Expert Systems with Applications 39 (2012) 8940–8946

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Effectiveness assessment of agricultural machinery based on fuzzy sets theory

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ARTICLE INFO

Keywords:
Agricultural machinery
Effectiveness
Fuzzy set
Max–min composition

ABSTRACT

The quality of service of agricultural machinery represents one of the basic factors for successful agricultural production. In this sense, there is a clear need for defining the exact indicator of the quality of these machines, according to which it could be possible to determine which machine is optimal for different working conditions. The concept of effectiveness represents one of synthesis indicators of the quality of service of the technical systems. In this paper the effectiveness is defined using the fuzzy set theory, and reliability, maintainability and functionality are used as influence indicators of the effectiveness. In that sense the model for assessing the effectiveness of tractor as a typical representative of agro machinery has been formed. The model is based on integration of linguistic description of the above mentioned influence indicators using fuzzy set theory and max–min composition. The model was tested on the example of three tractors of the same category, which are exploited in climatic and soil conditions in the wider Belgrade (Serbia) area. Even if the conditions in this experiment were approximately equal, the difference of the achieved effects was attained and very significant, compared to other operation parameters.

1. Introduction

Rapid expansion of global demands for agricultural products has caused much greater development of agricultural technique, apropos machines and equipments. It is widely recognized that contemporary agricultural systems demand careful and detailed planning and control of all relevant biological, technical, technological and other processes. An accurate and reliable predicting of the final outcome for each specified operation, as well as for the complete crop production process, is of special importance. Demands have intensified the introduction of sophisticated experimental, mathematical, statistical, mechanical and other methods in agricultural sciences during the last few decades. Besides the demands described above, an adequate technical system has to satisfy the criteria of productivity, imposed by the conditions of desired crop production. In most cases, the capacity of tractor-machinery systems on farms in Serbia is much over the optimal level (Nikolić, 2005), increasing the costs of crop production. Nowadays, the existing mathematical optimization methods, supported by the high-performance computers, can efficiently resolve the optimization problems (Dette & Weber, 1990; Duffy et al., 1994; Mileusnić, 2007; etc.). The formation of an optimal technical system in order to produce cheaper food, highly impacted reliability of tractors, its maintainability, and the functionality of the system.

With the beginning of systems' sciences development, practically after the II World War, in appropriate engineering and scientific literature a series of concepts have been defined, with the idea to describe essential characteristics of technical systems from the point of their quality of service. Reliability as the indicator of technical system behaviors in operation, and maintainability as the indicator of technical system behaviors during the period of failures can be stated as the most recognizable concepts. These two concepts and their implementations had the most progressive development. The concept of effectiveness was defined later in attempt to describe simultaneously technical systems' behaviors in operation and in periods of failure. This concept considered reliability and availability performances, as well as functionality of proposed technical system design (Papic & Milovanovic, 2007). In other words, the effectiveness of a technical system can be articulated as probability that a technical system will be put in function successfully and perform required criterion function within the limits of allowed discrepancies for given time period and given surrounding conditions. Although in the same spirit, some authors have defined effectiveness somewhat differently. In (Ebramhimipour & Suzuki, 2006) effectiveness was defined as overall indicator which contains efficiency, reliability and availability. These two cited definitions include parallel concerning of reliability and availability, although availability includes reliability and maintainability (Ivezić, Tanasijević, & Ignjatović, 2008). Therefore it can be agreed upon that the effectiveness is influenced by reliability, maintainability and functionality. Reliability is defined as characteristic of a system to continuously keep operating ability within the limits of allowed discrepancies

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doi:10.1016/j.eswa.2012.02.013

during the calendar period of time; maintainability as capacity of the system for prevention and finding failures and damages, for renewing operating ability and functionality through technical attending and repairs; and functionality as the degree of fulfilling the functional requirements, namely the adjustment to environment, or more precisely to the conditions in which the system operates.

In the case of monitoring reliability and maintainability it is common to monitor the time picture of state (Fig. 1) according to which the functions of reliability and maintainability can be determined, as well as the mean time in operation and the mean time in failure.

