distributions of the operating period with no failures, there can be used any continuous distribution (exponential, normal, Weibull, Raleyagh, Gamma, etc) from the theory of probabilities.

Exponential distribution plays an important part in the engineering of reliability. For most of the systems (especially the electric and digital systems), the distribution of failures all through their life is exponential.

According to Drenick’s theorem on the dynamics of deterioration, even if the separate components of a system follow another type of distribution and not the exponential one for a long period of operation, the consecutive times specific to the systems that can be repaired follow the said above distribution. Additionally, with the help of some simple conversions, a Weibull distribution with two or three parameters can be expressed as exponential distributions. Moreover it is widely recognized the fact that any distribution can be expressed as a combination of exponential distributions.

One of the parameters of the exponential distribution is the threshold value which is used to show the period of time when no faults shall occur. For most of the applications this parameter shall be zero. Consequently, the exponential distribution is being defined by one parameter called the intensity or the rate of deterioration, noted with λ (in relation to the periods which define failures).

The inverse of this parameter is equal to the average value of its distribution called mean time for good operation, noted with *MTBF*.

The exponential pattern is being used mostly for expressing the reliability parameters because:

- the largest part of the operating period for most of the system situates within the period when the rate of deteriorations is relatively constant, i.e. that length of curve which is almost horizontal, called the basic period and which is representative for the technical systems.
- for long operating periods (especially for the case of complex systems such as rotor excavators used in the lignite quarries, belt roller conveyors or waste dumping machines), the consecutive times specific to the occurrence of failures on the systems that can be repaired follow the exponential distribution.
- it is easier to perform tests for this type of distribution; also, it is easier to estimate the mean time of good operation, the rate of failures as well the confidence intervals of the estimated parameters.

The time elapsed until the occurrence of the first failure of the system is called the mean time to first failure *MTTF* (or *MTPPD*).

The best estimation of *MTBF* is the "total time" divided by the "total of failure":

$$M\hat{T}BF = \frac{\text{total working time of the system (systems)}}{\text{total number of failures}}, \text{ hours} \tag{18}$$

This estimate is the maximum probabilistic estimate both for incomplete or complete data with reference to both systems (which can be repaired and which cannot be repaired). Some papers use θ instead of $M\hat{T}BF$.

The value of the parameter *MTBF* estimated by the above said methodology shall have to adjust so as to get a value as near as possible to real life, for a definite confidence interval. This adjustment shall be made with the method of factors of the confidence interval. The use of factors of the confidence factors involves the use of the following stages as well of the information covered by the tables shown below.

1. The value of *MTBF* is being estimated by the standard procedure, i.e. the ratio between the total number of hours of operation and the total number of faults.
2. Then, confidence level is being selected which is expressed by the general equation 100 × (1 - α). Table 5 includes the values of α for different values taken by the confidence level.

Table 5. **Relations between the confidence level and α coefficient**

Nivelul de încredere, %	95	90	80	60
Valorile coeficientului α	0,05	0,10	0,20	0,40

3. Table 6 includes the upper and the lower limit values of the factors which limit the value range for *MTBF* for the selected confidence level and for a known number of faults.

Table 6. **Limitation factors of the value range for *MTBF* for different confidence level**

Number of faults, *r*	**Confidence level**							
	60%		80%		90%		95%	
	Min *MTBF*	Max *MTBF*	Min *MTBF*	Max *MTBF*	Min *MTBF*	Max *MTBF*	Min *MTBF*	Max *MTBF*
0	0,6213	-	0,4343	-	0,3338	-	0,2711	-
1	0,3340	4,4814	0,2571	9,4912	0,2108	19,4958	0,1795	39,4978
2	0,4674	2,4260	0,3758	3,7607	0,3177	5,6281	0,2768	8,2573
3	0,5440	1,9543	0,4490	2,7222	0,3869	3,6689	0,3422	4,8491
4	0,5952	1,7416	0,5004	2,2926	0,4370	2,9276	0,3906	3,6702
5	0,6324	1,6184	0,5391	2,0554	0,4756	2,5379	0,4285	3,0798
6	0,6611	1,5370	0,5697	1,9036	0,5067	2,2962	0,4594	2,7249
7	0,6841	1,4788	0,5947	1,7974	0,5324	2,1307	0,4853	2,4872
8	0,7030	1,4347	0,6156	1,7182	0,5542	2,0096	0,5075	2,3163
9	0,7189	1,4000	0,6335	1,6567	0,5731	1,9168	0,5268	2,1869
10	0,7326	1,3719	0,6491	1,6074	0,5895	1,8432	0,5438	2,0853
11	0,7444	1,3485	0,6627	1,5668	0,6041	1,7831	0,5589	2,0032
12	0,7548	1,3288	0,6749	1,5327	0,6172	1,7330	0,5725	1,9353
13	0,7641	1,3118	0,6857	1,5036	0,6290	1,6906	0,5848	1,8781
14	0,7724	1,2970	0,6955	1,4784	0,6397	1,6541	0,5960	1,8291
15	0,7799	1,2840	0,7045	1,4564	0,6494	1,6223	0,6063	1,7867
20	0,8088	1,2367	0,7395	1,3769	0,6882	1,5089	0,6475	1,6371
25	0,8288	1,2063	0,7643	1,3267	0,7160	1,4383	0,6774	1,5452
30	0,8436	1,1848	0,7830	1,2915	0,7373	1,3893	0,7005	1,4822
35	0,8552	1,1687	0,7978	1,2652	0,7542	1,3529	0,7190	1,4357
40	0,8645	1,1560	0,8099	1,2446	0,7682	1,3247	0,7344	1,3997
45	0,8722	1,1456	0,8200	1,2280	0,7800	1,3020	0,7473	1,3710
50	0,8788	1,1371	0,8286	1,2142	0,7901	1,2832	0,7585	1,3473
75	0,9012	1,1090	0,8585	1,1694	0,8252	1,2226	0,7978	1,2714
100	0,9145	1,0929	0,8766	1,1439	0,8469	1,1885	0,8222	1,2290
500	0,9614	1,0401	0,9436	1,0603	0,9287	1,0781	0,9161	1,093

