# RESEARCHES REGARDING THE RELIABILITY ASSESSMENT USING THE BOXPLOT METHOD

**Popa Ionut[1], Lupescu Octavian[1], Popa Valica [2] & Scurtu Popa Ramona[1]**

[1] "Gheorghe Asachi" Technical University of Iasi-Romania, Department of Machine Manufacturing Technology, Blvd. Mangeron No. 59A, 700050 Iasi, Romania
[2] S.C. "Rulmenti" S.A., 320 Republicii Street (European Road E 581), Barlad, Romania

Corresponding author: Popa Ionut, popa_ionut_ciprian@yahoo.com

***Abstract:*** In this paper, the authors had appreciated the reliability process through his two indicators: availability and Mean Time Between Failures (MTBF). The research was being effectuated for a three years time period (2007, 2008 and 2009) on a 118 number of technological equipments devided in 4 groups, function by the technological process that execute each of them, as: interior, super-finishing, cdr10 and cdr2. The research result was materialized, through the realization of a data base for all analized equipments and for the entire estudied time period, in which were determined the reliability indicators. These indicators will be analized using the BOXPLOT statistical method.
***Key words:*** technological equipments, availability, MTBF, reliability, BOXPLOT.

## 1. INTRODUCTION

Analysing the speciality literature (Billinton & Allan, 1992; Klyatis & Klyatis, 2004; Mărăşescu, 2004), the reliability represents the probability in which the component parts, products and systems perform their functions without faults for what they were designed, in the specificated conditions, for a certain time period and with a gived confidence level.
Some product or technological equipment reliability basis are being settled until his design time period, when is established the structure and his elements are being dimensioned (Billinton & Allan, 1992).
The reliability is assured in the manufacturing process through the right choose of the technological processes and equipments, respecting the manufacturing parameters and conditions, rigorous verification of the raw materials and manufactured materials quality.
The reliability theory problems for more times are situated in the economical problem area. In this way, knowing the ageing laws of some equipments, and also their usage degree in time is usefull for the choose of the best time replacement moments.
Because, the fault effects of a technological equipment element has consequences biggest than the element costs, in this case the researches are necessary to establish some profilactics measures that can eliminate or diminuate the number of these faults.
In the other word, the technological equipments reliability, in generally depends by the work productivity, production quality and in some cases even by the humans live.
In generally, the economical effects of a lower level or even of the reliability lack, can be marked out as (Sturzu et.al., 1996):

- the repair cost in materials and workforce (can arrive at 9% from workforce );
- unrealised production (6% from the complexe equipments time).

The researches from the reliability area suppose the realization of the followed objectives:

- to maintain the component elements, products and technological equipments in a good working estate for a time period, established through technological documents;
- the reworking possibility for technological equipments in smaller times and with the complete remarke of the initial characteristics of the good working;
- using some mathematically models, historical dates, as well as some laboratory tests to establish the optimum replacement time of a component element or even of technological equipment;
- to recovere the good working capacity and also to prelong the technological equipment used cicle time through some maintenance methods and strategies application;
- to maintain the availability and mean time between failures in normal parameters, established throug techical documents.

## 2. METHOD USED

To realize a case study for a technological equipments reliability estimation, the authors use two indicators of this process, as: the *availability* and the *Mean Time Between Failures* (MTBF).
The technological equipments *availability* (Strajescu, 2006): *represents the aptitude of these equipments to perform the specifical function under a combinate aspects of reliability, maintenability and maintenance*

*activities management.*

To determine the availability indicator it is necessary to define the following times:

- the *available planned time* ($T_{dp}$): that is equal with the multiplication between the working days number, daily planned shift number and the number of a one shift hours (in this case 8 hours).

$$T_{dp} = days\ number\ x\ shift\ number\ x\ 8\ hour/days \quad (1)$$

- the *planned time for stoppages* ($T_{po}$), represents the unworking planned time, due to the planned pauses, meetings, lunch break, etc.
- the *necessary availability* or the *real available time* ($D_n$), can be determined with relation 2:

$$D_n = T_{dp} - T_{po} \quad (2)$$

- *unworking time* or the *wasted time for stoppages* ($T_{nf}$), represents the real time in wich the equipment does not accomplished his function, this beeing stopped for unschedulated repaires.

In this way the availability can be determined with relation 3:

$$D = \frac{D_n - T_{nf}}{D_n} x100 \quad [\%] \quad (3)$$

where:

$D_n$ – represents the difference between the planed available time and the planned time for stoppages, as: preventive maintenance, launches, orders lack, etc;

$T_{nf}$ – represents the real time in which the equipment can not accomplish his function, these being stoped for unscheduled reparation due to the occured faults.

