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RaDMI 2008

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C O N T E N T S

PLENARY SESSION (INVITATION PAPERS)

SESSION A
RESEARCH AND DEVELOPMENT OF MANUFACTURING SYSTEMS, TOOLS AND TECHNOLOGIES, NEW MATERIALS AND PRODUCTION DESIGN

SESSION B
MAINTENANCE AND EFFECTIVENESS OF TECHNICAL SYSTEMS, QUALITY MANAGEMENT, ISO 9000, ISO 14000, TQM AND MANAGEMENT IN MECHANICAL ENGINEERING

SESSION C
APPLICATION OF INFORMATION TECHNOLOGIES IN MECHANICAL ENGINEERING

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APPLICATION OF MECHANICAL ENGINEERING IN OTHER INDUSTRIAL FIELDS

SESSION E
TRANSPORT SYSTEMS AND LOGISTICS

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RELIABILITY ANALYSIS SOFTWARE

Dragan S. Milčić[1], Miroslav M. Mijajlović[1], Dragoljub Veljanović[2]
[1] Faculty of Mechanical Engineering, Niš, SERBIA, e-mail: milcic@masfak.ni.ac.yu, miroslav_mijajlovic@masfak.ni.ac.yu
[2] AD Rudnik i flotacija "Rudnik", Rudnik, SERBIA, e-mail: veljanovic@yahoo.com

Summary: *Reliability analysis has to determine which of familiar theoretical distributions describes best experimental data – which distribution can interpret empiric data. Faculty of Mechanical Engineering in Nis develops Reliability Analysis Software, presented in this paper. Development platform of this software is Microsoft Excel.*

Keywords: *Reliability, Software, Analysis*

1. TECHNICAL SYSTEM'S AND ELEMENT'S RELIABILITY ANALYSIS

Beside lifetime, precaution of the faultless work for technical systems and elements is reliability. Reliability represents probability of faultless work of the system/element in working conditions. Reliability is, mostly, in time decreasing value. Beside reliability, another important goal of the reliability analysis is determination of theoretical distribution of random variable – time of work or time of failure. More precisely: main goal is to determine which theoretical probability distribution describes the best empirical data gathered from the system which is being analyzed. Definition of the adequate theoretical probability distribution enables easy prediction of the system's/element's reliability and behavior in working conditions, from the aspect of the faultless work. Theoretical probability distribution (in most cases it is continuous probability distribution) is defined if all parameters of the distribution are defined. For example, two – parameter Weibull distribution has shape parameter – β and scale parameter – η, and it is fully defined if both parameters are defined. Parameters of the distribution can be assessed by graphical or analytical methods. In both cases, basis for distribution definition is determined from the empirical data about failures of the investigated system/element. Empirical data, as data set, extracted from the compete data set, without consideration if it is taken from the single system/element or from the several identical systems, must be representative and must fully describe originate situation.
Further data processing gives a statement about data set failures. But, it is important to get realistic statement about failures of whole analyzed population. If data set is too small, it is expected to receive unreal and imprecise results about analyzed system/element. That is the reason for definition of reliability confidence limits, given on Figure 1, cross – hatched surface. Reliability confidence limits give probability of compliance between theoretical and empirical data. Reliability confidence limits are defined over significance ranks.
Graphical methods are very easy to use and very useful in engineering. Graphical definition of the probability distribution can be derived by probability plotting papers. Firstly, adequate probability distribution is assumed to be correct. Secondly, points with coordinates [t_i, $F(t_i)$] have to e drawn into the probability plotting paper. Symbol t_i is time of failure and $F(t_i)$ is unreliability in the t_i moment of time. Number of points is equal to the number of analyzed elements n or number of interval z, if data set is analyzed trough intervals. If drawn point can be approximated very well with a straight line, assumed distribution is correct. If not, assumption of the probability distribution is not correct. Graphical methods give distribution parameters, also.
Another possibility of graphical methods usage is design of histogram or empirical cumulative failure density function and comparison with assumed theoretical probability distribution's density function. If there is a similarity, it is possible that theoretical distribution is correct. But, probability plotting method is much easier to use and more often used than design of histogram.