The main problem that occurs in forming the time picture of state is data monitoring and recording. In real conditions the machines should be connected to information system which would precisely record each failure, duration and procedure of repair. This is usually expensive and improvised monitoring of the machine performance, namely of its shut downs, is imprecise. Moreover, statistical data processing provided by the time picture of the state requires that all machines work under equal conditions, which is difficult to achieve. As for the functionality of the technical system, there is no common way for its measuring and quantification. This is the reason why in this paper, in order to assess the effectiveness, expertise judgments of the employed in the working process of the analyzed machines will be used. Application of expertise judgments has been largely used in literature, primarily for data processing and the assessment of the technical systems in terms of: risk (Li & Liao, 2007), safety (Wang 2000; Wang, Yang, & Sen, 1995) or dependability (Ivezić et al., 2008; Tanasijevic, Ivezic, Ignjatovic, & Polovina, 2011). Expertise judgment is naturally given in linguistic form. Thereby, as the logical mathematical and conceptual model for processing the expertise judgments, namely for calculating with linguistic descriptions, the fuzzy set theory was used (Klir & Yuan, 1995; Zadeh, 1996). Application of fuzzy sets today represents one of the most frequently used tools for solving the problems in various areas of optimization (Huang, Gu, & Du, 2006) and identification (Chan, 1996) regarding engineering problems. Cai (1996) presents the overview of various application aspects of fuzzy methodology in system failure engineering, which is a problem close to effectiveness assessment.

Application of fuzzy logic theory and experts systems (Liao, 2011; Liebowitz, 1988) in general is also used for solving the optimizations problems from area of agro machinery. In article (Rohani, Abbaspour-Fard, & Abdolahpour, 2011) on the base of neural networks application, failures on tractors were predicted. In article (Ye, Yu, & Zhao, 2010) fuzzy mathematics, reliability theory and multi-objective optimization technology were applied to design tractor's final transmission. Predictability of machine downtimes and reliability, significantly depends on its effectiveness of technical systems.

The idea of this paper is to establish the model for effectiveness determination according to fuzzy sets theory utilization. Thereby the fuzzy sets were used to analyze reliability, maintainability and functionality performances (partial indicators of effectiveness) as well as for their integration into effectiveness. In this way effective model for the quality assessment of the technical systems in their working conditions is obtained. The model can be used as criteria for decision making related to any procedure in purchasing, operation or maintenance of the system, for prediction of repair and maintenance costs. Quality and functionality of the proposed model is shown in effectiveness determination of agricultural machinery, precisely tractors.

2. Effectiveness performance assessment based on fuzzy sets theory

Mathematical and conceptual model of effectiveness assessment is practically summarized in two steps: fuzzy proposition of effectiveness partial indicators; and fuzzy composition of mentioned indicators into one – synthesized. Fuzzy proposition is procedure for representing the statement that includes linguistic variables based on available information about considered technical system. In that sense it is necessary to define the names of linguistic variables that represent different grades of effectiveness of considered technical system and define the fuzzy sets that describe the mentioned variables. Composition is a model that provides structure of indicators' influences to the effectiveness performance.

2.1. Fuzzy model of problem solving

The first step in the creation of fuzzy model for effectiveness (E) assessment is defining linguistic variables related to itself and to reliability (R), maintainability (M) and functionality (F). Regarding number of linguistic variables, it can be found that seven is the maximal number of rationally recognizable expressions that human can simultaneously identify (Wang et al., 1995). However, for identification of considered characteristics even the smaller number of variables can be useful because flexibility of fuzzy sets to include transition phenomena as experts' judgments commonly is (Ivezić et al., 2008). According to the above, five linguistic variables for representing effectiveness performances are included: poor, adequate, average, good and excellent. Form of these linguistic variables is given as appropriate triangular fuzzy sets (Klir & Yuan, 1995), and they are presented in Fig. 2.

In Fig. 2, $j = 1,\ldots,5$ practically represents measurement units of effectiveness.

Thereby, partial indicators of effectiveness: R, M and F, presented as membership function μ:

$$\mu_R = (\mu_R^1,\ldots,\mu_R^5),\quad \mu_M = (\mu_M^1,\ldots,\mu_M^5),\quad \mu_F = (\mu_F^1,\ldots,\mu_F^5) \qquad (1)$$

In the next step, max–min composition is performed on them. Max–min composition, also called pessimistic, is often used in fuzzy algebra as a synthesis model (Ivezić et al., 2008; Tanasijevic et al., 2011; Wang et al., 1995; Wang 2000). The idea is to make overall assessment (E) equal to the partial virtual representative assessment. This assessment is identified as the best possible one between the worst partial grades expected (R, M or F).

