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Linguistic Assessment Model of Limited Corrosion Availability in Gas-pipeline Areas Based on the Application of Interval Fuzzy Sets of the Second Type

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Abstract: Linguistic assessment model of approximation level to the limited corrosion of gaspipeline areas has been developed. For solving of the task generalization of multicriterial method of alternative choice has been obtained in the case of rules of fuzzy products (RFP) with anticedens and consequents given by interval fuzzy sets of the second type (IFS2).

Keywords: Linguistic Model, Interval Fuzzy Sets of the Second Type, Rules of Fuzzy Products, Person Making Decision, Alternatives Multicriterial Choise, Limiting Corrosion Availability, Gaspipeline

1. Introduction

Experimental and theoretical investigations of exploitation reliability of main pipelines (MP) show that the main reasons of their breakdowns are corrosion destruction and corrosion cracking under the stress [1]. That's why the assessment of corrosion danger degree of MP areas is of great importance.

For solving of this task in the condition of incompleteness, inaccuracy and uncertainty of initial data the technology of fuzzy modeling is more constructive [2]. Application of fuzzy sets theory (FST), the founder of which is L. A. Zadeh [3], provides solution of the decision making problem in the uncertainty condition with the algebra methods of fuzzy logics. The principle feature of supporting of decision making in the uncertainty condition is the necessity of the taking account the fact that measurements of input and output data are carried out at the level of soft measurements.

The perspective direction of development of decision making methods in fuzzy initial information is the linguistic approach on the basis of fuzzy sets theory and linguistic variable [4]. At present in this direction concrete practical and theoretical results have been obtained. Their analysis allows to formulate main problems occurring in the development and realization of methods and models of decision making in fuzzy initial information [5-8]. Models formulating describing complex systems using fuzzy verbal parameter values and fuzzy relation between the objects are called linguistic models [5].

For presenting terms of input and output linguistic variables (LV) in the models of decision making fuzzy sets of the first type (FST1) $\tilde{A}$, determined by one function of belonging $\mu_{\tilde{A}}(x)$, and interval fuzzy sets of the second type (FST2)$\tilde{\tilde{A}}$, determined by the help of footprint of uncertainty characterized by "upper" $\overline{\mu}_{\tilde{\tilde{A}}}(x)$ and "lower" $\underline{\mu}_{\tilde{\tilde{A}}}(x)$ functions of belonging [9-10] can be used. Essentially, two fuzzy sets of first type $\overline{\tilde{A}}$and$\underline{\tilde{A}}$ as $\mu_{\overline{\tilde{A}}}(x) = \overline{\mu}_{\tilde{\tilde{A}}}(x)and\mu_{\underline{\tilde{A}}}(x) = \underline{\mu}_{\tilde{\tilde{A}}}(x)$ can be brought to conformity to set$\tilde{\tilde{A}}$. In discrete universal we obtain interval discrete fuzzy set of second type IDFST2, to which two discrete fuzzy sets of first type IDFST2 correspond.

In the given work linguistic model of assessment of limiting corrosion availability in various gaspipeline areas has been studied. For solving the task the method of alternatives multicriterial choice with information about the person making decision (PMD) given in the form of fuzzy judgements [11-12] has been used. Unlike work [8], where the method of alternatives multicriterial choice is used in the case of fuzzy production rules (FPR) with anticedents (messages) and consequents (consequences) given in the form of fuzzy sets of first type (FST1) we have considered more general system of decision making support on the basis ofinterval fuzzy sets of the second type (IFST2) using Mamdani's algorithm of fuzzy conclusion [13].

2. Setting up the Task

The depth of corrosion damages P is determined [1] by sum of variables x_i, not depending one from another and describing various parameters of the medium of pipe space: $P = f(\sum x_i)$, where x_i – i- variable describing each of influencing medium parameters. Variables x_i are determined in the form $x_i = k_i \cdot \tau$, where k_i is qualitive assessment of each i – medium parameter, τ- is time (of year) of gaspipeline exploitation.

Corrosion speed is derivative from value P:$V_{cor.} = \frac{dP}{dt}$. In linear function of f we have $V_{cor.} = \sum_i k_i$. It means that with the help of coefficients k_i, it is possible to describe corrosion process in the interested time of moment t.

Potential prognosis of corrosion speed is the speed of metal corrosion (is denoted as V_{pp}) which characterizes the growth of defect depth of pipeline external wall in the given moment time and depending on the activity of corrosion factors k_i, where development of the defect is assumed in any point of the studied gaspipeline area. In general value V_{pp} is determined as average on all factors:

$$V_{nn} = \sum_{i=1}^{n} \frac{k_i}{n},$$

where n is number of coefficients (factors) k_i, accepted for calculation V_{pp}.

As variable factors, influencing the speed of corrosion defects growth, we'll accept the following factors as the basis:

1. Specific electric resistance of the ground ρ (Ом·м), considering non-homogeneity of the ground on the depth of gaspipelinein corresponding racing of electrodes and indirectly characterizing availability of ground waters in the underground installation zone.
2. Oxidation – reduction potential of ground (B), so-called redox-potential or potential "pipeline-ground", characterizing speed of corrosion destruction of steel under the influence of microbiological activity of anaerobic bacteria.
3. Stresslevelingaspipelinewalls (MPa).
4. Metal state determined by residue thickness of pipe walls from design one, %.
5. Degree of anomaly danger, determined by difference 1-F; where F is a value of integral index F, calculated on all metal damages in the area.

Factors 1 and 2 can be obtained with the help of pit inspection and electrometric measurements in the open areas of gaspipeline. Factors 4 and 5 are obtained with the help of magnet tomography method (MTM). Factor 3 characterizing stress-deformation condition (SDC) of gaspipeline is one of the most important internal factors of corrosion development condioning possibility of its occurrence and development.

Study of gaspipeline can be carried out by using interpipe charges – defectoscopes (ICD) or by the magnet tomography method. The rest of the methods don't provide 100% control of metal pipeline and don't give an accurate information about technical state of the object during the whole work.

For carrying out interpipedefectoscopy it is necessary to supply the pipeline with cameras of input-output cleaning devices and charges-defectoscopes, to provide the required regime of passing of defectoscopes. While carrying out the examining by Magnet Tomography method change of pipeline exploitation regime and extra expenditures for examination preparation are not required. Besides using MTM assessment of mechanical stress level of the object has been done considering stress concentration.

