UNDERGOUND MINING ENGINEERING 18 (2011) 85-95 UDK 62
FACULTY OF MINING AND GEOLOGY, BELGRADE YU ISSN 03542904

Review paper

ESTIMATION OF BUCKET WHEEL EXCAVATOR REMAINING CAPABILITY USING FUZZY THEORY

Tanasijević Miloš[1], Jovančić Predrag[2], Ivezić Dejan[3]

Abstract: Evaluation model for bucket wheel excavator remaining capability is analyzed in this paper. Model was formed to introduce fuzzy theory in dependability analysis regards to performances of reliability, maintainability and maintenance support, as well for synthesis of dependability from lowest to higher level of excavators' structure. Dependability was used as the most complex performance which covers in total quality of service for specific technical system and fuzzy sets theory was introduced as a convenient mathematical model that gives mutual synergy to calculations with hybrid data.

Key words: bucket wheel excavator, dependability, fuzzy theory

1. INTRODUCTION

Expansion of demands for electricity power has caused much greater exploitations of lignite on the open step mines. The development of giant machinery, primary bucket wheel excavators (BWE), has followed that demands. Today BWEs are considered as one of the most complex machines. These machines are particularly characterized by continual development and modernization during their lifetime. In Serbia, almost thirty BWEs are in service on the open step mines Kolubara and Kostolac. Almost half of these machines are more than 30 years old, and significant resources are engaged in last years for their modernization and revitalization. Different activities has been undertaken for the redesigning of BWE's mechanical components and electro equipment, as well as for introduction of new solutions for maintenance logistics, technical diagnostics, control systems, global positions systems, etc. Significant costs of these activities have required the clear concept for assessment of the remaining capability of the machines, and for defining of their future (writing-off or revitalization).

According to Bolotin (Bolotin, 1988), few groups of methods can be identified for the prediction of the remaining service life of the machines.

The first group - diagnostic methods, uses current information about machine, obtained from observation and measurement, for the prediction of the remaining capability of technical systems. The most popular methodologies for prediction in this

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[1] University of Belgrade, Faculty of Mining and Geology, Đušina 7, 11000 Belgrade, Serbia, e-mail: tan@rgf.bg.ac.rs

[2] University of Belgrade, Faculty of Mining and Geology, Đušina 7, 11000 Belgrade, Serbia, e-mail: pjovancic@rgf.bg.ac.rs

[3] University of Belgrade, Faculty of Mining and Geology, Đušina 7, 11000 Belgrade, Serbia, e-mail: ivezic@rgf.bg.ac.rs

group use probability theory, the cumulative methods, semi-empirical methods, Markov chains or Poisson type models, and models based on examination with and/or without the destruction, as well as methods based to maintenance planning.

The second group of methods primary uses economic indicators of machines operation, regardless to their working potential. The most popular methods in this group are:

- Methods for determination of the optimal machines life time based to economic validation (operation costs, present values, expected profit, etc.);
- MAPI (Machinery and Allied Products Institute) analysis, that gives the answer to the question if it is more efficient to invest in replacement or revitalization and modernization of machines;
- Ford method which uses different economic indicators to find if the proposed redesign has the required technical characteristics, better than the existing solutions.

However, all previous methods require a series of data, technical and/or economic. BWEs are machines with a large working effects and their possible stopping, for the implementation of diagnostic methods, causes additional costs. Economic indicators are mostly not objective, because these machines have been operated in non-market economy for almost the half of their service life. Even now, price of electricity, as an indirect product of BWEs, is partly subsidized by the Serbian state. It can be concluded that, for the BWEs, as a systems with great investment value, great working performances and long working life, the existing methods for assessment the remaining capability can not provide quality results.

Coefficient of time efficiency, i.e. ratio between up-time and total – calendar time, has been mainly used global criteria, i.e. indicator of BWE quality of service (Ivkovic et.al., 2004), (Jovančić et.al., 2008). However, this indicator has not been suitable to find out the reasons for inadequate quality of service of BWE, to make distinctions between downtimes due to problems in production management or BWE construction, or for identification of weak points in BWE structure. This can be very important for defining the types of reconstruction actions.

