THE RESULTS OBTAINED IN ESTIMATING THE QUALITY OF SOME COMPONENTS OF THE WARMAN PUMP

VLAD ALEXANDRU FLOREA[1], GABRIEL PRAPORGESCU [2]

Abstract: Knowledge of the quality characteristics (reliability and maintainability) of a product or equipment is essential, whether it is a simple or complex system. Reliability influences maintenance, the lifespan of products and equipment, as well as an acceptable level of their security. Wear and tear on equipment and renewal are cost generators that must be managed efficiently. This is why emphasis is placed on a new field of investigation aimed at reducing these costs. This approach is primarily based on modeling the occurrence of defects over time and the corresponding remediation times. The paper aims to establish the reliability and maintainability of technological equipment, particularly those that experience a high number of failures, using data from a coal preparation plant in the Jiu Valley over a period of three years.

Keywords: bearing, sealing gasket, reliability, maintainability, distribution law

1. INTRODUCTION

In the technological flow of the preparation plant in Coroieşti, the supply of hydrocyclone batteries is carried out using Warman pumps (fig. 1), having the following technical characteristics:

- flow rate 550 mc/h;
- discharge height 45-50 m;
- motor power 132 kW/0.4V;
- motor speed 1500 rpm.

Over the course of three years, the operating times between failures and the repair times of the defects in the subassemblies of Warman pumps, which work in an impure and aggressive environment, were monitored. The main defects found were in the pump bearing (47) and the sealing gaskets (32).

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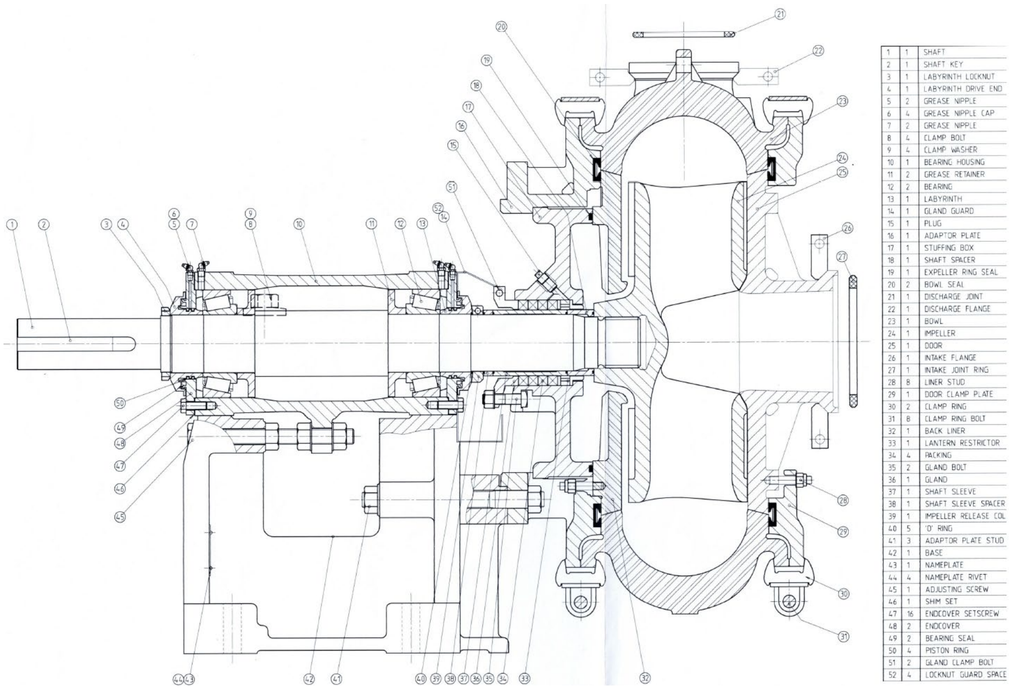

Fig.1. Warman type centrifugal pump

2. DISTRIBUTION LAWS USED IN THE STUDY OF THE RELIABILITY AND MAINTAINABILITY OF INDUSTRIAL EQUIPMENT

2.1. Exponential distribution law

The exponential model is used when the failure rate or intensity λ is constant, which, according to the "bathtub" model, begins at the end of the initial period and ends at the beginning of the final or old age stage, but it can also be successfully applied in the case of modeling the maintainability of mechanical systems, when the repair rate or intensity, μ, can be considered constant.