Value of integral index F (complex normed index of anomaly danger level according to PD 102-008-2002) is calculated on all defects of gaspipeline tube metal [14].

"Anomaly" means the pipeline area, where declination of magnet field conditioned by metal defects or increased level of stressdeformation state (SDS) has been fixed together causing mechanical stress concentration distinguishing from background values. The following types of metal defects have been considered: 1) loss of metal, characterizing corrosion damages of common or local type, erosion wear and etc.; 2) Cracklike defects, including (RFP) defects – stress – corrosion cracks; 3) geometry change; 4) continuity violation; 5) defects of welding joints; 6) anomalies of stress – deformation state.

For unaccessible defects (requiring immediate repair) value F is in within $0<F<0,2$; for defects within of accessible anomalies is $0,2<F<0,55$; all areas with good condition with $F>0,55$ value can be exploited in the working regime without repair – restore measurements as in the areas without defects.

While calculating danger of anomalies it is accepted to distinguish-magnetic anomalies of the 3-rd class (good condition of metal), characterized by insignificant corrosion wear and not causing significant concentration of mechanical stresses. According to PD 102-008-2002 such anomalies with index $F>0,55$ don't require repair-restore measure ments;

- magnetic anomalies of the 2-nd class (accessible metal state) with $F \in (0,2;\ 0,55]$, require carrying out planned repair at the speeded calculating time;
- anomalies of the 1-st class (unaccessible metal state) are characterized by $F \in (0;\ 0,2]$; index: such defects are

waiting the immediate repair.

As initial variables influencing the speed of corrosion defects growth we'll accept the followings:

X_1 – specific electric resestance of the ground (Om·m);

X_2 – oxidizing-reduction potential of the ground – redox-potential (B);

X_3 – stress level in gaspipeline walls (MPa);

X_4 – metal state determined residue thickness of pipe walls (from designed), %;

X_5 – level of anomalies danger (1- F).

InconsequencewiththelevelofvariableinfluenceX_1, X_2, X_3, X_4, X_5on occurrence and development of corrosion, their weight coefficients will be considered in the calculations:

$$\omega_1=0{,}12;\ \omega_2=0{,}08;\omega_3=0{,}25;\ \omega_4=0{,}35;\ \omega_5=0{,}20,$$

$$\sum_{i=1}^{5} \omega_i = 1 \quad (1)$$

For determining work ability of the areas with defects it is necessary to control gaspipeline metal during the whole work in order to assess the possibility of availability of transfer of defected areas into limiting state because of penetration corrosion or cracking and offer immediate repair plans of MP areas. That's why as output variable as it is shown in our former work [15], we'll chose "Possibility of availability of limiting corrosion (PALC)", considering monotone increase of this parameter from variable "Potentially prognozed corrosion speed (PPCS)".

Insetting of fuzzy model of assessment of output variable all considered variables are phased, that is fuzzy value-linguistic variable LV is put to each variable. As the first input LV "Specific electric resistance of the ground" we'll use the term – set T_1=("low", "average", "high"), for the second input LV "oxidized – reduction potential of the ground" – T_2=("very low", "low", "average", "high"), for the third input LV "stress level in gaspipeline walls", T_3=("low", "average", "increased", "high"), for the fourth input LV "metal state" –T_4= ("bad", "average", "good"), for the fifth input LV (Level of anomalies danger) – T_5=("low", "average", "high"). Belonging functions of input LV terms are described in figures 1-5 correspondingly.

In the rules of fuzzy products, shown below, for output variable "PALC" (let's denote it through Y) the following terms are used: T_0=("low", "moderate", "average", "increased", "high"), which we substitute correspondingly with the terms: "unsatisfactory (US), "almost satisfactory" (AS), "satisfactory" (S), "more than satisfactory" (MS), "very satisfactory" (VS) characterizing reliability degree of conclusion "PALC". Here abbrevations "S" from English "satisfactory". "US" is negative for S, that is "not S"; "AS" – almost S; "MS" – more S; "VS" – very S.

Each of the terms LV Y is determined in the form of interval fuzzy sets of the second class (IFST2), given in [9-10], which have "low" and "upper" functions of belonging at $u \in J$={0; 0,1;0,2;…;1}.

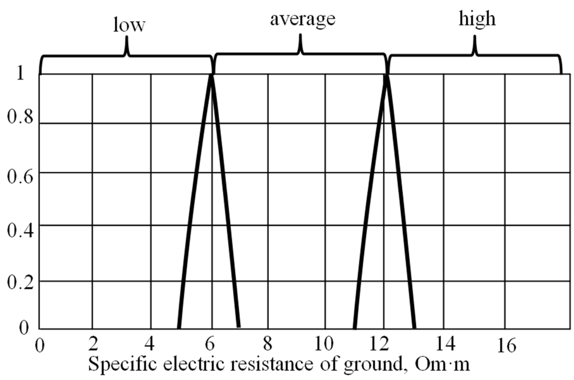

Figure 1. *Graphic of belonging functions for the terms of linguisticvariable"specific electric resistance of ground".*

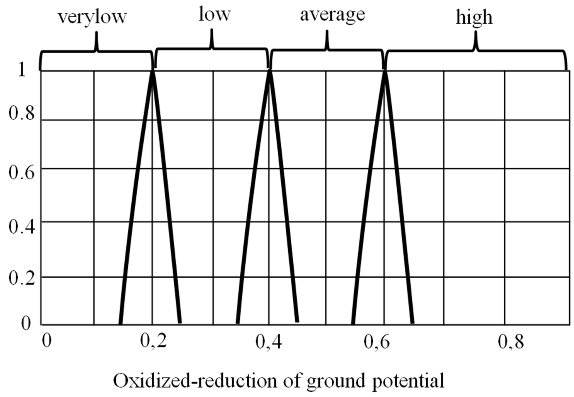

Figure 2. *Graphic of belonging functions of linguistic variable"Oxidized-reduction potential of ground (redox-potential)".*

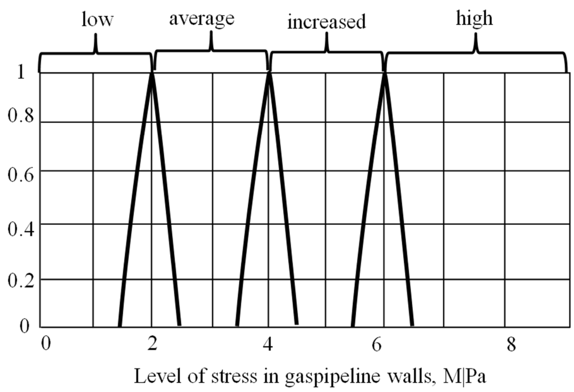

Figure 3. *Graphic of belonging functions for terms of linguisticvariable "Stress level in gaspipeline walls".*