It can be concluded that all elements of (R, M and F) that make the E have equal influence on E, so that max–min composition will be used, which in parallel way treats the partial ones onto the

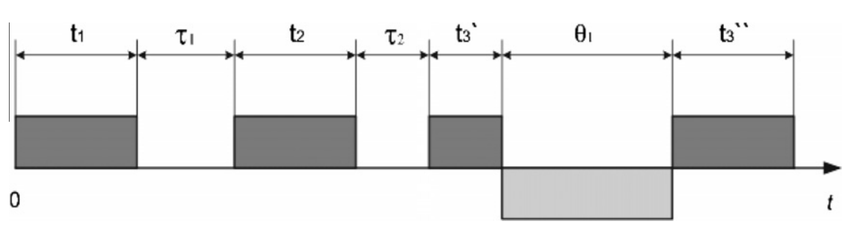

Fig. 1. Time picture of state, t – time spent in operation, τ – time in failure, θ – time of planned shut down due to preventive maintenance.

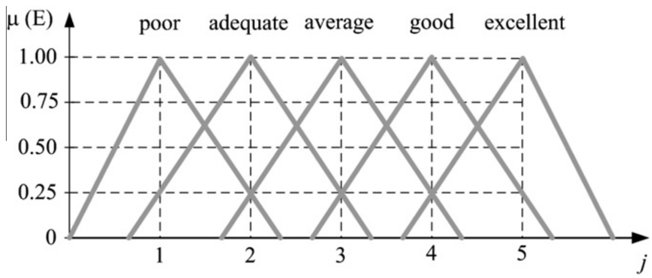

Fig. 2. Effectiveness fuzzy sets.

synthetic indicator. In literature (Ivezić et al., 2008; Wang et al., 1995) max–min compositions which by using operators ''AND'' and ''OR'' provide an advantage to certain elements over the others in the process of synthesis, are also used.

Precisely, if we look at three partial indicators, namely their membership function (1), it is possible to make $C = j^3 = 5^3$ combinations of their membership functions. Each of these combinations represents one possible synthesis effectiveness assessment (E).

$$E = \left[\mu_R^{j=1,\ldots,5}, \mu_M^{j=1,\ldots,5}, \ldots, \mu_F^{j=1,2,\ldots 5}\right], \quad \text{for all } c = 1 \text{ to } C \tag{2}$$

If we take into account only values if $\mu_{R,M,F}^{j=1,\ldots,5} \neq 0$, we get combinations that are named outcomes (o = 1 to O, where $O \subseteq C$).

Further, for each outcome its values are calculated (Ω_c). The outcome which would suit the combination c, it would be calculated following the equations:

$$\Omega_c = \frac{\left[\sum_{R,M,F} j\right]_c}{3} \tag{3}$$

Finally, all of these outcomes are treated with max–min composition, as follows:

(i) For each outcome search for the MINimum value of $\mu_{R,M,F}$ in vector E_c (2). The minimum which would suit the combination o, it would be calculated following the equations:

$$\mathrm{MIN}_0 = \min\{\mu_R^{j=1,\ldots,5}, \mu_M^{j=1,\ldots,5} \ldots, \mu_F^{j=1,\ldots,5}\}, \text{for all } o = 1 \text{ to } O \tag{4}$$

(ii) Outcomes are grouped according to their values Ω_c (3), namely the size of j.

(iii) Find the MAXimum between previously identified minimums (i) for each group (ii) of outcomes. The maximum which would suit value of j, would be calculated following the equations:

$$\mathrm{MAX}_j = \max\{\mathrm{MIN}_o\}, \text{ for every } j \tag{5}$$

E assessment of technical system is obtained in the form:

$$\mu_E = (\mathrm{MAX}_{j=1}, \ldots, \mathrm{MAX}_{j=5}) = (\mu_E^1, \ldots, \mu_E^5) \tag{6}$$