The probability that the product will not fail in the time period (0, t) is:

$$R(t;\lambda) = \exp\,(-\lambda \cdot t) \tag{1}$$

The average value of this distribution, namely the mean time between failures:

$$m = MTBF = \frac{1}{\lambda} \tag{2}$$

2.2. Normal distribution law (Gauss-Laplace)

The normal law finds its applicability in the case of processes influenced by a large number of random factors. In reliability, the normal distribution characterizes the phenomena of mechanical, electrical, thermal, etc. aging of elements and systems.

The function:

$$\Phi(u) = 1/\left(\sigma \cdot \sqrt{2 \cdot \pi}\right) \int_0^u e^{-u^2/2} du \tag{3}$$

is called the integral function of Laplace and u is the quantile of the Laplace function.

The reliability function for a normal failure model is given by the relation:

$$R(t; m, \sigma) = 1/2 - \Phi[(t - m)/\sigma], \tag{4}$$

where m and σ, the mean and the mean square deviation, respectively, are the distribution parameters.

2.3. Log-normal distribution law (Dalton)

The log-normal distribution is used to model technical systems that degrade due to the phenomenon of thermal fatigue. This distribution is also used in the analysis of technical system maintenance.

The reliability function is:

$$R(t; m, \sigma) = \frac{1}{2} - \Phi\left[\frac{ln(t-m)}{\sigma}\right]. \tag{5}$$

2.4. Weibull distribution law

The scope of applicability includes failure models determined by degradation processes such as fatigue, corrosion, diffusion or mechanical abrasion, as well as in phenomena regarding the strength of materials and the failure times of electronic and mechanical components.

Normed biparametric Weibull distribution

The biparametric Weibull distribution can be expressed in a more advantageous form by substituting the parameter λ and normalizing the time by a constant η which represents the real scale parameter, β being the scale parameter.

The probability that the product will not fail in the time interval (0, t) is:

$$R(t/\eta; \beta) = 1 - F(t/\eta; \beta) = exp\left[-(t/\eta)^{\beta}\right]. \tag{6}$$

Three-parameter Weibull distribution

This distribution model is a complete variant, using three parameters: β - the shape parameter; η - the scale parameter, or characteristic life, i.e. the life time up to which 63.2% of failures will occur; γ - the minimum life span, or the location, position or initialization parameter.

The reliability function, i.e. the probability that the product will not fail in the interval (0, t) is:

$$R(t;\eta,\beta,\gamma) = exp\{-[(t-\gamma)/\eta]^{\beta}\}. \quad (7)$$

3. ESTIMATION OF QUALITY PARAMETERS FOR THE BEARING AND SEALS OF THE WARMAN CENTRIFUGAL PUMP

3.1. Estimation of reliability parameters for the bearing

The analyzed database results in the effective operating times of the bearing, represented by the statistical series consisting of n=47 values (ordered in ascending order), in operating hours, until a defect occurs: 7; 7; 7; 14; 14; 14; 14; 14; 20; 21; 21; 26; 27; 28; 28; 29; 35; 37; 42; 44; 48; 55; 56; 63; 65; 69; 70; 72; 76; 77; 78; 79; 83; 105; 107; 114; 118; 127; 130; 149; 160; 178; 211; 227; 347; 533; 538.

The data thus obtained were run in the Weibull++ software, obtaining: the ranking of the different distribution laws (fig. 2), the adopted distribution law (fig. 3), the probability of acceptance of the distribution law (fig. 4). After adopting the distribution law, generally the one with the highest probability of acceptance was graphically represented: the probability of failure (fig. 5), reliability (fig. 6 and 7), unreliability (fig. 8), the probability density function (fig. 9) and the failure rate (fig. 10).