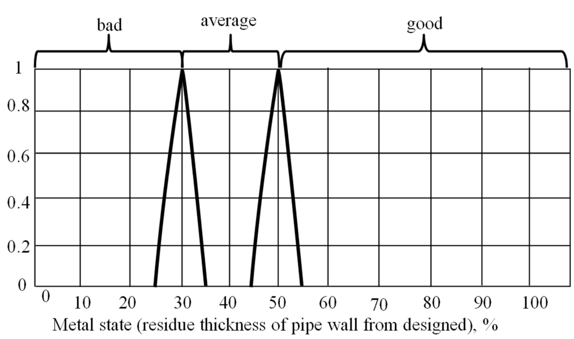

Figure 4. *Graphic of belonging functions for terms oflinguistic variable "Metal state".*

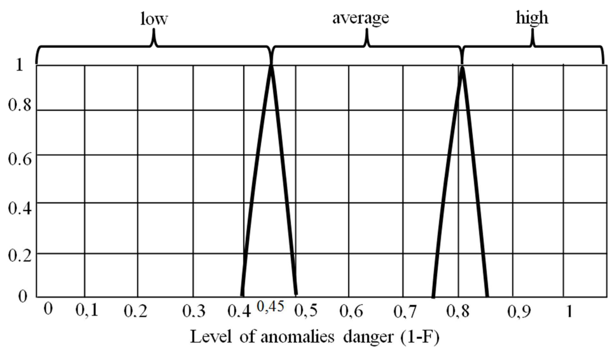

Figure 5. *Graphic of belonging functions for the terms ofLinguisticvariable "Level of anomalies danger".*

We'll suppose:

$$\underline{\mu}_{\tilde{\tilde{S}}}(x) = x\sqrt{x}, \overline{\mu}_{\tilde{\tilde{S}}}(x) = x, x \in \mathrm{J}; \qquad (2)$$

$$\underline{\mu}_{\widetilde{\widetilde{US}}}(x) = 1 - \overline{\mu}_{\tilde{\tilde{S}}}(x) = 1 - x, \overline{\mu}_{\widetilde{\widetilde{US}}}(x) = 1 - \underline{\mu}_{\tilde{\tilde{S}}}(x) = 1 - x\sqrt{x}, x \in \mathrm{J}; \qquad (3)$$

$$\underline{\mu}_{\widetilde{\widetilde{US}}}(x) = x^2, \overline{\mu}_{\widetilde{\widetilde{US}}}(x) = x\sqrt{x}, x \in \mathrm{J}; \qquad (4)$$

$$\underline{\mu}_{\widetilde{\widetilde{AS}}}(x) = 1 - \overline{\mu}_{\widetilde{\widetilde{MS}}}(x) = 1 - x\sqrt{x}, \overline{\mu}_{\widetilde{\widetilde{AS}}}(x) = 1 - \underline{\mu}_{\widetilde{\widetilde{MS}}}(x) = 1 - x^2, x \in \mathrm{J}; \qquad (5)$$

$$\underline{\mu}_{\widetilde{\widetilde{VS}}}(x) = x^3, \overline{\mu}_{\widetilde{\widetilde{VS}}}(x) = x^2, x \in \mathrm{J}; \qquad (6)$$

Let's mention that for LV "very A" (VA) it is assumed to consider [4]:$\mu_{VA}(x) = \mu_A^2(x)$, and for fussy sets UA (not A): $\mu_{UA}(x) = 1 - \mu_A(x)$. It is obvious if $\tilde{\tilde{A}}$ is IFST2, then $\widetilde{\widetilde{UA}}$ is also IFST2 and $\overline{\mu}_{\widetilde{\widetilde{UA}}}(x) = 1 - \overline{\mu}_{\tilde{\tilde{A}}}(x)$ and $\overline{\mu}_{\widetilde{\widetilde{UA}}}(x) = 1 - \underline{\mu}_{\tilde{\tilde{A}}}(x)$; correlations (3) and (5) may be drawn here.

Let's denote the terms of variable X_1in the order of their position in T_1 through $X_{1,1}$; $X_{1,2}$; $X_{1,3}$. In the same form let's denote the terms X_2 through $X_{2,1}$, $X_{2,3}$, $X_{2,4}$; $X_{3,1}$, $X_{3,2}$, $X_{3,3}$, $X_{3,4}$ – termsX_3; $X_{4,1}$, $X_{4,2}$, $X_{4,3}$ – terms X_4; $X_{5,1}$, $X_{5,2}$, $X_{5,3}$ – terms X_5.

Considered gaspipeline areas will be named as alternatives u_1, u_2,…, u_j,…, u_{jn}, for which on each sign $X_i$expert interval values $\left(a_i^{(j)}, b_i^{(j)}\right)$ of X_i sign values for alternative u_j are given.

As an example we'll consider 4 areas (j_0=4) of the gaspipeline "Kazi-Magomed-Kazakh": 62-70 km (j=1); 134-135 km (j=2); 139-140.5 km (j=3) and 154-155.5 km (j=4) for which expert interval values $\left(a_i^{(j)}, b_i^{(j)}\right)$ of the change of sign i for object j have been given in table 1, on the basis of which it is easy to calculate belongings of terms $X_{i,1}$ of sign i (i=1,2,…,5) (figure 1-5) considering weight coefficients ω_I, "low" $\alpha_{i,l}^{(i)}$ and "upper" $\beta_{i,l}^{(j)}$ of the value of belonging function of term $X_{i,1}$ for object j:

$$\alpha_{i,l}^{j} = \omega_i \cdot \mu_{i,l}\left(a_i^{(j)}\right), \beta_{i,l}^{j} = \omega_i \cdot \mu_{i,l}\left(b_i^{(j)}\right), \qquad (7)$$

where $\mu_{I,l}(x)$ – is the function of belonging of term $X_{i,l}$, where $\mu_{I,l}(x)$=0, if $x \notin$ supp $X_{i,l}$ (sup $X_{i,l}$ –carrier of term $X_{i,l}$, that is set of x points for which $\mu_{I,l}(x) \neq 0$).