This expression (6) is necessary to map back to the E fuzzy sets (Fig. 2). Best-fit (Wang et al., 1995), method is used for transformation of E description (6) to form that defines grade of membership to fuzzy sets: poor, adequate, average, good and excellent. This procedure is recognized as identification. Best-fit method uses distance (d) between E obtained by ''max–min'' composition (6) and each of the E expressions (according to Fig. 2), to represent the degree to which E is confirmed to each of fuzzy sets of effectiveness (Fig. 2).

$$d_i(E_j, H_i) = \sqrt{\sum_{j=1}^{5}(\mu^j E - \mu^j H_j)^2}, \quad j = 1, \ldots, 5; H_i = \{\text{excellent}, \text{goodaverage}, \text{adequate}, \text{poor}\} \tag{7}$$

where is (according to Fig. 2):

$\mu_{exc.} = (0,0,0,0.25,1)$; $\mu_{good} = (0,0,0.25,1,0.25)$;
$\mu_{aver.} = (0,0.25,1,0.25,0)$; $\mu_{adeq.} = (0.25,1,0.25,0,0)$;
$\mu_{poor} = (1,0.25,0,0,0)$.

The closer μ_E (6) is to the ith linguistic variable, the smaller d_i is. Distance d_i is equal to zero, if μ_E (6) is just the same as the ith expression in terms of the membership functions. In such a case, E should not be evaluated to other expressions at all, due to the exclusiveness of these expressions.

Suppose $d_{i\min}$ (i = 1,...,5) is the smallest among the obtained distances for E_j and let $\alpha_1, \ldots, \alpha_5$ represent the reciprocals of the relative distances (which is calculated as the ratio between corresponding distance d_i (7) and the mentioned values $d_{i\min}$). Then, α_i can be defined as follows:

$$\alpha_i = \frac{1}{d_i/d_{i\min}}, \quad i = 1, \ldots, 5 \tag{8}$$

If $d_i = 0$ it follows that $\alpha_i = 1$ and the others are equal to zero. Then, α_i can be normalized by:

$$\beta_i = \frac{\alpha_j}{\sum_{m=1}^{5}\alpha_{im}}, \quad i = 1, \ldots, 5 \quad \sum_{i=1}^{5}\beta_i = 1 \tag{9}$$

Each β_i represents the extent to which E belongs to the ith defined E expressions. It can be noted that if E_i completely belongs to the ith expression then β_i is equal to 1 and the others are equal to 0. Thus β_j could be viewed as a degree of confidence that E_i belongs to the ith E expressions. Final expression for E performance at the level of technical system, have been obtained in the form (10)

$$E_i = \{(\beta_{i=1}, \text{“poor”}), (\beta_{i=2}, \text{“adequate”}), (\beta_{i=3}, \text{“good”}), (\beta_{i=4}, \text{“average”}), (\beta_{i=5}, \text{“excellent”})\} \tag{10}$$

3. An illustrative example

As an illustrative example of evaluation of agriculture machinery effectiveness, the comparative analysis of three tractors A[1] B[2], and C[2] is given in this article.

In tractor A a 7.146 l engine LO4V TCD 2013 is installed. Thanks to the reserves of torque from 35%, the tractor is able to meet all the requirements expected in the worst performing farming operations in agriculture. Total tractor mass is 16,000 kg. According to OECD (CODE II) report maximum power measured at the PTO shaft is 243 kW at 2200 rpm with specific fuel consumption of 198 g/kW h (ECE-R24). Maximum engine torque is 1482 Nm at engine regime of 1450 rpm. Transmission gear is ''vario'' continious transmision. Linkage mechanism is a Category II/III with lifting force of 11,800 daN.

In tractors B[2] and C[2] 8.134 l engine 6081HRW37 JD is installed, with reserve torque of 40%, and this tractor was able to meet all the requirements expected in the worst performance of the farming operations in agriculture. Total tractor weight is 14,000 kg. According to OECD (CODE II) report maximum power measured at the PTO shaft is 217 kW at 2002 rpm with specific fuel consumption of 193 g/kW h (ECE-R24). Maximum torque is 1320 Nm at engine revs of 1400 rpm. Transmission is ''AutoPower. Linkage mechanism is a Category II/III with lifting force of 10,790 daN.

Both models have electronically controlled tractor engine and fuel supply system that meets the regulations on emissions.