Current Results Matrix
Matrix Order:

Distribution	Ranking	LKV	BIC	AIC
Lognormal	1	-256,84	521,39	517,69
3P-Weibull	2	-256,47	524,49	518,94
Loglogistic	2	-257,69	523,07	519,37
G-Gamma	3	-257,53	526,62	521,07
1P-Exponential	3	-260,54	524,94	523,09
Gamma	4	-260,86	529,43	525,73
2P-Weibull	5	-263,02	533,74	530,04
2P-Exponential	6	-270,31	548,33	544,63
Logistic	7	-282,38	572,45	568,75
Normal	8	-291,18	590,05	586,35
Gumbel	9	-1227,4	2462,4	2458,7

Fig.2. Distribution law ranking

Results Report	
Report Type	Weibull++ Results
User Info	
Name	Vlad Alexandru Florea
Company	University of Petrosani
Date	02.04.2022
Parameters	
Distribution	Lognormal 2P
Analysis	RRX
CB Method	FM
Ranking	MED
Log-Mean (hr)	3,982778
Log-Std	1,097289
LK Value	-256,843263
Rho	0,993154
Fail \ Susp	47 \ 0
LOCAL VAR/COV MATRIX	
Var-LnMu=0,025618	LnCoVar=-1,045229E-09
LnCoVar=-1,045229E-09	Var-LnSigma=0,014067

Fig.3. Distribution law

These representations result in relatively low values of the bearing reliability, the probability that it will not fail after 41.7 hours of actual operation being 60% (the risk margin of 40% being very high), therefore we must expect that after about 5 days of operation (8 hours/day) of the conveyor, the bearing will fail.

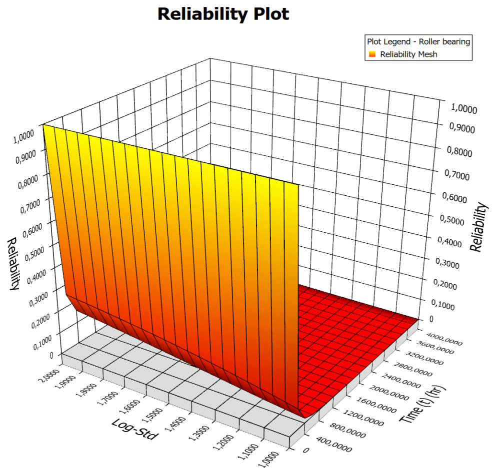

Fig. 4. Probability of acceptance of the distribution law

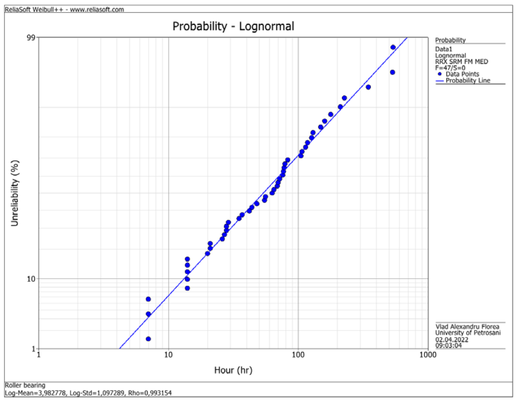

Fig.5. Probability of failure

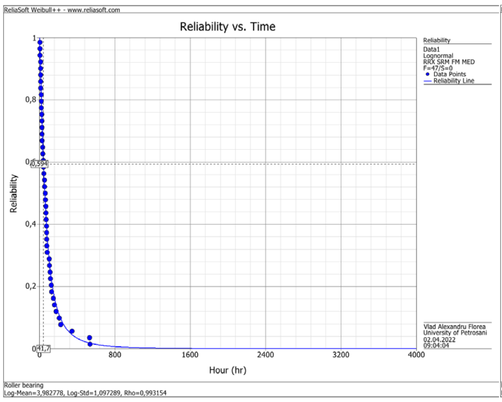

Fig. 6. Reliability (60%)