The values of the main features in some parts of the gas pipeline

"Kazi-Maqomed-Kazakh"

Table 1. *The input datas.*

Location of area	Level of anomaly danger		Residue thickness of pipe wall from designed, %	Specific electric resistance of groundOm·m(X_1)	Potential "pipe-ground" in volts(X_2)	Level of stresses in gaspipeline walls, MPa (X_3)
	0,814–0,845	I	16,5±0,5			
62–70 км	0,527–0,715	II	19,2±0,5	0,63–1,56	(–0,617)–(–0,538)	1,71–1,95
	0,114–0,279	III	46,6±0,5			
	0,819–0,833	I	14,8±0,5			
134–135 км	0,511–0,674	II	16,7±0,5	2,76–3,28	(–0,525)–(–0,6050)	1,65–1,88
	0,09–0,195	III	42,2±0,5			
	0,815–0,824	I	14,2±0,5			
139–140,5км	0,582–0,688	II	15,3±0,5	8,6–11,3	(–0,493) – (–0,511)	1,75–1,98
	0,154–0,224	III	40,6±0,5			
154–155,5км	0,856–0,874	I	13,2±0,5			
	0,635–0,789	II	14,0±0,5	12,7–16,4	(–0,351) – (–0,533)	1,6–1,95
	0,215–0,374	III	38,4±0,5			

On the basis of (7) each term X_{il} of variable can be presented in the form of IFST2 determined on discrete base sets $U=\{u_1,u_2,u_3,u_4\}$:

$$\tilde{\tilde{X}}_{i,l} = \left\{ \frac{\alpha_{i,l(1)}}{\beta_{i,l(1)}}/u_1, \frac{\alpha_{i,l(2)}}{\beta_{i,l(2)}}/u_2, \frac{\alpha_{i,l(3)}}{\beta_{i,l(3)}}/u_3, \frac{\alpha_{i,l(4)}}{\beta_{i,l(4)}}/u_4 \right\} \qquad (8)$$

For assessment of corrosion speed we'll use the following rules of fuzzy products (RFP):

$$\begin{aligned}
&d1: \text{IF}(X = X3,1)\text{THEN}(Y = US);\\
&d2: \text{IF}(X = X3,2)\text{THEN}(Y = AS);\\
&d3: \text{IF}(X = X3,3)\text{THEN}(Y = S);\\
&d4: \text{IF}(X = X3,4)\text{THEN}(Y = MS);\\
&d5: \text{IF}(X = X1,1)\text{THEN}(Y = S);\\
&d6: \text{IF}(X = X1,2)\text{THEN}(Y = AS);\\
&d7: \text{IF } (X = X1,3)\text{THEN}(Y = US);\\
&d8: \text{IF}(X = X2,4)\text{THEN}(Y = US);\\
&d9: \text{IF}(X = X2,3)\text{THEN}(Y = S);\\
&d10: \text{IF}(X = X2,2)\text{THEN}(Y = MS);\\
&d11: \text{IF}(X = X2,1)\text{THEN}(Y = VS);\\
&d12: \text{IF}(X = X5,3)\text{THEN}(Y = VS);\\
&d13: \text{IF}(X = X5,2)\text{THEN}(Y = S);\\
&d14: \text{IF}(X = X5,1)\text{THEN}(Y = US);\\
&d15: \text{IF}(X = X4,3\text{и } X5,1) \text{ THEN } (Y = US);\\
&d16: \text{IF}(X = X4,2\text{и } X5,2) \text{ THEN } (Y = S);\\
&d17: \text{IF}(X = X4,1\text{и } X5,3) \text{ THEN } (Y = VS).
\end{aligned} \quad (9)$$

where $X_{i,l}$ and US, AS, S, MS, VS are presented by interval fuzzy sets of the second type (IFST2).

The task, we are interested in is formulated by the following: to calculate satisfaction as determining from section 2 for each alternative $u_j \in U$ and chose alternative with the biggest satisfaction value requiring immediate repair, as the biggest reliability of "PALC" corresponds to it among considered alternatives totality.

3. Method of Task Solution

For solving of the given task let's use the method of multicriterial choice of alternatives offered in [11-12] for the case of fuzzy sets of the first type (FST1), generalizing it for interval fuzzy sets of the second type (IFST2).

The essence of the method following.

Let set of solutions are characterized by criteria $X_1,X_2,\ldots X_q$, that is linguistic variables on the basis of sets $U_1,U_2,\ldots,U_q$ correspondingly. Set of some criteria with corresponding values characterizes opinions about (PTD) with availability of accessions.

Output variable Y "satisfaction" is linguistic.

In common case the statement d_k (rule of fuzzy productions (RFP)) has the form:

$$d_k\text{: IF}(X_1=A_{k,1}\text{и}X_2=A_{k,2}\text{ end}\ldots\text{end } X_q=A_{k,q}) \text{ THEN}(Y=D_k) \quad (10)$$

Let's denote crossing $(X_1=A_{k,1}\cap X_2=A_{k,2}\cap\ldots\cap X_q=A_{k,q})$ through $X=A_k$. Each rule d_k consists of part IF, called antecedent, and part THEN, called consequent. Variables $X_1,\ldots,X_q$ and Y can accept both linguistic (for example, "bad", "average", "good"), and number values. Basis of rules, presenting fuzzy sets of rules $d_k(k=1,\ldots,N)$ of the (10) with linguistic variable is called linguistic model.

Operations of fuzzy sets crossing correspond to finding of the minimum of their belonging functions:

$$\mu_{A_k}(v) = min\left(\mu_{A_{1,1}}(u_1), \mu_{A_{1,2}}(u_1), \ldots, \mu_{A_{k,q}}(u_q)\right); v\epsilon V, \quad (11)$$

where $V=U_1\times U_2\times\ldots\times U_q$; $\upsilon=(u_1, u_2,\ldots,u_q)$; $\mu_{A_{k,j}}(u_j)$ – belonging function of the element $u_j$to fuzzy set $\mu_{A_{k,j}}$. Then rule (10) can be written in the form of fuzzy implication:

$$d_k\text{:IF } (X=A_k) \text{ THEN } (Y=B_k), \quad (12)$$

where $A_k=A_{k,1}\cap\ldots\cap A_{k,q}$.

Let's denote base set U or V through W. Then A_k is fuzzy subset W, while D_k is fuzzy subset of single interval I=[0,1].