From the submitted technical characteristics of the tractor A, B and C it is seen that all three tractors are fully functional for

[1] Tractor Fendt Vario 936.
[2] Tractor John Deere 8520.

performing difficult operations for different technologies of agricultural production. Tractors B and C have the same technical characteristics, and practice is the same type and model, except that the tractor B entered into operation in May 2007, a tractor C in June 2007. A tractor on the experimental farm, which is the technical documentation for the base model, comes into operation in July 2009. The main task of maintaining agricultural techniques is to provide functionality and reliability of machines. Maintenance of all three tractors is done by machine shop owned by the user upgrade option.

Ten engineers (analysts) working on maintenance and operation of tractors were interviewed. Their evaluation of R, D and F are given in Table 1.

First, the effectiveness of tractor A is calculated. It can be seen that the reliability was assessed as excellent by six out of ten analysts (6/10 = 0.6), as average by three (0.3) and as good by one (0.1). In this way the assessment R is obtained in the form (11):

$$R = (0.6/\text{exc},\ 0.3/\text{good},\ 0.1/\text{aver},\ 0/\text{adeq},\ 0/\text{poor}) \tag{11}$$

In the same way the assessments for M and F are obtained:

$$M = (0.4/\text{exc},\ 0.4/\text{good},\ 0.2/\text{aver},\ 0/\text{adeq},\ 0/\text{poor})$$
$$F = (0.5/\text{exc},\ 0.5/\text{good},\ 0/\text{aver},\ 0/\text{adeq},\ 0/\text{poor})$$

In the next step, these assessments are mapped on fuzzy sets (Fig. 1) in order to obtain assessment in the form (1). For example, Reliability in this example is determined as (11), where it is to linguistic variable excellent joined weight 0.6. Thereby, fuzzy set excellent is defined as: R_{exc} = (1/0, 2/0, 3/0, 4/0.25, 5/1.0) (according to Fig. 1). In this way the specific values of fuzzy set excellent $R_{exc0.6} = (1/(0 \times 0.6),\ 2/(0 \times 0.6),\ 3/(0 \times 0.6),\ 4/(0.25 \times 0.6),\ 5/(1.0 \times 0.6)\}$ are obtained. The remaining four linguistic variables are treated in the same way. In the end for each $j = 1,\ldots,5$ specific membership functions (last row, Table 2) are added into the final fuzzy form (1) of tractor A reliability:

$$\mu_{RA} = (0, 0.025, 0.175, 0.475, 0.675)$$

In the same way, based on the questionnaire (Table 1) values for maintainability and functionality are obtained:

$$\mu_{MA} = (0, 0.05, 0.3, 0.55, 0.5);$$
$$\mu_{FA} = 0, 0, 0.125, 0.625, 0.625) \tag{12}$$

These fuzzificated assessments (11) and (12) are necessary to synthesize into assessment of effectiveness, using max–min logics. In this case it is possible to make $C = 5^3 = 125$ combinations, out of which the 48 outcomes. First outcome would be for combination 2-2-3: $E_{2\text{-}2\text{-}3} = [0.025, 0.05, 0.125]$, where is $\Omega_{2\text{-}2\text{-}3} = (2 + 2 + 3)/3 = 2$ (rounded as integer). Smallest value among the membership functions of this outcome is 0.025. Other outcomes and corresponding values of Ω_c are shown in Table 3. All these outcomes can be grouped around sizes Ω = 2, 3, 4 and 5.

For example, for outcome $\Omega = 5$ it can be written:

$$E_{4-5-5} = [0.475, 0.5, 0.625]; E_{5-4-5} = [0.675, 0.55, 0.625]; E_{5-5-4} = [0.675, 0.5, 0.625]; E_{5-5-5} = [0.675, 0.5, 0.625]$$

Further, for each of them, minimum between membership function is sought:

Table 1
Results of questionnaire.

Analyst		Linguistic variables														
		Tractor A					Tractor B					Tractor C				
		Excellent	Good	Average	Adequate	Poor	Excellent	Good	Average	Adequate	Poor	Excellent	Good	Average	Adequate	Poor
1	R		x				x						x			
	M	x					x						x			
	F		x					x					x			
2	R		x						x					x		
	M			x				x						x		
	F		x						x					x		
3	R	x						x					x			
	M		x						x					x		
	F	x							x					x		
4	R		x					x						x		
	M		x						x					x		
	F	x						x							x	
5	R	x						x					x			
	M	x							x			x				
	F		x					x					x			
6	R			x			x					x				
	M			x			x						x			
	F		x					x				x				
7	R	x							x						x	
	M		x						x					x		
	F	x								x					x	
8	R	x					x						x			
	M	x					x						x			
	F		x					x						x		
9	R	x						x					x			
	M	x					x					x				
	F	x						x					x			
10	R	x					x								x	
	M		x					x						x		
	F	x					x									x

Table 2
Calculation of specific values of fuzzy sets.