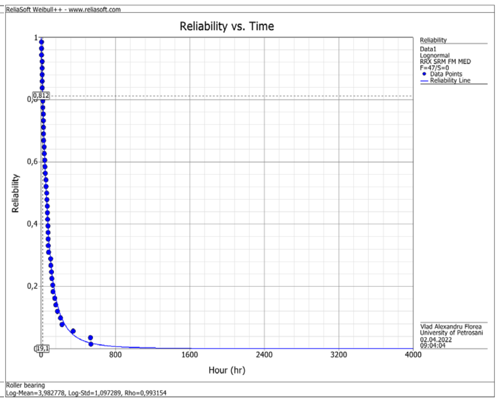

Fig. 7. Reliability (80%)

If a reliability of 80% is imposed, which is a reasonable value in technology, the result is a failure-free operating time of 19.1 hours, which means that after about two days of operation it is necessary to intervene to repair the bearing.

3.2. Estimation of reliability parameters for sealing gaskets

The analyzed data, in number of 32 (operating hours, ordered ascending), are the following: 7; 7; 8; 14; 15; 22; 27; 28; 35; 41; 42; 44; 48; 49; 49; 50; 51; 56; 57; 63; 64; 132; 141; 146; 161; 162; 188; 232; 273; 301; 364; 366.

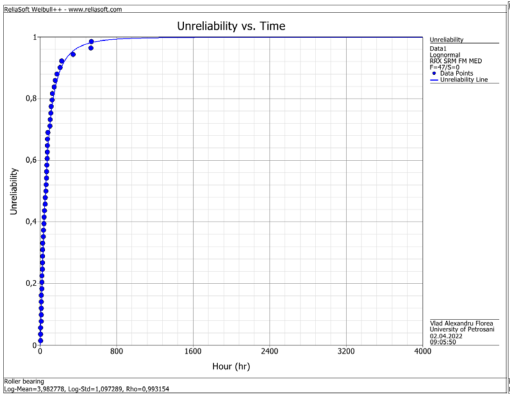

Fig. 8. Unreliability

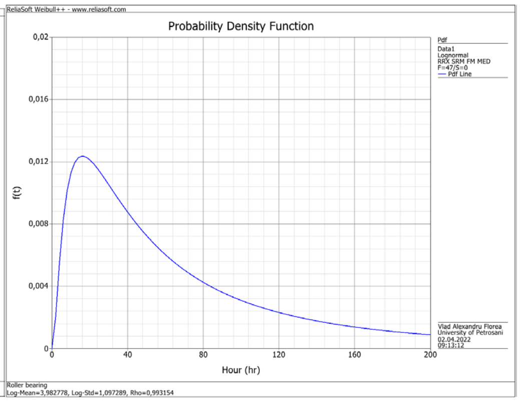

Fig. 9. Probability density function

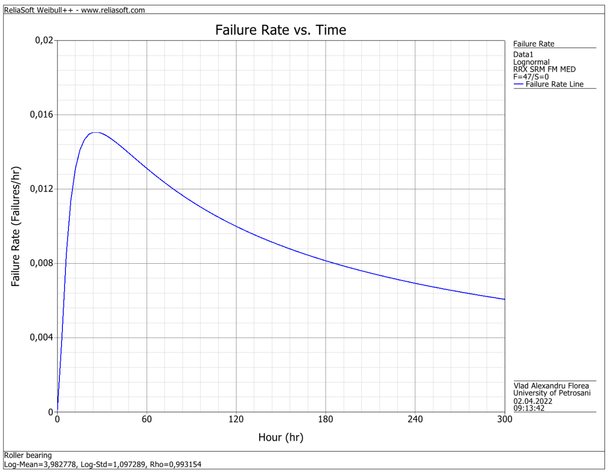

Fig. 10. Failure rate

The data thus obtained were run in the Weibull++ software, obtaining: the ranking of the different distribution laws (fig. 11), the adopted distribution law (fig. 12). After adopting the distribution law, generally the one with the highest acceptance probability, different reliability values were analyzed (fig. 13 and 14).

It is observed that the probability that it will not fail after 54.8 hours of operation is approximately 60%, and to obtain an acceptable reliability of 80%, the operating time decreases to 23.6 hours of operation.