Analytical methods can determine distribution parameters more precisely then graphically. They are very good to use in special cases, for example, for Weibull distribution, when shape parameter β, has extreme values. Since analytical methods use complex mathematical tools and require many calculations, graphical methods are more useful in engineering. Graphical methods give satisfying precision, at all.
Some of analytical methods for distribution parameters values determination are:

- Regression Analyze,
- Moments Method,
- Maximum Likelihood Method.

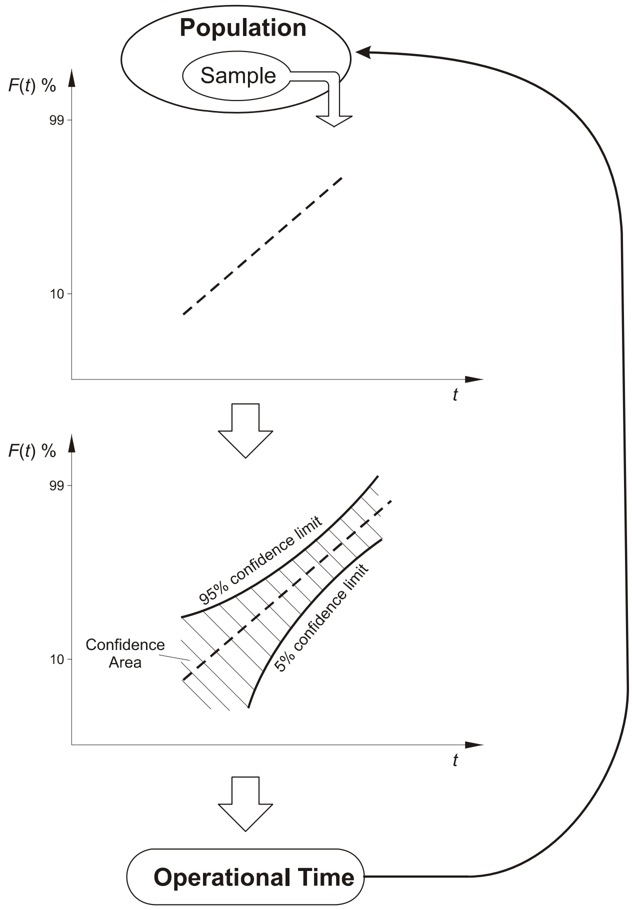
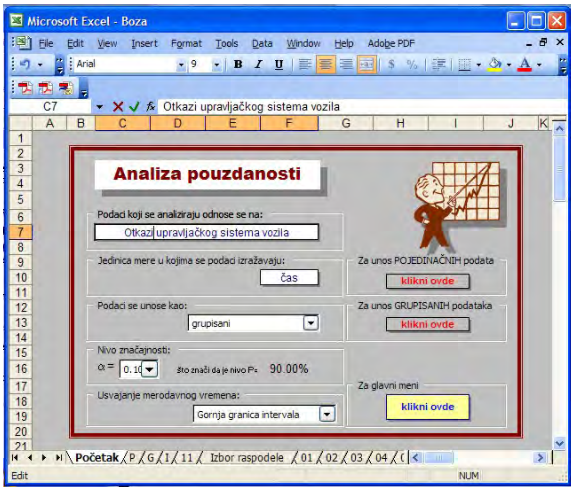
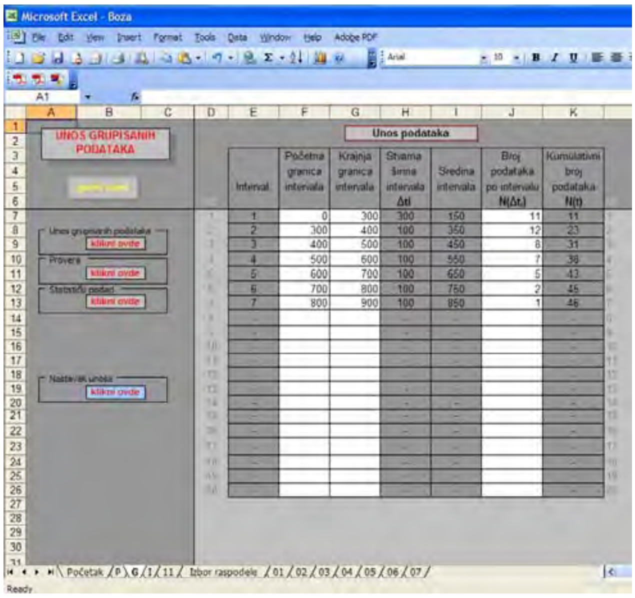