	1	2	3	4	5
0.6/exc.	0×0.6	0×0.6	0×0.6	0.25×0.6	1.0×0.6
0.3/good	0×0.3	0×0.3	0.25×0.3	1.0×0.3	0.25×0.3
0.1/aver.	0×0.1	0.25×0.1	1.0×0.1	0.25×0.1	0×0.1
0/adeq.	0.25×0	1.0×0	0.25×0	0×0	0×0
0/poor	1.0×0	0.25×0	0×0	0×0	0×0
$\sum$**R**	**0**	**0.025**	**0.175**	**0.475**	**0.675**

Table 3
Structure of MAX–MIN composition.

Comb.	Ω	μ	MIN			
			2	3	4	5
2-2-3	2	[0.025,0.05,0.125]	0.025			
2-2-4	3	[0.025,0.05,0.625]		0.025		
2-2-5	3	[0.025,0.05,0.625]		0.025		
2-3-3	3	[0.025,0.3,0.125]		0.025		
2-3-4	3	[0.025,0.3,0.625]		0.025		
2-3-5	3	[0.025,0.3,0.625]		0.025		
2-4-3	3	[0.025,0.55,0.125]		0.025		
2-4-4	3	[0.025,0.55,0.625]		0.025		
2-4-5	4	[0.025,0.55,0.625]			0.025	
2-5-3	3	[0.025,0.5,0.125]		0.025		
2-5-4	4	[0.025,0.5,0.625]			0.025	
2-5-5	4	[0.025,0.5,0.625]			0.025	
3-2-3	3	[0.175,0.05,0.125]		0.05		
3-2-4	3	[0.175,0.05,0.625]		0.05		
3-2-5	3	[0.175,0.05,0.625]		0.05		
3-3-3	3	[0.175,0.3,0.125]		0.125		
3-3-4	3	[0.175,0.3,0.625]		0.175		
3-3-5	4	[0.175,0.3,0.625]		0	0.175	
3-4-3	3	[0.175,0.55,0.125]		0.125		
3-4-4	4	[0.175,0.55,0.625]			0.175	
3-4-5	4	[0.175,0.55,0.625]			0.175	
3-5-3	4	[0.175,0.5,0.125]			0.125	
3-5-4	4	[0.175,0.5,0.625]			0.175	
3-5-5	4	[0.175,0.5,0.625]			0.175	
4-2-3	3	[0.475,0.05,0.125]		0.05		
4-2-4	3	[0.475,0.05,0.625]		0.05		
4-2-5	4	[0.475,0.05,0.625]			0.05	
4-3-3	3	[0.475,0.3,0.125]		0.125		
4-3-4	4	[0.475,0.3,0.625]			0.3	
4-3-5	4	[0.475,0.3,0.625]			0.3	
4-4-3	4	[0.475,0.55,0.125]			0.125	
4-4-4	4	[0.475,0.55,0.625]			0.475	
4-4-5	4	[0.475,0.55,0.625]			0.475	
4-5-3	4	[0.475,0.5,0.125]			0.125	
4-5-4	4	[0.475,0.5,0.625]			0.475	
4-5-5	5	[0.475,0.5,0.625]				0.475
5-2-3	3	[0.675,0.05,0.125]		0.05		
5-2-4	4	[0.675,0.05,0.625]			0.05	
5-2-5	4	[0.675,0.05,0.625]			0.05	
5-3-3	4	[0.675,0.3,0.125]			0.125	
5-3-4	4	[0.675,0.3,0.625]			0.3	
5-3-5	4	[0.675,0.3,0.625]			0.3	
5-4-3	4	[0.675,0.55,0.125]			0.125	
5-4-4	4	[0.675,0.55,0.625]			0.55	
5-4-5	5	[0.675,0.55,0.625]				0.55
5-5-3	4	[0.675,0.5,0.125]			0.125	
5-5-4	5	[0.675,0.5,0.625]				0.5
5-5-5	5	[0.675,0.5,0.625]				0.5
MAX			0.025	0.175	0.55	0.55

$$\mathrm{MIN}E_{4-5-5} = \min\{0.475, 0.5, 0.625\} = 0.475; \mathrm{MIN}E_{5-4-5} = 0.55; \mathrm{MIN}E_{5-5-4} = 0.5; \mathrm{MIN}E_{5-5-5} = 0.5$$