4. The estimated value for *MTBF* is being multiplied with the two factors (the upper and the lower factor); consequently, we get $MTBF_{\text{minimum}}$ and $MTBF_{\text{maximum}}$.
5. Whether $r = 0$ (the number of faults is equal to zero) the estimated value is being multiplied with the minimum factor that correspond to the line 0; we

get the lower limit value for *MTBF* that corresponds to $100\times\left(1-\frac{\alpha}{2}\right)\%$.

When $r = 0$ there is no upper limit value for *MTBF*.

6. The values for $MTBF_{\text{minimum}}$ and $MTBF_{\text{maximum}}$ are being used to get the value of *MTBF* and the intensity of deterioration, λ, for a confidence range $100 \times (1 - \alpha)$ %, with $r > 0$.
7. $MTBF_{\text{minimum}}$ is being used as a minimum limit value for a confidence level of $100\times\left(1-\frac{\alpha}{2}\right)\%$.
8. $MTBF_{\text{maximum}}$ is being used as a maximum limit value for a confidence level of $100\times\left(1-\frac{\alpha}{2}\right)\%$.
9. The values of $\left(\frac{1}{MTBF_{\text{minimum}}}, \frac{1}{MTBF_{\text{maximum}}}\right)$ are being used to get the intensity of deterioration λ, for a confidence range $100 \times (1 - \alpha)$ %
10. $\frac{1}{MTBF_{\text{minimum}}}$ is being used as a lower limit value for the intensity of deterioration, λ, for a confidence level of $100\times\left(1-\frac{\alpha}{2}\right)\%$.
11. $\frac{1}{MTBF_{\text{maximum}}}$ is being used as an upper limit value for the intensity of deterioration, λ, for a confidence level of $100\times\left(1-\frac{\alpha}{2}\right)\%$.

4.2. How to get the reliability indices of the rotor excavators

The 13 excavators in operation at Jilt Mining Unit were under direct surveillance between 20.06.2005 and 02.05.2006 and registered a total of 36536 hours of operation. The total number of failures within this period was of 52.

How to get the mean time of good operation, MTBF

According to the equation (18) the mean time of good operation estimated for the rotor excavators is:

$$M\hat{T}BF = \frac{36536}{13\times 52} = 54{,}05 \text{ h}ours.$$

For a confidence level of 90% (the value normally used in engineering) and to which we have a coefficient α = 0.10%, the maximum and minimum values of *MTBF* are the following ones:

- the minimum value $MTBF_{\text{minimum}}$ for 52 failures and a coefficient of correction of 0.7929 (according Table 6) is:

$$MTBF_{\min imum} = 54{,}05 \times 0{,}7929 = 42{,}86 \text{ h}ours$$

- the maximum value $MTBF_{\text{maximum}}$ or 52 failures and a coefficient of correction of 1.288 (according Table 6) is:

$$MTBF_{\max imum} = 54{,}05 \times 1{,}288 = 69{,}62 \text{ h}ours$$

How to get the intensity of failure, λ

For the same confidence limit (90%), the maximum and the minimum values of the intensity of failure λ are the following ones:

- the maximum value, λ_{maximum}:

$$\lambda_{\max imum} = \frac{1}{MTBF_{\min imum}} = \frac{1}{42{,}86} = 0{,}0233 \frac{\text{failures}}{\text{hour}}$$