Dependability concept has been introduced through ISO-IEC standards (Standberg, 1991), (Tanasijević, 2007) as the most complete concept that describes availability of considered technical system, i.e. presents the most complete quality of service measure. Implementation of dependability concept in essence includes information about system behaviors during up and down time concerning design and logistic indicators (concrete information related to reliability, maintainability and maintenance support).

The problem, how to find “weak” components (with low dependability), at the BWE structure and reasons (design, maintenance, logistic) for their “weakness”, can be practically resolved by evaluation of dependability. A model for dependability evaluation has been developed in research (Tanasijević, 2007), (Ivezić et.al., 2008). This model has been based on fuzzy sets theory (Klir & Yuan, 1995) and has tried to completely absorb expertise opinions and judgments given in linguistic forms. However, complex, hierarchical structure of BWE has not been treated by this model, and synthesis of the information from different hierarchical levels is not clear.

To overcome this problem, this paper presents a model for determining the dependability of excavators based to fuzzy sets theory and fazzy algebra use. Fuzzy sets are used for identification and integration of reliability, maintainability and maintenance support performances to the dependability performance of single elements, as well as for the synthesis of partial assessment of the dependability to higher levels in the excavators' structure. Key role in the process of integration and synthesis, is to define how the composition of partial impact to overall level. In the paper max-min composition, also called pessimistic, is used. The idea is to make overall assessment equal to the partial virtual representative assessment. This assessment is identified as the best possible one between expected the worst partial grades.

2. EVALUTION OF DEPENDABILITY

Implementation of dependability concept was developed in detail in IEC-300 standards. The special attention was devoted to degree of customers' satisfaction with appropriate product, by defining requirements for dependability, as well as to the connection of producers and users organization. Dependability evaluation, in accordance with this should enable the analysis of partial indicators (reliability, maintainability and maintenance support) and their synthesis. In that way, estimation for verification of achieved availability of technical systems is obtained.

The first step in forming evaluations model is defining the hierarchical structure of technical systems, i.e. the decomposition of the system, in the case BWE. Excavator is considered as the four-level hierarchical structure (Durst & Vogt, 1986): component level, subsystem level, systems level and the highest level – excavator. Decomposition is performed based to construction – functional position. At the system level next nine systems can be identified: Digging, Transport of material, Transport of excavator, Boom lifting, Slewing of superstructure, Main structure, Accessory structure, Control system and Electro supply. Other levels in the hierarchical structure of the excavator will not be listed on this site due to limited space. It should be noted that the quality of the technical system evaluation largely depends on the decomposition, and that it is necessary to perform decomposition to as low construction levels as possible, but with clearly defined function.

2.1. Analyses of dependability

Dependability performance estimation is obtained regards to analysis of its indicators: reliability, maintainability and maintenance support. In order to identify quality of elements in terms of reliability, it is necessary to define a fuzzy set, i.e. names (linguistic variables) and membership functions μ. Five fuzzy sets are propesed, with names: highly reliable, very reliable, averagely reliable, acceptable reliable, unreliable. As the measuring unit, can be introduced class, as usually used concept for representing performances' quality (1st to 7th, so is 1 highest quality class, ie. with the highest reliability ...), for all three indicators. Hence, the structure of dependability indicators and linguistic variables with seven classes as measures of appropriate fuzzy sets will be as follows (Tanasijevic, 2007):

$\mu_R = \left(\mu^1{}_R, \mu^2{}_R, ..., \mu^n{}_R \right)$, for $n = 7$ class

$R_{(unreliable)} = (1/0; ...; 5/0; 6/0.25; 7/1)$

$R_{(acceptable\ r.)} = (1/0; ...; 4/0; 5/1;\ 6/0.5; 7/0)$

$R_{(averagely\ r.)} = (1/0; 2/0; 3/0.5;\ 4/1; 5/0.5;\ 6/0; 7/0)$

$R_{(very\ r.)} = (1/0; 2/1; 3/0.25;\ 4/0; ...; 7/0)$

$R_{(highly\ r.)} = (1/1; 2/0.25; 3/0;\ ...; 7/0)$

Maintainability is primary concerned to system design accommodation to maintenance actions. Generally, next five expressions of maintainability, apropos fuzzy sets, can be identified: optimal, easy, average, complicate and hard for maintenance. The position, shape and coverage of these linguistic variables, depending on the class is given in form (Tanasijevic, 2007):