Between these minimums, in the end it seeks maximum:

$$\mathrm{MAX}\Omega_{\delta=5} = \max\{0.475, 0.55, 0.5, 0.5\} = 0.55$$

Also for other values: Ω: $\mathrm{MAX}_{\Omega=2} = 0.025$; $\mathrm{MAX}_{\Omega=3} = 0.175$; $\mathrm{MAX}_{\Omega=4} = 0.55$ (Table 1.)

Finally, we get expression for membership function of effectiveness of tractor A:

$$\mu_{EA} = (0, 0.025, 0.175, 0.55, 0.55)$$

Best-fit method (7–9) and proposed E fuzzy set (Fig. 1) give the final effectiveness assessment for the tractor A:

$$d_1(E,exc) = \sqrt{\sum_{j=1}^{5}(\mu_E^j - \mu^j exc)^2} = \sqrt{(0-0)^2 + (0.025-0)^2 + (0.175-0)^2 + (0.55-0.25)^2 + (0.55-1)^2} = 0.56899$$

where is : $\mu_E = (0, 0.025, 0.175, 0.55, 0.55)$
$\mu_{exc} = (0, 0, 0, 0.25, 1)$

For other fuzzy sets: $d_2(E,$ good) = 0.54658, $d_3(E,$ aver) = 1.06007, $d_4(E,$ adeq) = 1.27426, $d_5(E,$ poor) = 1.29856.

for $d_{min} = d_2$:

$$\alpha_1 = \frac{1}{d_1/d_2} = \frac{1}{0.56899/0.54658} = 0.96061,$$

$$\alpha_2 = 1.00000, \alpha_3 = 0.51561, \alpha_4 = 0.42894, \alpha_5 = 0.42091.$$

$$\beta_1 = \frac{\alpha_1}{\sum_{i=1}^{5}\alpha_i} = \frac{0.96901}{0.96901 + 1 + 0.51561 + 0.42894 + 0.42091} = 0.28881,$$

$$\beta_2 = 0.30065, \beta_3 = 0.15502, \beta_4 = 0.12896, \beta_5 = 0.12655.$$

Finally, we get the assessment of effectiveness of tractor A, in form (10):

E_A = {(β_1, "excellent"), (β_2, "good"), (β_3, "average"), (β_4, "adequate"), (β_5, "poor")} = {(0.28881, "excellent"), (0.30065, "good"), (0.15502, "average"), (0.12896, "adequate"), (0.12655, "poor")}

In the same way, we get the assessments for other two tractors B and C:

E_B = {(0.23793, "excellent"), (0.27538, "good"), (0.20635, "average"), (0.14693, "adequate"), (0.13342, "poor")}
E_C = {(0.17507, "excellent"), (0.25092, "good"), (0.25468, "average"), (0.17633, "adequate"), (0.14300, "poor")}.

Tractor A is in great extent of 0.30065 (in relation to 30 %) assessed as good, tractor B in great extent of 0.27538 (27.5%) assessed as good, while tractor C is in great extent of 0.25468 (25.5%) assessed as average. It can be concluded that C is the worst, while tractor A is only somewhat better than B, especially if we see

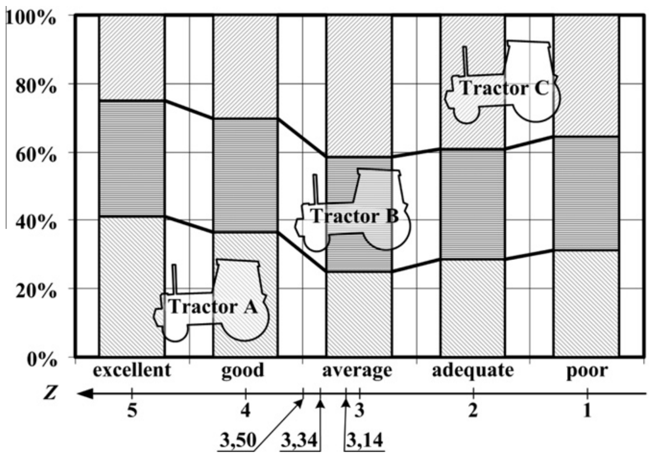

Fig. 3. Relationship of effectiveness of observed tractors.