Figure 1. Reliability Confidence Limits

2. RELIABILITY ANALYSIS SOFTWARE

Faculty of Mechanical Engineering Nis's stuff is working on development of the software for reliability analysis. Platform for software development is Microsoft Excel because the possibility of very easy table – calculations. Input for the analysis are empirical data collected for the system/element being analysed.
Graphical input user interface of the software (Figure 2, a) defines singular or grouped data input into the software. Grouped data is given in specified or calculated intervals of time (Figure 2, b). It is necessary to input data about units used during analysis, for example m, km, hours etc. Since one of the main tasks of reliability analysis is determination of the theoretical probability distribution which can approximate actual empirical data, for further analysis, it is important to grade selected probability distribution with statistical tests (Kolmogorov-Smirnov or d_α-test, Pierson χ^2-test). This requires definition of significance level α, in order to have precise results.



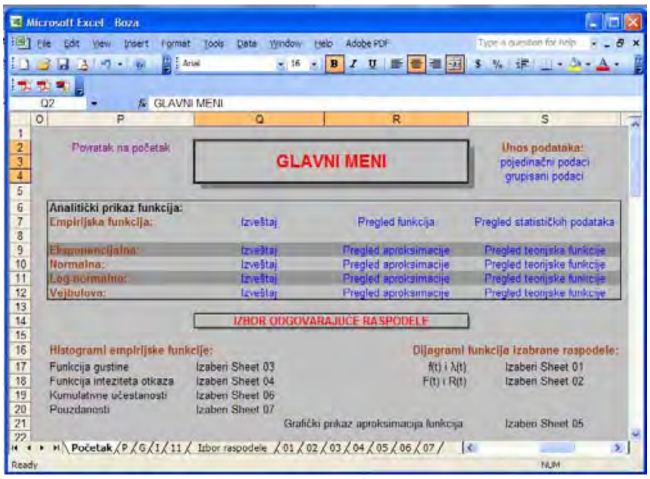


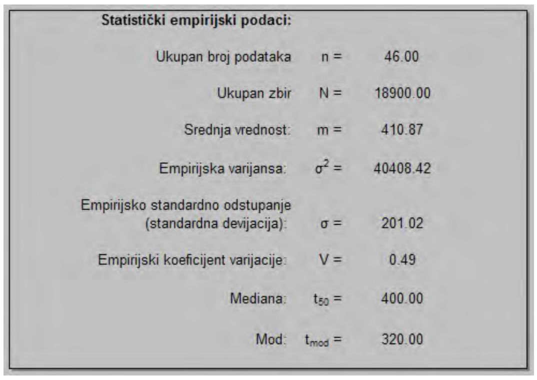
a) Input Interface – Start b) Main Input Menu

Figure 2: Reliability Software User Interface in Microsoft Excel

If there are singular data about technical elements/systems failures, then, if it is required to, software determines number of intervals, which gather singular data, width of intervals and counts failures in every interval, and then continues further analysis.

User interface (Figure 3, a) guides user to the results and gives statistical empirical data (Figure 3, b): mean, empirical variance, empirical standard deviation, empirical coefficient of variation, median and mod.