3.3. Estimation of maintainability parameters for the bearing

From the analyzed database, the bearing replacement times result, represented by the statistical series consisting of n=47 values (ordered in ascending order), in minutes: 120; 6x180; 190; 200; 205; 2x220; 3x230; 6x240; 250; 6x260; 4x270; 2x290; 6x300; 2x310; 320; 330; 360; 450; 840.

Current Results Matrix
Matrix Order:

Distribution	Ranking	LKV	BIC	AIC
1P-Exponential	1	-179,9	363,2	361,7
3P-Weibull	2	-177,8	365,9	361,5
Lognormal	3	-179,1	365,2	362,2
Loglogistic	4	-179,9	366,7	363,8
Gamma	5	-180,1	367,2	364,3
2P-Weibull	6	-180,2	367,3	364,4
G-Gamma	7	-179,6	369,6	365,2
2P-Exponential	8	-182	370,9	368
Logistic	9	-193,5	393,8	390,9
Normal	10	-193,8	394,5	391,6
Gumbel	11	-239,2	485,3	482,4

Fig. 11. Distribution law ranking

Results Report	
Report Type	Weibull++ Results
User Info	
Name	Vlad Alexandru Florea
Company	University of Petrosani
Date	02.04.2022
Parameters	
Distribution	Exponential 1P
Analysis	RRX
CB Method	FM
Ranking	MED
Mean Time (hr)	107,74151
LK Value	-179,851337
Rho	-0,974524
Fail \ Susp	32 \ 0
LOCAL VAR/COV MATRIX	
Var-Theta=411,644745	
[Note: Theta = 1 / Lambda]	

Fig. 12. Distribution law

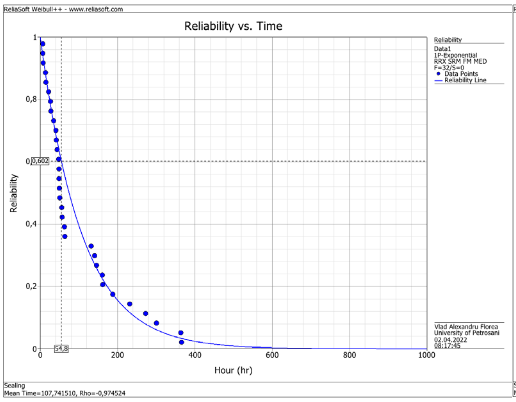

Fig. 13. Reliability (60%)

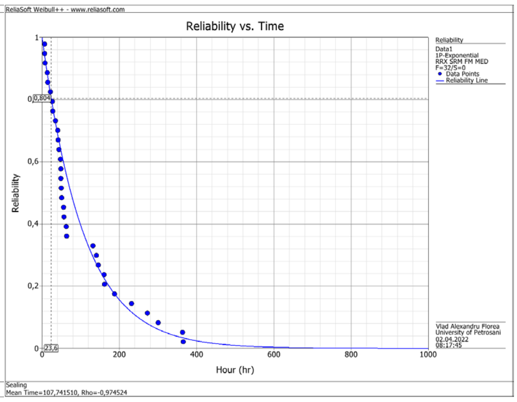

Fig. 14. Reliability (80%)

The data thus obtained were run in the Weibull++ software, obtaining: the ranking of the different distribution laws (fig. 15), the adopted distribution law (fig. 16). After adopting the distribution law, generally the one with the highest probability of acceptance or graphically represented: maintainability (fig. 17 and 18) and the repair rate (fig. 19).

From the analysis of the maintainability graphs, it is observed that the probability that the bearing will be replaced in 238 minutes is only 40%, while to have an 80% certainty that the bearing will be replaced, 322 minutes are needed.