$\mu_M = \left(\mu^1{}_M, \mu^2{}_M, ..., \mu^n{}_M \right)$, for $n = 7$ class

$M_{(hard)} = (1/0; ...; 5/0; 6/0.25; 7/1)$

$M_{(complicate)} = (1/0; ...; 4/0; 5/0.5; 6/1; 7/0)$

$M_{(average)} = (1/0; 2/0; 3/0.5; 4/1; 5/0.5; 6/0; 7/0)$

$M_{(easy)} = (1/0; 2/1; 3/0.5; 4/0; ...; 7/0)$

$M_{(optimal)} = (1/1; 2/0.25; 3/0; ...; 7/0)$

By analysis of maintenance conditions that usually exist at Serbia lignite mines and also at complex industrial systems four maintenance support systems can be identified: excellently developed well developed, limited and inexistence of maintenance support. The position, shape and coverage of these linguistic variables, depending on the class is given in form (Tanasijevic, 2007):

$\mu_L = \left(\mu^1{}_L, \mu^2{}_L, ..., \mu^n{}_L \right)$, for $n = 7$ class

$L_{(inexistence)} = (1/0; ...; 5/0; 6/0.25; 7/1)$

$L_{(limited)} = (1/0; 2/0; 3/0; 4/0.5; 5/1; 6/0.5; 7/0)$

$L_{(well\ developed)} = (1/0; 2/0.5; 3/1; 4/0.5; 5/0; 6/0; 7/0)$

$L_{(excellently\ dev.)} = (1/1; 2/0.75; 3/0; ...; 7/0)$

The next step is a synthesis of estimation for reliability *R*, maintainbility *M* and maintenance support *L* to the level of dependability *D*. Synthesis is done based on the corresponding fuzzy compositions. In the case "max-min" composition (Wang et.al., 1995) is used, defined as follows:

$$D = R \circ M \times L \tag{1}$$

Cartesian product (and the corresponding membership function) of two sets $M \times L$ as an indicator related to maintenance, i.e. related to the period while the system is out of operation, is defined as follows:

$$\mu_{M\times L} = \left(\mu^{ij}{}_{M\times L}\right)_{n\times n} \tag{2}$$

where is:

$$\mu^{ij}{}_{M\times L} = \min\left(\mu^{i}{}_{M}, \mu^{j}{}_{L}\right) \tag{3}$$

Finally, the membership functions for the set D can be obtained as follows:

$$\mu_D = \mu_{Ro\, M\times L} = \left(\mu^{j}{}_{D}\right)_{1\times n} \tag{4}$$

where is:

$$\mu^{j}{}_{D} = \max\left(\min\left(\mu^{1}{}_{R}, \mu^{1j}{}_{M\times L}\right), \ldots, \min\left(\mu^{n}{}_{R}, \mu^{nj}{}_{M\times L}\right)\right), \quad j = 1,2,\ldots,n \tag{5}$$

Thus defined "max-min" composition, locates the fuzzy set L as the "critical", in other words, in the case that some element of excavator has high reliability R and maintenance support L, dependability D rating will also be low.

As the output of fuzzy composition, dependability of elements is obtained in the form related to classes, as:

$\mu_D = \left(\mu^{1}{}_{D}, \mu^{2}{}_{D}, \ldots, \mu^{n}{}_{D}\right)$, or

D = (1/(0...1.0), 2/(0...1.0), 3/(0...1.0), 4/(0...1.0), 5/(0...1.0), 6/(0...1.0), 7/(0...1.0))

In relation to the class (1 to 7) dependability and their membership functions can be defined as: excellent, good, average and poor:

$D_{(poor)} = (1/0; \ldots; 5/0; 6/0.75; 7/1)$

$D_{(average)} = (1/0; 2/0; 3/0; 4/0.5; 5/1; 6/0.25; 7/0)$

$D_{(good)} = (1/0; 2/0.25; 3/1; 4/0.5; 5/0; 6/0; 7/0)$

$D_{(excellent)} = (1/1; 2/0.75; 3/0; \ldots; 7/0)$

Dependability can be identified (Tanasijević, 2010) according to the dependability fuzzy sets by center of mass point calculation Z:

$$Z = \frac{\sum_{i=1}^{7} \mu_{C_i} \cdot C}{\sum_{i=1}^{7} \mu_{C_i}} = 1 \ldots 7 \tag{6}$$

where is C class (1 to 7), μ_C membership funtion to the intersection of number Z and class C.