Implication of fuzzy sets (12) is expressed in the following way [8]:

$$\mu_H(w,i)=min(1,(1-\mu_A(w)+ \mu_B(i)), \quad (13)$$

where H is fuzzy subset from $W\times I$, $w\in W$, $i\in I$.

Analogously statestments $d_1,d_2,\ldots,d_N$ are transformed to sets $H_1,H_2,\ldots,H_N$. Their unification is set

$$D=H_1\cap H_2\cap\ldots\cap H_N \quad (14)$$

and for each $(w,i)\in W\times I$

$$\mu_D(w,i) = \underline{\min}_{k=1,N}\left(\mu_{H_k}(w,i)\right) \quad (15)$$

Let's write method of alternatives choice j (j=1,…,q), each of them is described by fuzzy subset G_j from W.

Satisfaction of alternative j is on the basis of compositional rule of fuzzy conclusion is:

$$E_j=G_j\cdot D, \quad (16)$$

where $E$is fuzzy subset of interval 1. Then

$$\mu_{E_j}(i) = \max_{w\epsilon W}\left(min\left(\mu_{G_j}(w), \mu_D(w,i)\right)\right). \quad (17)$$

Comparison of alternatives takes place on the basis of point values. For fuzzy set A. α - level set ($\alpha\in[0,1]$) is determined.

$$A_\alpha = \{x|\mu_A(x) \geq \alpha, x\epsilon J\} \quad (18)$$

For each A_α average number of elements - $M(A_\alpha)$ can be calculated. For set from n elements.

$$M(A_\alpha) = \sum_{x\epsilon A_\alpha}\frac{x_i}{n} \quad (19)$$

Then point value for fuzzy set $\tilde{A}$:

$$F(\tilde{A}) = \frac{1}{\alpha_{max}}\int_0^{\alpha_{max}} M(A_\alpha)d\alpha, \quad (20)$$

where α_{max} – is maximum value α, where A_α is not empty set.

When chosing alternatives for each of them there is satisfaction and corresponding point evaluation is calculated. The best is the alternative with its biggest value.

Abo vementioned method is based on fuzzy sets of the first type (FST1). The more common support system of decision making on the base of IFST2 using algorithm of Mamdani's fuzzy conclusion has feen considered in [9-10] where expressions of “low” and “upper” FB resulting IFST2, have been obtained.

These expressions themselves and their conclusion are bulky that’s why we won’t present them here. Let’s show how it is possible directly to generalize the method

[8] in the case of interval fuzzy sets of the second type.

4. Numerical Solution of the Task

Formulated task about the choice of alternative with the biggest satisfaction at the end of section 1 is the support system of decision making containing q=5 inlets and one outlet.

First of all let’s calculate values (7) from considering table 1.

$$\alpha_{1,1}^{(1)}=0{,}12;\alpha_{1,2}^{(1)}=0;\ \alpha_{1,3}^{(1)}=0;\ \alpha_{1,1}^{(2)}=0{,}12;\alpha_{1,2}^{(2)}=0;\ \alpha_{1,3}^{(2)}=0;$$

$$\alpha_{1,1}^{(3)}=0;\alpha_{1,2}^{(3)}=0{,}12;\ \alpha_{1,3}^{(3)}=0;\ \alpha_{1,1}^{(4)}=0;\ \alpha_{1,2}^{(4)}=0;\ \alpha_{1,3}^{(4)}=0{,}12;$$

$$\beta_{1,1}^{(1)}=0{,}12;\beta_{1,2}^{(1)}=0;\ \beta_{1,3}^{(1)}=0;\beta_{1,1}^{(2)}=0{,}12;\beta_{1,2}^{(2)}=0;\ \beta_{1,3}^{(2)}=0;$$

$$\beta_{1,1}^{(3)}=0;\ \beta_{1,2}^{(3)}=0{,}12;\ \beta_{1,3}^{(2)}=0{,}018;\beta_{1,1}^{(4)}=0;\ \beta_{1,2}^{(4)}=0;\ \beta_{1,3}^{(4)}=0{,}12;$$

$$\alpha_{2,1}^{(1)}=0;\alpha_{2,2}^{(1)}=0;\ \alpha_{2,3}^{(1)}=0{,}008;\ \alpha_{2,4}^{(1)}=0{,}08;\alpha_{2,1}^{(2)}=0;\alpha_{2,2}^{(2)}=0;\ \alpha_{2,3}^{(2)}=0{,}08;\ \alpha_{2,4}^{(2)}=0;$$

$$\alpha_{2,1}^{(3)}=0;\alpha_{2,2}^{(3)}=0;\ \alpha_{2,3}^{(3)}=0{,}08;\ \alpha_{2,4}^{(3)}=0;\alpha_{2,1}^{(4)}=0;\alpha_{2,2}^{(4)}=0;\ \alpha_{2,3}^{(4)}=0{,}08;\ \alpha_{2,4}^{(4)}=0;$$

$$\beta_{2,1}^{(1)}=0;\beta_{2,2}^{(1)}=0;\ \beta_{2,3}^{(1)}=0{,}01;\ \beta_{2,4}^{(1)}=0{,}08;\beta_{2,1}^{(2)}=0;\beta_{2,2}^{(2)}=0;\ \beta_{2,3}^{(2)}=0{,}08;\ \beta_{2,4}^{(2)}=0{,}08;$$

$$\beta_{2,1}^{(3)}=0;\beta_{2,2}^{(3)}=0;\ \beta_{2,3}^{(3)}=0{,}08;\ \beta_{2,4}^{(3)}=0;\beta_{2,1}^{(4)}=0;\beta_{2,2}^{(4)}=0;\ \beta_{2,3}^{(4)}=0{,}08;\ \beta_{2,4}^{(4)}=0;$$

$$\alpha_{3,1}^{(1)}=0{,}225;\alpha_{3,2}^{(1)}=0{,}225;\ \alpha_{3,3}^{(1)}=0;\ \alpha_{3,4}^{(1)}=0;\alpha_{3,1}^{(2)}=0{,}25;\alpha_{3,2}^{(2)}=0{,}05;\ \alpha_{3,3}^{(2)}=0;\ \alpha_{3,4}^{(2)}=0;$$

$$\alpha_{3,1}^{(3)}=0{,}225;\alpha_{3,2}^{(3)}=0{,}25;\ \alpha_{3,3}^{(3)}=0;\ \alpha_{3,4}^{(3)}=0;\alpha_{3,1}^{(4)}=0{,}25;\alpha_{3,2}^{(4)}=0{,}025;\ \alpha_{3,3}^{(4)}=0;\ \alpha_{3,4}^{(4)}=0;$$