Current Results Matrix
Matrix Order:

Distribution	Ranking	LKV	BIC	AIC
Lognormal	1	-268,38	544,46	540,76
Logistic	2	-271,75	551,21	547,51
Gamma	3	-280,25	568,2	564,5
2P-Exponential	4	-282,27	572,25	568,55
Normal	5	-286,22	580,14	576,44
3P-Weibull	6	-287,78	587,12	581,56
1P-Exponential	7	-312,74	629,33	627,48
G-Gamma	8	-396,57	804,68	799,13
2P-Weibull	9	-416,39	840,47	836,77
Gumbel	10	-9980,9	19969,5	19965,8

Fig. 15. Distribution law ranking

Results Report	
Report Type	Weibull++ Results
User Info	
Name	Vlad Alexandru Florea
Company	University of Petrosani
Date	02.04.2022
Parameters	
Distribution	Lognormal 2P
Analysis	RRX
CB Method	FM
Ranking	MED
Log-Mean (hr)	5,540637
Log-Std	0,27548
LK Value	-268,37954
Rho	0,926853
Fail \ Susp	47 \ 0
LOCAL VAR/COV MATRIX	
Var-LnMu=0,001615	LnCoVar=-5,358007E-11
LnCoVar=-5,358007E-11	Var-LnSigma=0,000721

Fig. 16. Distribution law

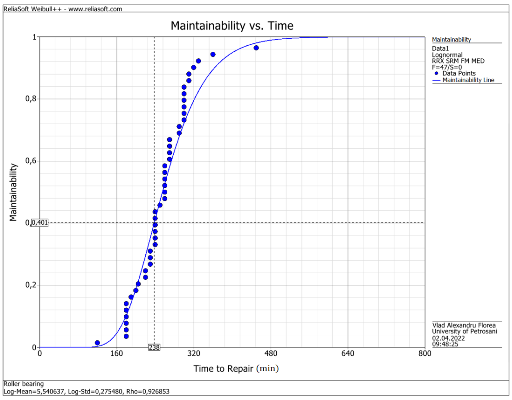

Fig. 17. Maintainability (40%)

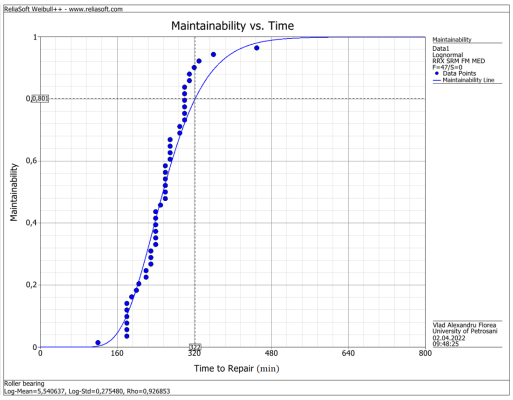

Fig. 18. Maintainability (80%)

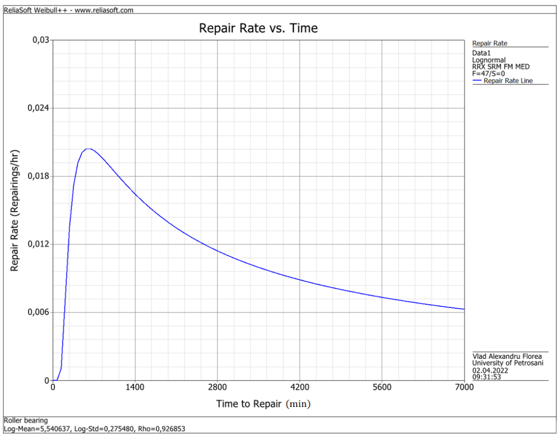

Fig. 19. Repair rate

3.4. Estimation of maintainability parameters for seals

The repair times, in number of 32, for seals, ordered in ascending order, in minutes are: 3x30; 4x40; 7x50; 12x60; 70; 2x80; 3x100.

The data thus obtained were run in the Weibull++ software, obtaining: the ranking of the different distribution laws (fig. 20), the adopted distribution law (fig. 21). After adopting the distribution law, generally the one with the highest probability of acceptance was graphically represented: maintainability (fig. 22 and 23) and repair rate (fig. 24).