that A is assessed as excellent in the extent of 28.8% while B in the extent of 23.8%. Effectiveness of analyzed tractors can be presented as in Fig. 3., where it can be more clearly seen that tractor A has the biggest effectiveness.

If this assessment (E_A, E_B, E_C) is defuzzificated by center of mass point calculation – Z (Bowles & Pelaez, 1995), we get the assessment of effectiveness as follows:

$$Z_A = \frac{\sum_{i=1}^{5}\beta_i \cdot C_i}{\sum_{i=1}^{5}\beta_i} = \frac{0.28881\cdot 5 + 0.30065\cdot 4 + 0.15502\cdot 3 + 0.12896\cdot 2 + 0.12655\cdot 1}{0.28881 + 0.30065 + 0.15502 + 0.12896 + 0.12655} = 3.50 \quad Z_B = 3.34 \text{ and } Z_C = 3.14$$

where C is numerical equivalent for linguistic variables (poor = 1, adequate = 2...)

This would mean that on the scale of 1–5 (i.e. from poor to excellent) tractor A is the best and tractor C is the worst.

For verification of achieved results, statistical analysis of availability, like family concept with effectiveness, has been used. That is, in our model showed that the tractor A is of a best, and C of worst effectiveness. In reality, if we analyze the availability, it is seen that the tractor A spent in work 2904 moto-hours, out of 3130 available moto-hours; if calculated on 10,000 moto-hours, it would spend in work 9244 moto-hours. As of the tractor B, out of 10,004 available moto-hours, it spent 9069 moto-hours in work, and tractor C out of 9981 available moto-hours spent 9045 in work.

The experiment showed that the more reliable and efficient tractors are the less frequent are delays. In part, this initial advantage wiped out worse logistics of delivery of spare parts when it comes to tractor A. in 1100 moto-hours work of the tractor, due to poor logistics in maintaining hoped to eight working days, and it greatly influenced the decline in benefits of maintainability of a given tractor and thus the decline in total exploitation of the same efficiency (Internal technical documentation PKB).

4. Conclusion

This paper presents a model for effectiveness assessment of technical systems, precisely agricultural machinery, based on fuzzy sets theory. Effectiveness performance has been adopted as overall indicator of system's quality of service, i.e. as entire measure of technical system availability. Reliability, maintainability and functionality performances have been recognized as effectiveness parameters or indicators. Linguistic form can be appointed as the common characteristics of all mentioned indicators. Therefore fuzzy sets theory has appeared as natural tool for effectiveness modeling. In this article, for application of fuzzy set theory, it was necessary to define: linguistic variables and their description by a membership function, rules of fuzzy composition and models of integration and defuzzification. Fuzzy composition i.e. max–min logic has been used for integration of effectiveness indicators in the overall effectiveness performance, best fit method for integration of membership function in fuzzy set and center of mass point calculation for defuzzification of fuzzy number in numeric values. Max–min composition model, which is exposed in this paper, has not been processed in this way in corresponding literatures. Also, in case study, the model of fuzzification of results of questionnaire is presented, which represent precisely shown way of accumulation of engineer knowledge and expertise.

Presented model can be used as a simple tool for the fast estimation of effectiveness i.e. quality of service for agricultural machinery, based on experts judgments and estimations. At the same time, the model does not require a complex IT infrastructure. Analysis of achieved effectiveness fuzzy sets and appropriate fuzzy sets for reliability, maintainability and functionality performances can be the guideline for corrective actions in the directions of purchase of equipment, construction adjustment, changing of maintenance policy or management/operators alteration.

The paper specifically analyzes the three tractors, marked A, B and C, which showed that the more efficient tractors the less frequent downtimes. In part, this initial advantage is annulled poorer delivery of spare parts logistics.

Acknowledgement

The research work is supported by the Ministry of Education and Science of the Republic of Serbia.

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