$$\beta_{3,1}^{(1)}=0{,}25;\beta_{3,2}^{(1)}=0{,}237;\ \beta_{3,3}^{(1)}=0;\ \beta_{3,4}^{(1)}=0;\beta_{3,1}^{(2)}=0{,}25;\beta_{3,2}^{(2)}=0{,}242;\ \beta_{3,3}^{(2)}=0;\ \beta_{3,4}^{(2)}=0;$$

$$\beta_{3,1}^{(3)}=0{,}25;\beta_{3,2}^{(3)}=0{,}25;\ \beta_{3,3}^{(3)}=0;\ \beta_{3,4}^{(3)}=0;\beta_{3,1}^{(4)}=0{,}25;\beta_{3,2}^{(4)}=0{,}237;\ \beta_{3,3}^{(4)}=0;\ \beta_{3,4}^{(4)}=0;$$

$$\alpha_{4,1}^{(1)}=0{,}35;\alpha_{4,2}^{(1)}=0;\ \alpha_{4,3}^{(1)}=0;\ \alpha_{3,4}^{(1)}=0;\alpha_{4,1}^{(2)}=0{,}35;\alpha_{42}^{(2)}=0;\ \alpha_{4,3}^{(2)}=0;$$

$$\alpha_{4,1}^{(3)}=0{,}35;\alpha_{4,2}^{(3)}=0;\ \alpha_{4,3}^{(3)}=0;\alpha_{4,1}^{(4)}=0{,}35;\alpha_{4,2}^{(4)}=0;\ \alpha_{4,3}^{(4)}=0;$$

$$\beta_{4,1}^{(1)}=0{,}35;\beta_{4,2}^{(1)}=0;\ \beta_{4,3}^{(1)}=0;\beta_{4,1}^{(2)}=0{,}35;\beta_{4,2}^{(2)}=0;\ \beta_{4,3}^{(2)}=0;$$

$$\beta_{4,1}^{(3)}=0{,}35;\beta_{4,2}^{(3)}=0;\ \beta_{4,3}^{(3)}=0;\beta_{4,1}^{(4)}=0{,}35;\beta_{4,2}^{(4)}=0;\ \beta_{4,3}^{(4)}=0;$$

$$\alpha_{5,1}^{(1)}=0;\alpha_{5,2}^{(1)}=0{,}2;\ \alpha_{5,3}^{(1)}=0;\alpha_{5,1}^{(2)}=0;\alpha_{5,2}^{(2)}=0{,}2\cdot 1=0{,}2;\ \alpha_{5,3}^{(2)}=0;$$

$$\alpha_{5,1}^{(3)}=0;\alpha_{5,2}^{(3)}=0{,}2;\ \alpha_{5,3}^{(3)}=0;\alpha_{5,1}^{(4)}=0;\alpha_{5,2}^{(4)}=0.2;\ \alpha_{5,3}^{(4)}=0;$$

$$\beta_{5,1}^{(1)}=0;\beta_{5,2}^{(1)}=0{,}2;\ \beta_{5,3}^{(1)}=0{,}2;\beta_{5,1}^{(2)}=0;\beta_{5,2}^{(2)}=0{,}2;\ \beta_{5,3}^{(2)}=0{,}2;$$

$$\beta_{5,1}^{(3)}=0;\beta_{5,2}^{(3)}=0{,}2;\ \beta_{5,3}^{(3)}=0{,}2;\beta_{5,1}^{(4)}=0;\beta_{5,2}^{(4)}=0{,}2;\ \beta_{5,3}^{(4)}=0{,}2;$$

We find from here

$$\tilde{\tilde{X}}_{1,1}=\left\{\tfrac{0{,}12}{0{,}12}/u_1\,;\tfrac{0{,}12}{0{,}12}/u_2\,;\tfrac{0}{0}/u_3\,;\tfrac{0}{0}/u_4\right\};\tilde{\tilde{X}}_{1,2}=\left\{\tfrac{0}{0}/u_1\,;\tfrac{0{,}12}{0}/u_2\,;\tfrac{0{,}12}{0{,}12}/u_3\,;\tfrac{0}{0}/u_4\right\};$$

$$\tilde{\tilde{X}}_{1,3}=\left\{\tfrac{0}{0}/u_1\,;\tfrac{0}{0}/u_2\,;\tfrac{0}{0}/u_3\,;\ \tfrac{0{,}12}{0{,}12}/u_4\right\};\tilde{\tilde{X}}_{2,1}=\left\{\tfrac{0}{0}/u_1\,;\tfrac{0}{0}/u_2\,;\tfrac{0}{0}/u_3\,;\ \tfrac{0}{0}/u_4\right\};$$

$$\tilde{\tilde{X}}_{2,2}=\left\{\tfrac{0}{0}/u_1\,;\tfrac{0}{0}/u_2\,;\tfrac{0}{0}/u_3\,;\tfrac{0}{0}/u_4\right\};\tilde{\tilde{X}}_{2,3}=\left\{\tfrac{0{,}01}{0{,}008}/u_1\,;\tfrac{0{,}08}{0{,}08}/u_2\,;\tfrac{0{,}08}{0{,}08}/u_3\,;\tfrac{0{,}08}{0{,}08}/u_4\right\};$$

$$\tilde{\tilde{X}}_{2,4}=\left\{\tfrac{0{,}08}{0{,}08}/u_1\,;\ \tfrac{0{,}08}{0}/u_2\,;\tfrac{0}{0}/u_3\,;\ \tfrac{0}{0}/u_4\right\};\tilde{\tilde{X}}_{3,1}=\left\{\tfrac{0{,}25}{0{,}225}/u_1\,;\ \tfrac{0{,}25}{0{,}25}/u_2\,;\tfrac{0{,}25}{0{,}225}/u_3\,;\ \tfrac{0{,}25}{0{,}25}/u_4\right\};$$

$\tilde{\tilde{X}}_{3,2} = \left\{\frac{0,237}{0,225}/u_1\,;\, \frac{0,242}{0,05}/u_2\,;\frac{0,25}{0,25}/u_3\,;\frac{0,237}{0,025}/u_4\right\};\tilde{\tilde{X}}_{3,3} = \left\{\frac{0}{0}/u_1\,;\,\frac{0}{0}/u_2\,;\frac{0}{0}/u_3\,;\frac{0}{0}/u_4\right\};$