In relation (4) it is presented the efectively working time ($T_e$):

$$T_e = D_n - T_{nf} \quad (4)$$

Because the efectively working time represents the difference between $D_n$ and $T_{nf}$, replacing in rel (3) we will obtain:

$$D = \frac{T_e}{D_n} \cdot 100\ [\%] \quad (5)$$

The second indicator used by the authors for the reliability estimation is *Mean Time Between Failures* (MTBF), this represents *the arithmetic mean of the working time between system failures, this being a sinthetical estimation indicator of the reliability in case of redundante technological equipments* (Smith, 2005).

Analitically expresion of these indicators can be writen as:

$$MTBF = \frac{Available\ planed\ time - (\sum unworking\ time)}{Number\ of\ \ foults} \Rightarrow \quad (6)$$

$$MTBF = \frac{Efectivelly\ working\ time\ (Te)}{Number\ of\ \ faults}$$

The authours, realised the reliability estimation using the BOXPLOT method. This method is based on a diagram realisation, that can ofter informations (Tukey, 1977) regarding the centred trend and studiate distribution form.

To make the BOXPLOT diagrams, we use the Minitab 14 program, this being a PC application specialized in statistically analyzes. The Minitab program was realized in Pennsylvania State University by the researchers: Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in the year 1972.

This program is often used toghether with some improvement methods implementation, especialy with the Six Sigma method.

In other words, a BOXPLOT diagram, graphicaly reflects the distribution through 6 values, as:

- the minimum value, named also the 0 percentile, is noted with $X_{min}$, and represents the smaller value observed in the values series, excepting the outliers;
- the first quatile or the inferior quartile, noted with $Q_1$, assign the most smaller 25% of the observed values, in the other word, this represents one fourth of these values;
- median, $M_e$, assign 50% from values, that is the interval of the most smaller observed values (contain 50% of this interval) and the remaining interval is included between the median value and the most bigger observed value;
- the third quartile or the supperior quartile, $Q_3$, assign the most bigger 25% of the observed values;
- maximum value, noted with $X_{max}$, named also the 100 percentiles, is the biggest observed value, excepting the outliers;
- the interval between quartiles, noted with IQR, represents the interval between the $Q_3$ and $Q_1$.

Also, this graphic can present even the extreme values or the values situated outside of the distribution, named also outliers. These are simbolised with „* ”.

These outliers are considerated as being values bigger that Q3+1,5IQR or values smaller that Q1-1,5IQR. The IQR interval is represented as a rectangle („box”). Inside this rectangle is the median, graphically represented as a horizontal line. The (Xmin, Q1) and (Q3, Xmax) intervals are represented by a line („whiskers”) drawned further the rectangle.

To exemplificate the manner in which this statistical method calculate the distribution values for the

BOXPLOT realisation, one consider a stochastic value series, such as: 1, 2, 1, 4, 7, 5, 1, 3, 4, 1, 8. Sorting ascending this values (1, 1, 1, 1, 2, 3, 4, 4, 5, 7, 8) one can determine:

- $X_{min}$ (0 percentile) = 1;
- $X_{max}$ (100 percentile) = 8;
- Median = 3;
- $Q_1$ – will be at the half of the interval, between minimum value and median, so he will have the value 1;
- $Q_3$ - will be at the half of the interval, between maximum value and median, so he will have the value 5;
- IQR, will have value 4, ($Q_3$-$Q_1$).

The BOXPLOT method determine the distribution type, function by the arithmetical mean of the series values and median. So, in case in wich the difference between these two values is small, then the distribution is different by the normal one, and in case in wich the value is significant, the distribution become approximatelly with the normal one. In this case, calculating the arithmetical mean we will obtain 3,36, then the difference between this and the median will be a small value (0,36), fact that means that the distribution of this series is different by the normal distribution.

The graphical representation can be made on horizontal or vertical, but the terms semnification are identical. On this graphic can be read also those six values of the distribution.

In figure 1 is presented on example of a such graphical representation, realized on the vertical direction:

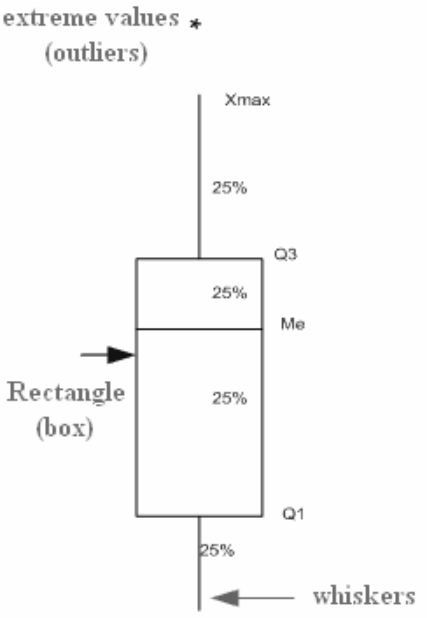


Fig. 1. Example of a BOXPLOT diagram

## 3. RESULTS

The researchers from this paper have been realised on a 118 technical equipments number (machine tools for grinding), that were divided in four groups: interior, superfinishing, cdr2 and cdr10. For a good estimations of the reliability researches were efectuated on a three years time period (2007, 2008 and 2009). The relation of these researches, suppose to create a data base in Microsoft Office Excell that can offer us some informatious about all technological equipments that were analised. Using relations 3 and 4 in this data base, the authours can determine the values, for the two reliability indicators for the entire researched time period, as we can observe in figure 2:

| Equipments group | Equipment type | Inventory No. | Dn | Dn-Tnf | Failures No. | Availability | MTBF |
|---|---|---|---|---|---|---|---|
| cdr2 | KRG | 42947 | 3824 | 3686 | 39 | 96,4 | 95 |
| interior | T 118 | 47850 | 6339 | 6081 | 63 | 95,9 | 97 |
| super | SF - 80 | 42538 | 3014 | 2869 | 17 | 95,2 | 169 |
| cdr10 | SIW | 46690 | 2956 | 2823 | 38 | 95,5 | 74 |
| cdr10 | T 159 | 42528 | | | | | |
| super | SF - 81 | 42542 | 3715 | 3529 | 29 | 95,0 | 122 |
| cdr2 | KRG | 42511 | 3233 | 3112 | 35 | 96,3 | 89 |
| interior | T 118 | 47716 | 3334 | 3217 | 30 | 96,5 | 107 |
| super | SF - 80 | 43000 | 3369 | 3267 | 30 | 97,0 | 109 |
| cdr10 | T 159 | 42955 | 2736 | 2638 | 35 | 96,4 | 75 |
| cdr10 | T 159 | 42358 | 2383 | 2283 | 50 | 95,8 | 46 |
| super | SF - 81 | 42990 | 3253 | 3153 | 27 | 96,9 | 117 |
| cdr2 | KRG | 42504 | 3641 | 3490 | 44 | 95,9 | 79 |
| interior | T 118 | 47701 | 3746 | 3592 | 40 | 95,9 | 90 |
| super | SF - 80 | 42992 | 3323 | 3200 | 32 | 96,3 | 100 |
| cdr10 | T 159 | 47850 | 4899 | 4732 | 54 | 96,6 | 88 |
| cdr10 | T 159 | 47830 | 3222 | 3104 | 32 | 96,3 | 97 |
| super | SF - 81 | 42551 | 2980 | 2881 | 21 | 96,7 | 137 |

Fig. 2. Date base used to determine the values for availability and MTBF

After we have determined these values, we analyze the technological equipments reliability using the BOXPLOT method from Minitab 14 program. In this way, for the availability indicator of all four groups of equipments, we have the following diagram:

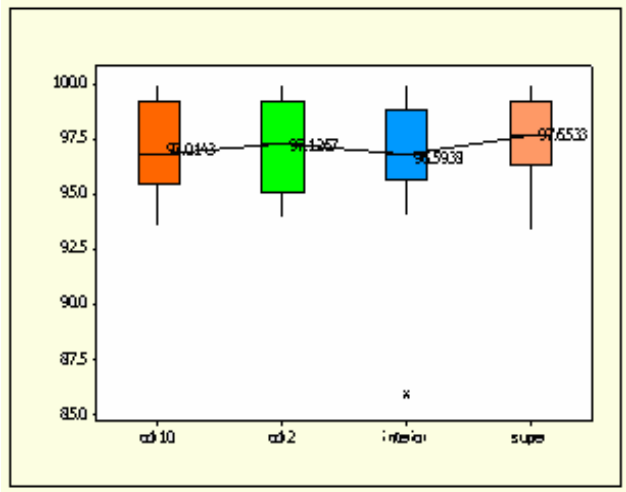


Fig.3. BOXPLOT Diagram for the availability indicator for all equipments groups

As we can see from figure 3, the statistical values resulted from the BOXPLOT diagram distribution is presented in the following table, as:

Table 1. Statistical values for availability, resulted from the BOXPLOT diagram distribution

| Equipments group | cdr10 | cdr2 | interior | Super finishing |
|---|---|---|---|---|
| **Q1** | 95.5 | 95.1 | 95.7 | 96.35 |
| **Median** | 96.8 | 97.3 | 96.85 | 97.65 |

| | | | | |
|---|---|---|---|---|
| **Q3** | 99.25 | 99.2 | 98.85 | 99.2 |
| **IQR** | 3.75 | 4.1 | 3.15 | 2.85 |

For the second reliability indicator, Mean Time Between Failures, we will have the following BOXPLOT diagram distribution, realized in the Minitab 14 computer program:

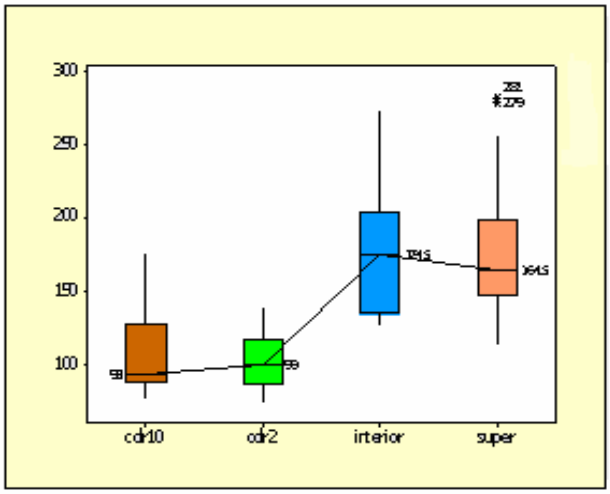


Fig. 4. The BOXPLOT diagram for Mean Time Between Failures for all technological equipments

The statistical values resulted from the BOXPLOT diagram distributions are presented in table 2:

Tab.2. Statistical values for MTBF, resulted from the BOXPLOT diagram distribution

| **Equipments group** | **cdr10** | **cdr2** | **interior** | **Super finishing** |
|---|---|---|---|---|
| **Q1** | 87.5 | 86 | 134.75 | 146.75 |
| **Median** | 93 | 99 | 174.5 | 164.75 |
| **Q3** | 128 | 117 | 204 | 198.25 |
| **IQR** | 40.5 | 31 | 69.25 | 51.5 |

Analyzing the reliability through the results that were obtained after we applied the BOXPLOT method, one can say that:

–in the case of the first indicator, *availability*, this does not have significant values for all technological equipments groups that were analyzed, because these have relatively the same dispersion, as we can see from figure 3 (the areas are overlapped), and their medians values are approximately identical (between 96,6% and 97,6%);

–in the case of the second indicator, Mean Time Between Failures, analyzing figure 4, one can observe that between those four groups of equipments are significant differences. The cdr 10 and cdr 2 groups had marked out a more limited distribution (as we can see in figure 2), having the median values between 93 and 99, while the interior and superfinishing groups have a bigger value for median, these being between 164,75 and 174,5. This thing is determined by the fact that the Mean Time Between Failures for cdr 2 and cdr 10 is lower than the one for the interior and superfinishing groups. Also, on this diagram one can observe that at the super finishing group are presented 2 outliers.

## 4. CONCLUSIONS

Using BOXPLOT method one can realize a reliability level appreciation for all technological equipments that were estudied. In this way, if in the case of the first reliability indicator, has not been marked out major differences between all four technological groups, in the second group, for MTBF, one determine for equipments from cdr2 and cdr10 a Mean Time Between Failure lower than the values of other two groups.

The used method is very practical when one wants to improve the technical equipments reliability, because his application helps to direct the research only on those technological equipments that have a lower reliability.

## 5. FUTURE RESEARCHES

After the BOXPLOT analyze utilization, the future researches will be directed to study the causes that had influenced the decreasing of the technological equipments MTBF value for cdr10 and cdr2 groups. For this, it will be necessary to estudiate the fault appearance causes for these equipments, using the FMEA or AMDEC methods.

## 6. REFERENCES

1.Billinton, R., Allan, R., N., (1992), *Reliability evaluation of engineering systems: concepts and techniques*, Plenum, New York, ISBN: 0-306-44063-6

2.Klyatis, L. M., Klyatis, E. L., (2004), *Accelerated reliability testing problems solutions*, Reliability and Robust Design in Automotive Engineering, 2004 SAE WorldCongress, Detroit, MI, March 8-11, pp. 283-290, ISBN–13: 978-0-08-044924-1

3.Nicolae Mărăşescu, (2004), *Fiabilitate şi diagnoză*, Publisher of "Dunărea de Jos" University Foundation, Galaţi, ISBN 973-627-140-4

4.Smith, David J., (2005), *Reliability, Maintainability and Risk*, Seventh Edition, Elsevier, U.K, ISBN: 0 7506 5168 7

5.Strajescu Eugen, (2006), *Bazele disponibilitatii sistemului*, BREN, Bucuresti, ISBN: 973-648-556-8; ISBN: 978-973-648-566-4

6.Sturzu, A., Roman, I., Joiţa, P., (1996), *Calitatea şi fiabilitatea produselor*, Editura Didactică şi Pedagogică, pp. 65-68, Bucureşti

7.Tukey, John W., (1977), *Exploratory Data Analysis*, Addison-Wesley, Reading, MA

Received: 16 November 2009 / Accepted: 20 December 2009 /
Abstract published online: 15 January 2010