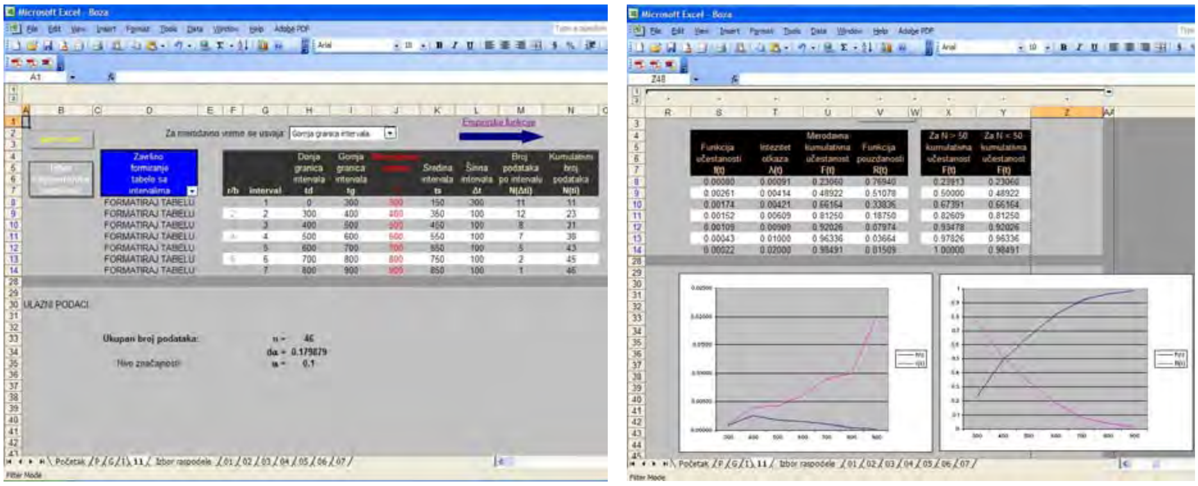




a) Main Menu – User Interface b) Some results – Statistical Empirical Data

Figure 3: User interface

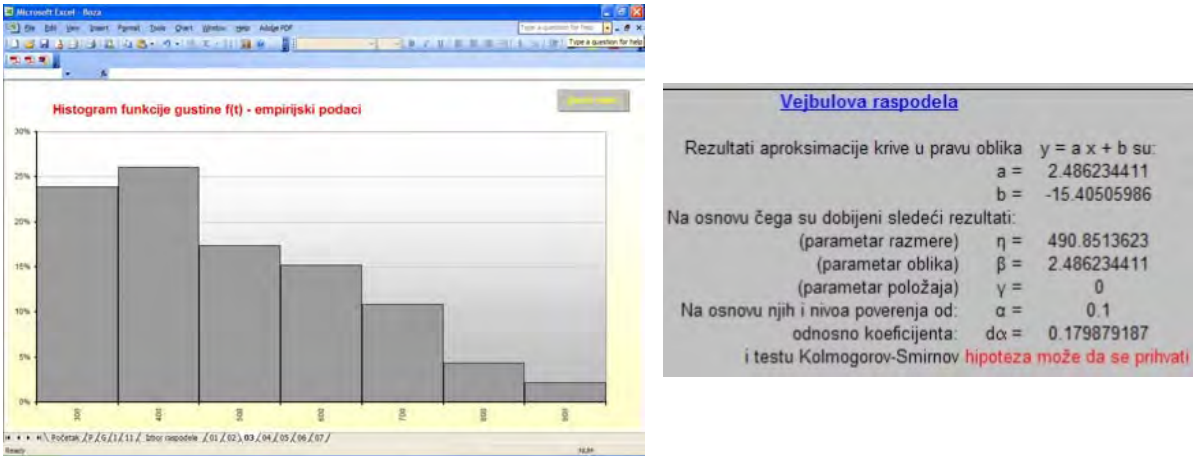
After formulation and generation of results table, software calculates empirical density function $f(t)$, failure rate $\lambda(t)$, reliability $R(t)$ and unreliability $F(t)$ (Figure 4).