$\tilde{\tilde{X}}_{3,4} = \left\{\frac{0}{0}/u_1\,;\,\frac{0}{0}/u_2\,;\,\frac{0}{0}/u_3\,;\frac{0}{0}/u_4\right\};\tilde{\tilde{X}}_{4,1} = \left\{\frac{0,35}{0,35}/u_1\,;\,\frac{0,35}{0,35}/u_2\,;\frac{0,35}{0,35}/u_3\,;\,\frac{0,35}{0,35}/u_4\right\};$

$\tilde{\tilde{X}}_{4,2} = \left\{\frac{0}{0}/u_1\,;\,\frac{0}{0}/u_2\,;\,\frac{0}{0}/u_3\,;\,\frac{0}{0}/u_4\right\};\tilde{\tilde{X}}_{4,3} = \left\{\frac{0}{0}/u_1\,;\frac{0}{0}/u_2\,;\frac{0}{0}/u_3\,;\frac{0}{0}/u_4\right\};$

$\tilde{\tilde{X}}_{5,1} = \left\{\frac{0}{0}/u_1\,;\,\frac{0}{0}/u_2\,;\frac{0}{0}/u_3\,;\,\frac{0}{0}/u_4\right\};\tilde{\tilde{X}}_{5,2} = \left\{\frac{0,2}{0,2}/u_1\,;\,\frac{0,2}{0,2}/u_2\,;\,\frac{0,2}{0,2}/u_3\,;\,\frac{0,2}{0,2}/u_4\right\};$

$\tilde{\tilde{X}}_{5,3} = \left\{\frac{0,2}{0}/u_1\,;\frac{0,2}{0}/u_2\,;\frac{0,2}{0}/u_3\,;\frac{0,2}{0}/u_4\right\};$

Let's carry out computation of "upper" FBforresultingIFST-2, marking all calculations with aline above, asonly "upper" FB of inlets and outlets LV. Will be used.

Using rule (11), from section 3 we'll ob lain:

for: d_1: $\mu_{\overline{\tilde{M}}_1}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{3,1}}(u); \overline{\tilde{M}}_1 = \{0{,}25/u_1\,;0{,}25/u_2\,;0{,}25/u_3\,;0{,}25/u_4\};$

for:d_2: $\mu_{\overline{\tilde{M}}_2}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{3,2}}(u); \overline{\tilde{M}}_2 = \{0{,}237/u_1\,;0{,}242/u_2\,;0{,}25/u_3\,;0{,}237/u_4\};$

for:d_3: $\mu_{\overline{\tilde{M}}_3}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{3,3}}(u); \overline{\tilde{M}}_3 = \{0/u_1\,;0/u_2\,;0/u_3\,;0/u_4\};$

for:d_4: $\mu_{\overline{\tilde{M}}_4}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{3,4}}(u); \overline{\tilde{M}}_4 = \{0/u_1\,;0{,}12/u_2\,;0/u_3\,;0/u_4\};$

for:d_5: $\mu_{\overline{\tilde{M}}_5}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{1,1}}(u); \overline{\tilde{M}}_5 = \{0{,}12/u_1\,;0/u_2\,;0/u_3\,;0/u_4\};$

for:d_6: $\mu_{\overline{\tilde{M}}_6}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{1,2}}(u); \overline{\tilde{M}}_6 = \{0/u_1\,;0{,}12/u_2\,;0{,}12/u_3\,;0/u_4\};$

for:d_7: $\mu_{\overline{\tilde{M}}_7}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{1,3}}(u); \overline{\tilde{M}}_7 = \{0/u_1\,;0/u_2\,;0/u_3\,;0{,}12/u_4\};$

for:d_8: $\mu_{\overline{\tilde{M}}_8}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{2,4}}(u); \overline{\tilde{M}}_8 = \{0{,}08/u_1\,;0{,}08/u_2\,;0/u_3\,;0/u_4\};$

for:d_9: $\mu_{\overline{\tilde{M}}_9}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{2,3}}(u); \overline{\tilde{M}}_9 = \{0{,}01/u_1\,;0{,}08/u_2\,;0{,}08/u_3\,;0{,}08/u_4\};$

for:d_{10}: $\mu_{\overline{\tilde{M}}_{10}}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{2,2}}(u); \overline{\tilde{M}}_{10} = \{0/u_1\,;0/u_2\,;0/u_3\,;0/u_4\}$

for:d_{11}: $\mu_{\overline{\tilde{M}}_{11}}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{2,1}}(u); \overline{\tilde{M}}_{11} = \{0/u_1\,;0/u_2\,;0/u_3\,;0/u_4\};$

for:d_{12}: $\mu_{\overline{\tilde{M}}_{12}}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{5,3}}(u); \overline{\tilde{M}}_{12} = \{0{,}2/u_1\,;0{,}2/u_2\,;0{,}2/u_3\,;0{,}2/u_4\};$

for:d_{13}: $\mu_{\overline{\tilde{M}}_{13}}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{5,2}}(u); \overline{\tilde{M}}_{13} = \{0{,}2/u_1\,;0{,}2/u_2\,;0{,}2/u_3\,;0{,}2/u_4\};$

for:d_{14}: $\mu_{\overline{\tilde{M}}_{14}}(u) = \overline{\mu}_{\tilde{\tilde{X}}_{5,1}}(u); \overline{\tilde{M}}_{14} = \{0/u_1\,;0/u_2\,;0/u_3\,;0/u_4\};$

for:d_{15}: $\mu_{\overline{\tilde{M}}_{15}}(u) = \min\left(\overline{\mu}_{\tilde{\tilde{X}}_{4,3}}(u), \overline{\mu}_{\tilde{\tilde{X}}_{5,1}}(u)\right); \overline{\tilde{M}}_{15} = \{0/u_1\,;0/u_2\,;0/u_3\,;0/u_4\};$

for:d_{16}: $\mu_{\overline{\tilde{M}}_{16}}(u) = min\left(\overline{\mu}_{\tilde{\tilde{X}}_{4,2}}(u), \overline{\mu}_{\tilde{\tilde{X}}_{5,2}}(u)\right); \overline{\tilde{M}}_{16} = \{0/u_1\,;0/u_2\,;0/u_3\,;0/u_4\};$

for:d_{17}: $\mu_{\overline{\tilde{M}}_{17}}(u) = min\left(\overline{\mu}_{\tilde{\tilde{X}}_{4,1}}(u), \overline{\mu}_{\tilde{\tilde{X}}_{5,3}}(u)\right);$