2.2. Synthesis of dependability

For the synthesis of membership functions μ_D fuzzy algebra, i.e. max-min composition can be used. If the membership functions D of the elements are observed, the possible combinations of the fuzzy sets of dependability can be identified and for each of them the outcome can be determined. It is customary to use the "IF-THEN" rules. E.g. IF all the elements of the partial evaluation are "excellent", THEN the outcome of a set of elements (at higher hierarchical level) is "excellent". In the case that a combination of different elements assessments is occurred, average assessment should be calculated and determination of outcome should be done based to it. Max-min composition is then applied as follows:

- for each combination, search for the MINimum value of the intersection of dependability fuzzy sets and the value of the Z for each element;
- for each of the outcomes find the MAXimum between previously identified minimums;
- finally, the maximum value is normalized to 1.

In this way, the assessment of dependability for set of elements is obtained as follows:

$D = ((\mu_1$, "poor"), (μ_2, "average"), (μ_3, "good"), (μ_4, "excellent"))

3. CASE STUDY: EXCAVATOR SCHRS 630, KOLUBARA – TAMNAVA WEST FIELD

As an application example of developed methods for dependability determination, analysis of BWE (first level of excavators decomposition) will be presented, as well as the synthesis to the level of excavator. These systems will be considered as elements, and excavator as a technical system. Estimations are obtained as experts' by the staff employed operation and maintenance.

1. System for digging:

Reliability of the system for digging was evaluated in inquiry as very reliable by all engineers (100%). However, two of them (20%) selected also averagely reliable. In accordance with fuzzy sets R, gets the evaluation of the reliability of the system for digging, as given in Table 1

Table 1. Procedure of reliability evaluation of digging system

Linguistic variable	% of respondents	Class 1.	2.	3.	4.	5.	6.	7.
Very	100%	0x100%	1.0x100%	0.5x100%	0x100%	0x100%	0x100%	0x100%
Average	20%	0x20%	0x20%	0.5x20%	1.0x20%	0.5x20%	0x20%	0x20%
ΣR_1		0	1,0	0,6	0,2	0	0	0

$R_1 = (1/0, 2/1.0, 3/0.6, 4/0.2, 5/0, 6/0, 7/0)$

In the same way the maintainability and maintenance support are rated, for system for digging:

$M_1 = (1/0, 2/1.0, 3/0.5, 4/0.1, 5/0, 6/0, 7/0)$, $L_1 = (1/0, 2/0, 3/0.1, 4/0.5, 5/1.0, 6/0.4, 7/0)$

Max-min composition is expressed as follows:

$$\mu_{M\times L} = \left(\mu^{ij}{}_{M\times L}\right)_{7\times 7}$$

$$\mu^{ij}{}_{M\times L} = \min\left(\mu^{j}{}_{M}, \mu^{j}{}_{L}\right) = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.1 & 0.5 & 1.0 & 0.4 & 0 \\ 0 & 0 & 0.1 & 0.5 & 0.5 & 0.4 & 0 \\ 0 & 0 & 0.1 & 0.1 & 0.1 & 0.1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\mu^{j}{}_{D} = \max\left(\min\left(\mu^{1}{}_{R}, \mu^{1j}{}_{M\times L}\right), \ldots, \min\left(\mu^{7}{}_{R}, \mu^{7j}{}_{M\times L}\right)\right)_{j=1,\ldots,7}$$

$$\mu_D = \mu_{R_o\, M\times L} = \left(\mu^{j}{}_{D}\right)_{1\times 7} = \left(0;\, 0;\, 0.1;\, 0.5;\, 1.0;\, 0.4;\, 0\right)$$

Dependability for the system for digging is finally obtained in the form:

$D_1 = \left(1/0;\, 2/0;\, 3/0.1;\, 4/0.5;\, 5/1.0;\, 6/0.4;\, 7/0\right)$

2. System materials' transport

$R_2 = \left(1/0.8;\, 2/1.0;\, 3/0.1;\, 4/0;\, 5/0;\, 6/0;\, 7/0\right)$

$M_2 = \left(1/1.0;\, 2/0.6;\, 3/0;\, 4/0;\, 5/0;\, 6/0;\, 7/0\right)$

$L_2 = \left(1/0.7;\, 2/1.0;\, 3/0.3;\, 4/0;\, 5/0;\, 6/0;\, 7/0\right)$

$D_2 = \left(1/0.7;\, 2/0.8;\, 3/0.3;\, 4/0;\, 5/0;\, 6/0;\, 7/0\right)$

3. System for excavator's transport

$R_3 = \left(1/0;\, 2/0.3;\, 3/0.7;\, 4/1.0;\, 5/0.2;\, 6/0;\, 7/0\right)$

$M_3 = \left(1/0;\, 2/1.0;\, 3/0.4;\, 4/0.1;\, 5/0;\, 6/0;\, 7/0\right)$

$L_3 = \left(1/0;\, 2/0.3;\, 3/1.0;\, 4/0.5;\, 5/0.2;\, 6/0;\, 7/0\right)$

$D_3 = \left(1/0;\, 2/0.3;\, 3/0.4;\, 4/0.4;\, 5/0.2;\, 6/0;\, 7/0\right)$

4. Boom lifting

$R_4 = \left(1/0.2;\, 2/1.0;\, 3/0.4;\, 4/0;\, 5/0;\, 6/0;\, 7/0\right)$

$M_4 = \left(1/0.1;\, 2/1.0;\, 3/0.6;\, 4/0;\, 5/0;\, 6/0;\, 7/0\right)$

$L_4 = \left(1/0.1;\, 2/0.6;\, 3/1.0;\, 4/0.2;\, 5/0;\, 6/0;\, 7/0\right)$

$D_4 = \left(1/0.1;\, 2/0.6;\, 3/1.0;\, 4/0.2;\, 5/0;\, 6/0;\, 7/0\right)$

5. Slewing of superstructure

$R_5 = \left(1/0;\, 2/1.0;\, 3/0.7;\, 4/0.4;\, 5/0.1;\, 6/0;\, 7/0\right)$

$M_5 = \left(1/0;\, 2/1.0;\, 3/0.7;\, 4/0.3;\, 5/0;\, 6/0;\, 7/0\right)$

$L_5 = \left(1/0;\, 2/0.4;\, 3/1.0;\, 4/0.4;\, 5/0.1;\, 6/0;\, 7/0\right)$

$D_5 = \left(1/0;\, 2/0.4;\, 3/1.0;\, 4/0.4;\, 5/0.1;\, 6/0;\, 7/0\right)$

6. Main structure

$$R_6 = (1/0.1;\, 2/1.0;\, 3/0.5;\, 4/0.1;\, 5/0;\, 6/0;\, 7/0)$$
$$M_6 = (1/0.3;\, 2/1.0;\, 3/0.3;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$
$$L_6 = (1/1.0;\, 2/0.7;\, 3/0.1;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$
$$D_6 = (1/1.0;\, 2/0.7;\, 3/0.1;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$

7. Accessory structure

$$R_7 = (1/0.2;\, 2/1.0;\, 3/0.5;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$
$$M_7 = (1/0.3;\, 2/1.0;\, 3/0.3;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$
$$L_7 = (1/1.0;\, 2/0.7;\, 3/0.1;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$
$$D_7 = (1/1.0;\, 2/0.7;\, 3/0.1;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$

8. Electr control

$$R_8 = (1/1.0;\, 2/0.25;\, 3/0;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$
$$M_8 = (1/1.0;\, 2/0.25;\, 3/0;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$
$$L_8 = (1/1.0;\, 2/0.75;\, 3/0;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$
$$D_8 = (1/1.0;\, 2/0.75;\, 3/0;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$

9. Electro supply

$$R_9 = (1/1.0;\, 2/0.25;\, 3/0;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$
$$M_9 = (1/1.0;\, 2/0.25;\, 3/0;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$
$$L_9 = (1/1.0;\, 2/0.75;\, 3/0;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$
$$D_9 = (1/1.0;\, 2/0.75;\, 3/0;\, 4/0;\, 5/0;\, 6/0;\, 7/0)$$