a) Main Menu – Results Table b) Some results – Empirical Functions

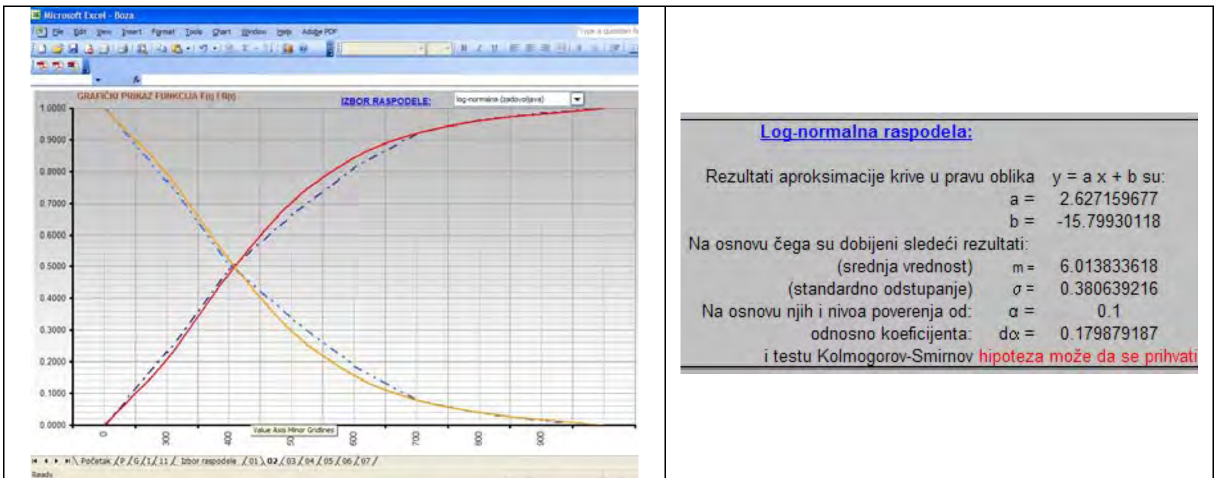
Figure 4: User Interface

As another result, software gives histogram of density function (Figure 5, a), histogram of cumulative density function, histogram of failure rate and histogram of non-failure systems/elements.



a) Main Menu – Histogram of Density Function b) Some results – Weibull Distribution

Figure 5: Some results



a) Main Menu – Empirical Reliability Function b) Some results – Lognormal Distribution

Figure 6: Some results

Regression analyze gives parameters for four different theoretical probability distributions: Weibull, Exponential, Normal and Lognormal. Figure 5, b shows parameters for Weibull distribution (β=2,48 and η=490,85) and possibility of distribution acceptance according to the Kolmogorov-Smirnov test for significance level α=0,1. For the same input data, software shows that test Kolmogorov-Smirnov approves usage of lognormal distribution with parameters *m*=6,0138 and σ=0,38063. Graphics of theoretical and empirical reliability and unreliability functions are given in Figure 6, a. Similarly to the previous probability plot papers, inserted into to the software, give parameters of the distributions. Figure 7, a shows probability plotting paper for Weibull distribution, with data inserted in and Figure 7, b shows theoretical density function and failure rate function.