Current Results Matrix
Matrix Order:

Distribution	Ranking	LKV	BIC	AIC
Lognormal	1	-136,2	279,4	276,5
Gamma	2	-136,6	280,1	277,2
Logistic	3	-137,6	282,2	279,3
G-Gamma	3	-136,5	283,3	278,9
3P-Weibull	4	-136,6	283,6	279,2
Normal	4	-138,2	283,3	280,4
2P-Exponential	5	-138,8	284,4	281,5
2P-Weibull	6	-140,3	287,5	284,6
Gumbel	7	-157,8	322,5	319,6
1P-Exponential	8	-164	331,5	330,1

Fig. 20. Distribution law ranking

Results Report	
Report Type	Weibull++ Results
User Info	
Name	Vlad Alexandru Florea
Company	University of Petrosani
Date	02.04.2022
Parameters	
Distribution	Lognormal 2P
Analysis	RRX
CB Method	FM
Ranking	MED
Log-Mean (hr)	4,009483
Log-Std	0,314295
LK Value	-136,228138
Rho	0,962769
Fail \ Susp	32 \ 0
LOCAL VAR/COV MATRIX	
Var-LnMu=0,003087	LnCoVar=-1,856253E-10
LnCoVar=-1,856253E-10	Var-LnSigma=0,001610

Fig. 21. Distribution law

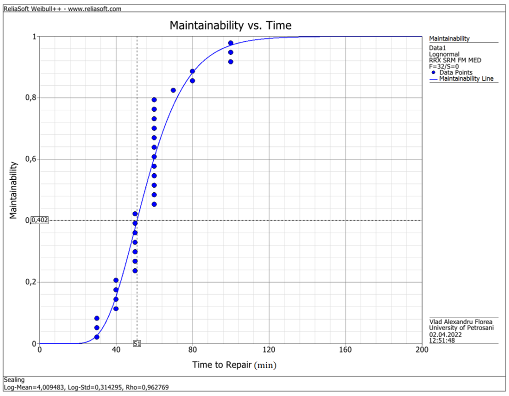

Fig. 22. Maintainability (40%)

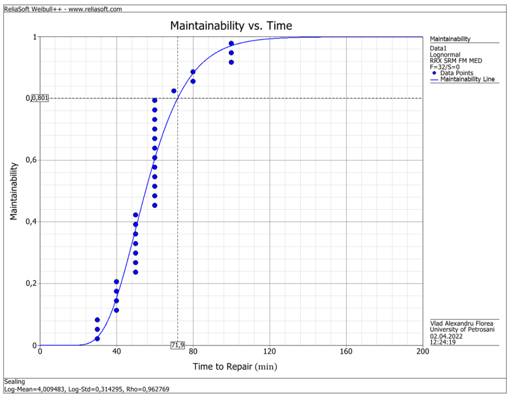

Fig. 23. Maintainability (80%)

From the analysis of the maintainability graphs, it is observed that the probability that the seal will be replaced in 51 minutes is only 40%, while to have an 80% certainty that the bearing will be replaced, approximately 72 minutes are needed.

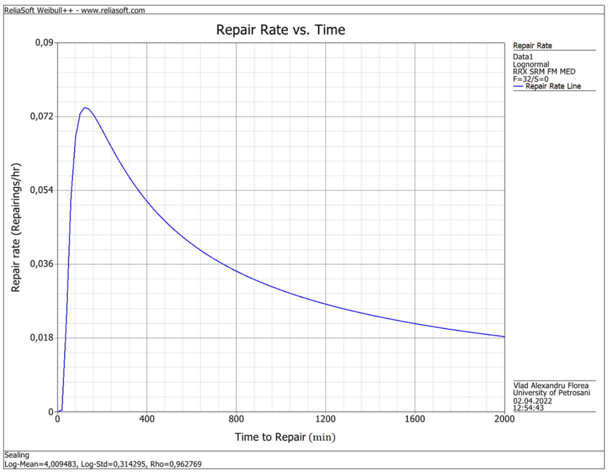

Fig. 24. Repair rate

4. CONCLUSIONS

The reliability and maintainability analysis conducted on the components with the highest failure rates, specifically the Warman pump, its bearing, and seal, reveals that their reduced reliability is due to improper use of the conveyor—namely, processing coal mixed with tailings in significant quantities and sizes, which exceed the usage guidelines outlined in the equipment documentation. Reducing bearing and seal replacement times can be achieved by adopting a preventive-maintenance strategy.

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