In the second step of synthesis, Z values are calculated for each $n = 9$ systems:

$$Z_1 = \frac{\sum_{i=1}^{7} \mu_{C_i} \cdot C}{\sum_{i=1}^{7} \mu_{C_i}} = \frac{0 \cdot 1 + 0 \cdot 2 + 0.1 \cdot 3 + 0.5 \cdot 4 + 1.0 \cdot 5 + 0.4 \cdot 6 + 0 \cdot 7}{0 + 0 + 0.1 + 0.5 + 1.0 + 0.4 + 0} = 4.85$$

$$Z_2 = 1.78;\, Z_3 = 3.38;\, Z_4 = 2.68;\, Z_5 = 3.11;\, Z_6 = 1.50;\, Z_7 = 1.50;\, Z_8 = 1.43;\, Z_8 = 1.43$$

They are further presented depending on the fuzzy sets D, and the value of membership functions $\mu(D)$ are read for the intersection point of Z values and corresponding reliability fuzzy sets (Table 2).

Table 2. Intersections of dependability fuzzy sets and center of mass point for excavator systems

Fuzzy set \ Center of mass	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9
Poor									
Average	1.0000								
Good		0.0833	1.0000	0.7632	1.0000				
Excellent		0.9167		0.2368		1.0000	1.0000	1.0000	1.0000

On the basis of defined intersections, four combinations of estimations for nine systems of excavators are realistic, and the expected outcomes are (Table 3):

Table 3. Outcomes by fuzzy sets combinations of dependability for excavator systems

Comb. \ System	1.	2.	3.	4.	5.	6.	7.	8.	9.	Outcomes
1.	A	G	G	G	G	E	E	E	E	G
2.	A	E	G	G	G	E	E	E	E	G
3.	A	G	G	E	G	E	E	E	E	G
4.	A	E	G	E	G	E	E	E	E	E

In the table, assessments are marked by letters (E - excellent, etc..), and outcomes are determined by allocation of numerical value to each linguistic evaluation (excellent = 4, good = 3, etc..), average evaluation is:

$I_{1.comb.} = \frac{2+3+3+3+3+4+4+4+4}{9} = 3.33$, belong to outcome ″good″;

$I_{2.comb.} = 3.44 \rightarrow$ good;

$I_{3.comb.} = 3.44 \rightarrow$ good;

$I_{4.comb.} = 3.55 \rightarrow$ excellent.

Application of max-min composition is shown in Table 4:

Table 4. Structure of max-min composition for the synthesis of the system of excavator

Outcome	P	A	G	E
Combination	MIN for outcome			
1.	0	0	0.0833	0
2.	0	0	0.7632	0
3.	0	0	0.0833	0
4.	0	0	0	0.2368
MAX	0	0	0.7632	0.2368
Normal.	0	0	0.7632	0.2368

In this way, assessment of dependability of bucket wheel excavator SchRs 630 is: $D_{(B.W.E)}$ = ((0, "poor"), (0, "average"), (0.7632, "good"), (0.2368, "excellent"))

For the observed excavator can be said that his Dependability in large measure on the 76% good, and that to that extent be expected to have sufficient remaining capabilities.

4. CONCULSION

Exposed mathematical and conceptual model of excavators' dependability evaluation, based to fuzzy theory, has been tried to fully absorb all the influential factors on the remaining capabilities these machine. Thereby, evaluation of the remaining capabilities was done by dependability' assessment. Dependability is overall indicator for quality of service, and considers simultaneously reliability, maintainability and maintenance support. As bucket wheel excavator is a technical system with a complex hierarchical structure, synthesis of information given in fuzzy form from the level of components to subsystems, functional systems and whole bucket wheel excavator is necessary.

This fuzzy form is found as the most suitable for introduction of knowledge and experiences accumulated during BWE design, operation and maintenance, as well as related to BWE structure and its logistic characteristics. Presented model can be used as a simple tool for fast estimation of dependability and remaining capability also, for BWE, based to experts' judgments. The model is shown in detail on the excavator SchRs 630. Proposed model can easily be used for quality of service assessment for other technical systems with complex hierarchical structure.

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