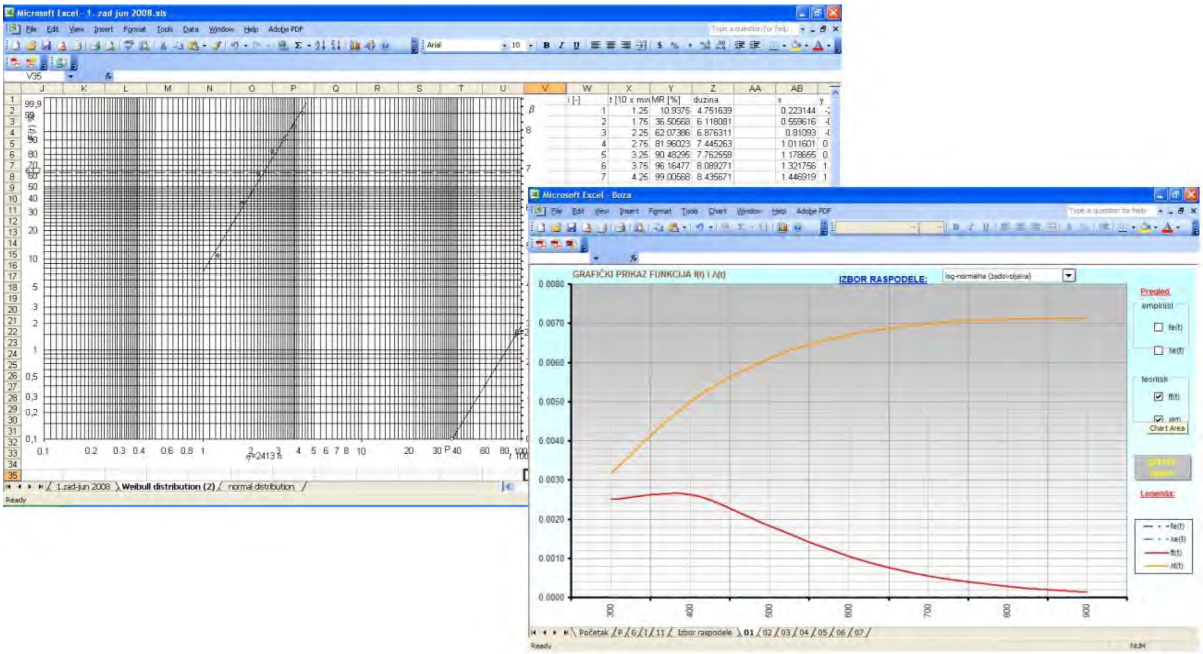


Figure 7: Probability Plotting Paper And Graphics

Weibull probability plotting paper, shown in Figure 8, has been designed at Faculty of Mechanical Engineering Nis.

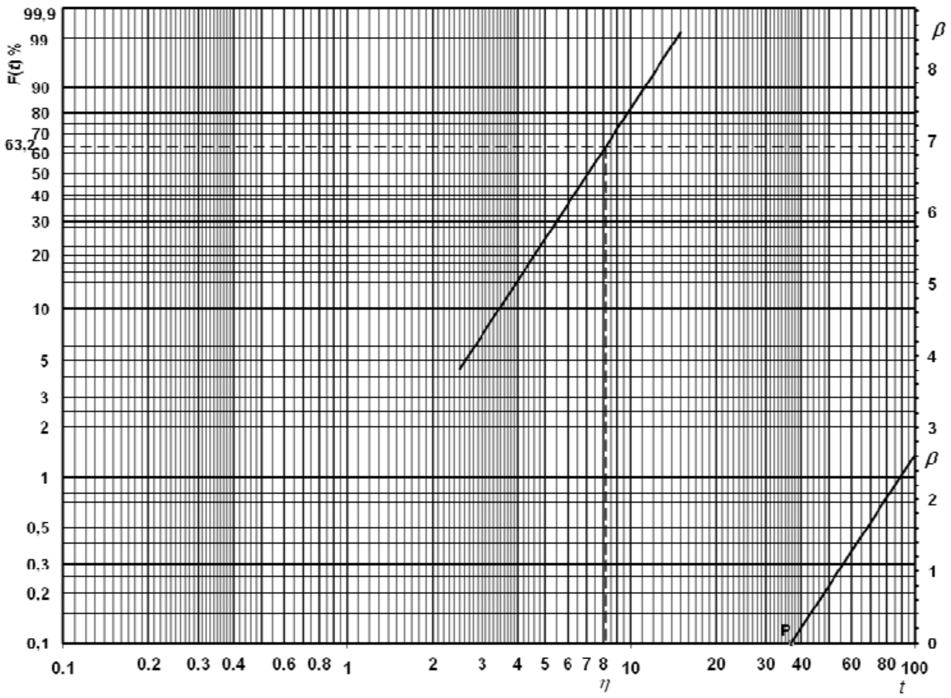


Figure 8: Probability Plotting Paper for Weibull Distribution

Weibull probability plotting paper's abscissa is logarithmically scaled and ordinate is twice logarithmic scale:

$x = \ln t$ (1)

$y = \ln\{-\ln[1-F(t)]\}$ or, $y = \ln[-\ln R(t)]$ (2)

These expressions are extracted from the Weibull distribution's reliability function:

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad (3)$$

After transformation and natural logarithm of expression (3):

$$\ln\left\{\ln\left[\frac{1}{1-F(t)}\right]\right\} = \beta \cdot \ln t - \beta \cdot \ln \eta \quad (4)$$

Since normal shape of straight line function is $y = a \cdot x + b$, there is a conclusion that expression (4) is straight line function with:

$$x = \ln t,\ \ a = \beta,\ b = -\beta \cdot \ln \eta, \quad (5)$$

$$y = \ln\left\{\ln\left[\frac{1}{1-F(t)}\right]\right\} = \ln\left\{-\ln\left[1-F(t)\right]\right\} \quad (6)$$

Weibull probability plotting paper gives, for $F(t)$=63,2 %, marked with sectioned line (Figure 9), on abscissa parameter of scale η. Shape parameter β can be read on the right ordinate, when Weibull line is moved to the pole P (Figure 9). Pole P has coordinates: [lnt_P; 0] and linear (right) ordinate, for parameter of shape β, can be determined based on the expression:

$$\beta = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{\ln t_2 - \ln t_1} \quad (7)$$

For β=1:

$$\frac{y_{100} - y_P}{\ln t_{100} - \ln t_P} = 1 \quad (8)$$

where coordinates of points are: 1 [lnt_P; y_P]=[lnt_P; 0] and 2 [lnt_{100}; y_{100}]=[ln100; 1], measured on the linear scale ordinate. This gives:

$$\frac{1-0}{\ln 100 - \ln t_P} = 1 \quad (9)$$

Solution of expression (9), gives t_P=36,788 and coordinates of pole P are [36,788; 0].
In order to determine linear value of 1, for right ordinate, it is necessary to make a ration between values of linear and double logarithmic ordinates for value of 1:

$$\frac{y_2 - y_1}{\ln\left\{-\ln\left[1-F(t_2)\right]\right\} - \ln\left\{-\ln\left[1-F(t_1)\right]\right\}} = 1 \quad (10)$$

$$\frac{1}{\ln\left\{-\ln\left[1-F(t_2)\right]\right\} - \ln\left[-\ln\left(1-0{,}1/100\right)\right]} = 1 \quad (11)$$

Inverse logarithm of expression (11), gives:

$$-\ln\left[1-F(t_2)\right] = e^{\ln(-\ln 0{,}999)+1} \quad (12)$$

Inverse logarithm of expression (12), gives:

$$F(t_2) = 1 - e^{-e^{\ln(-\ln 0{,}999)+1}} = 0{,}002716 = 0{,}2716\% \quad (13)$$

So, linear value for 1, measured on linear scale, is equal to the value of $F(t)$=0,2716 % twice logarithm scale.

3. CONCLUSION

This software enables fast and precise reliability analysis with possibility to determine parameters of probability distributions. Grading and acceptance assessment of the distribution for the given empirical data is provided over the statistical tests. Platform of the software is Microsoft Excel since it is very useful for calculations and graphing.

REFERENCES

[1] Milčić, D.: *Pouzdanost mašinskih sistema*, Mašinski fakultet Niš, Niš, 2005.
[2] Milčić, D., Mijajlović, M.: *Pouzdanost mašinskih sistema* – Zbirka rešenih zadataka, Mašinski fakultet Niš, Niš, 2008.
[3] Bertsche B., Lechner G.: *Zuverlässigkeit im Maschinenbau – Ermittlung von Bauteil- und System-Zuverlässigkeiten*. Springer-Verlag, 1990.
[4] Vujanović N.: *Teorija pouzdanosti tehničkih sistema*. Vojnoizdavački i novinski centar, Beograd, 1990.