- the minimum value, λ_{minimum}:

$$\lambda_{\min imum} = \frac{1}{MTBF_{\max imum}} = \frac{1}{69{,}62} = 0{,}0143 \frac{\text{failures}}{\text{hour}}$$

The mean value of the intensity of deterioration is:

$$\lambda_{\text{mean}} = \frac{\lambda_{\text{minimum}} + \lambda_{\text{maximum}}}{2} = \frac{0{,}0143 + 0{,}0233}{2} = 0{,}0188 \frac{\text{failures}}{\text{hour}}$$

How to get probable density for the occurrence of failures

For the case of an exponential distribution, one should settle the range that shows the probable density for the occurrence of failure versus time (Fig. 5). The values are being calculated for the two extreme values of the intensity of deterioration.

How to determine reliability and the non-operation reliability R(*t*)*; F*(*t*)*.*

Fig 6 shows the variation range of the reliability and of the non-operating reliability functions versus time for the rotor excavators used at Jilt Mining Unit.

So, according to this diagram, the following aspects can be concluded:

- the two categories of curves (for reliability and for non-operation reliability) are complementary, i.e. the probability that the excavator be in state of operation plus the probability that the excavator be in out of order gives 100%;
- the reliability of excavators is pretty low; for ex. for an operating period of 50 hours, the reliability of the excavator is between 30% and 50%, with a mean value of 40% which may a very low value at first sight. Nevertheless, considering the data basis that has been used to calculate the mean time of

$t := 1..300 \qquad \lambda max := 0.0233 \qquad \lambda min := 0.0143$

$f1(t) := \lambda min \cdot e^{-\lambda min \cdot t} \qquad f2(t) := \lambda max \cdot e^{-\lambda max \cdot t}$

Probable density

f1(t)

f2(t)

t

Time, hours

Fig. 5. Diagram on the probable density for the occurrence of failure

$t := 1..300 \qquad \lambda max := 0.0233 \qquad \lambda min := 0.0143$

$Rmin(t) := e^{-\lambda max \cdot t} \qquad Rmax(t) := e^{-\lambda min \cdot t}$

$Fmin(t) := 1 - Rmin(t) \qquad Fmax(t) := 1 - Rmax(t)$

Reliability, non-operating reliability

Rmin(t)

Rmax(t)

Fmin(t)

Fmax(t)

t

Time, hours

Fig. 6. Variation range of reliability and of non-operating reliability for the rotor excavators

good operation (there have been taken into consideration only those periods when the machine excavates), this period shall be as the effective time of operation and not as calendar time. All the other related periods have been removed: here we speak about the periods assigned to work out failures of the other equipment used in the technological flow, the periods due to engineering stoppage, due to organization shortages. There haven't been considered those periods assigned for current revision and repairing periods.

How to get the mean time for repairing

The total stoppage time of excavators equivalent with the time necessary for their re-commissioning as a result of the 52 failures that came up within the period under analysis on the 13 excavators, is of 953 hours. In compliance with the equation (2.13), the mean time for repairing operations is:

$$MTR = \frac{593}{52} = 11{,}4 \text{ hours}$$

How to get the intensity or the rate of repairing, μ

For the mean time of repairing calculated above, the intensity of repairing has the following value (according to equation (2.14):

$$\mu = \frac{1}{11{,}4} = 0{,}0877 \quad \frac{\text{repairing}}{\text{hour}}$$

5. CONCLUSIONS

The reliability study of a mining system with the use of Pareto charts shall start with the conditions a product should meet so as to display safety in operation and with the full methodology for producing Pareto charts. The theoretical aspects on the said methodology are followed by a study case for Jilt Mining Unit. This case covers the period between June 20, 2005 and May 2, 2006 and takes into consideration the current data for the two quarries and includes 13 1400 - type rotor excavators and 6 dumping machines.

An analysis of Pareto charts shows that this equipment needs an up-to-date of: the rotor excavators (rotor with the driving system, motion system, distribution carriage (BRS)), dumping machines (drums of the belt conveyors, motion system).

Generally speaking for the case of machines used in quarries, it is quite difficult to produce a reliability study because there are several types of machines and equipment, because such studies need a lot of observations, there is not an adequate information system, there are no concrete reference on the working equipment that is being used in quarries, etc.

The data were processed for a confidence level of 90% (the most often used figure in the technical domain) we have got a mean time of good operation (*MTBF*) of 54 hours for the 13 excavators used in Jilt South and Jilt North quarries and monitored for an operating period of 36535 hours, with 52 mechanical defects; these figures give a mean intensity of deterioration of 0.0188 failures / hour. Considering an effective length of operation of 50 hours and the above-said data, we may conclude the reliability of this equipment is between 30 and 50%. Consequently, we daresay that there are enough places for improvements.

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