$\overline{\tilde{M}}_{17} = \{0{,}2/u_1\,;0{,}2/u_2\,;0{,}2/u_3\,;0{,}2/u_4\}.$

This:

d_1:if$\left(X = \overline{\tilde{M}}_1\right)$then$\left(Y = \overline{\tilde{U}}S\right)$; d_2:if$\left(X = \overline{\tilde{M}}_2\right)$then$\left(Y = \overline{\tilde{A}}S\right)$;

d_3:if$\left(X = \overline{\tilde{M}}_3\right)$then$\left(Y = \overline{\tilde{S}}\right)$; d_4:if$\left(X = \overline{\tilde{M}}_4\right)$then$\left(Y = \overline{\tilde{M}}S\right)$;

d_5:if$\left(X = \overline{\tilde{M}}_5\right)$then$\left(Y = \overline{\tilde{S}}\right)$; d_6:if $\left(X = \overline{\tilde{M}}_6\right)$then$\left(Y = \overline{\tilde{A}}S\right)$;

d_7:if$\left(X = \overline{\tilde{M}}_7\right)$then$\left(Y = \overline{\tilde{U}}S\right)$; d_8:if$\left(X = \overline{\tilde{M}}_8\right)$then$\left(Y = \overline{\tilde{U}}S\right)$;

d_9:if$\left(X = \overline{\tilde{M}}_9\right)$then$\left(Y = \overline{\tilde{S}}\right)$; d_{10}:if$\left(X = \overline{\tilde{M}}_{10}\right)$then$\left(Y = \overline{\tilde{M}}S\right)$;

d_{11}:if$\left(X = \overline{\tilde{M}}_{11}\right)$then$\left(Y = \overline{\tilde{V}}S\right)$; d_{12}:if$\left(X = \overline{\tilde{M}}_{12}\right)$then$\left(Y = \overline{\tilde{V}}S\right)$;

d_{13}:if$\left(X = \overline{\tilde{M}}_{12}\right)$then$\left(Y = \overline{\tilde{S}}\right)$; d_{14}:if$\left(X = \overline{\tilde{M}}_{14}\right)$then$\left(Y = \overline{\tilde{U}}S\right)$;

d_{15}:if$\left(X = \overline{\tilde{M}}_{15}\right)$then$\left(Y = \overline{\tilde{U}}S\right)$; d_{16}:if$\left(X = \overline{\tilde{M}}_{16}\right)$then$\left(Y = \overline{\tilde{S}}\right)$;

d_{17}:if$\left(X = \overline{\tilde{M}}_{17}\right)$then$\left(Y = \overline{\tilde{V}}S\right)$. (21)

Here and then for each IFST2 $\tilde{\tilde{A}}$ through $\overline{\tilde{A}}$and $\underline{\tilde{A}}$correspondingFST1 aredenoted, for which

$$\mu_{\overline{\tilde{A}}}(x) = \overline{\mu}_{\tilde{\tilde{A}}}(x)\text{and}\mu_{\underline{\tilde{A}}}(x) = \underline{\mu}_{\tilde{\tilde{A}}}(x)$$

Using rule (13) of implication transfer

$$\text{If}\left(\text{X} = \overline{\tilde{M}}_j\right)\text{ then }\left(Y = \overline{\tilde{Q}}_j\right)\text{in expression}\mu_{\overline{\tilde{D}}_j}(u,i) = min\left(1{,}1 - \mu_{\overline{\tilde{M}}_j}(u) + \overline{\mu}_{\overline{\tilde{Q}}}(i)\right),$$

foreachpair $(u,i)\in U\times I$we get the following fuzzy subsets from $U\times I$:

$$\overline{\tilde{D}}_1 = \begin{array}{r} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{array}\left\|\begin{array}{lllllllllll} 0 & 0{,}1 & 0{,}2 & 0{,}3 & 0{,}4 & 0{,}5 & 0{,}6 & 0{,}7 & 0{,}8 & 0{,}9 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0{,}9 & 0{,}75 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0{,}9 & 0{,}75 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0{,}9 & 0{,}75 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0{,}9 & 0{,}75 \end{array}\right\|$$

$$\overline{\tilde{D}}_2 = \begin{array}{r} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{array}\left\|\begin{array}{lllllllllll} 0 & 0{,}1 & 0{,}2 & 0{,}3 & 0{,}4 & 0{,}5 & 0{,}6 & 0{,}7 & 0{,}8 & 0{,}9 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0{,}953 & 0{,}763 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0{,}948 & 0{,}758 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0{,}94 & 0{,}75 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0{,}953 & 0{,}763 \end{array}\right\|$$

$$\overline{\tilde{D}}_3 = \begin{array}{r} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{array}\left\|\begin{array}{lllllllllll} 0 & 0{,}1 & 0{,}2 & 0{,}3 & 0{,}4 & 0{,}5 & 0{,}6 & 0{,}7 & 0{,}8 & 0{,}9 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{array}\right\|$$

$$\overline{\tilde{D}}_4 = \begin{array}{r} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{array}\left\|\begin{array}{lllllllllll} 0 & 0{,}1 & 0{,}2 & 0{,}3 & 0{,}4 & 0{,}5 & 0{,}6 & 0{,}7 & 0{,}8 & 0{,}9 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{array}\right\|$$

$$\overline{\tilde{D}}_5 = \begin{array}{r} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{array}\left\|\begin{array}{ccccccccccc} 0 & 0{,}1 & 0{,}2 & 0{,}3 & 0{,}4 & 0{,}5 & 0{,}6 & 0{,}7 & 0{,}8 & 0{,}9 & 1 \\ 0{,}88 & 0{,}98 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{array}\right\|$$

$$\overline{\widetilde{D}}_6 = \begin{matrix} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{matrix} \left\| \begin{matrix} 0 & 0,1 & 0,2 & 0,3 & 0,4 & 0,5 & 0,6 & 0,7 & 0,8 & 0,9 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0,88 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0,88 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{matrix} \right\|$$

$$\overline{\widetilde{D}}_7 = \begin{matrix} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{matrix} \left\| \begin{matrix} 0 & 0,1 & 0,2 & 0,3 & 0,4 & 0,5 & 0,6 & 0,7 & 0,8 & 0,9 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0,88 \end{matrix} \right\|$$

$$\overline{\widetilde{D}}_8 = \begin{matrix} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{matrix} \left\| \begin{matrix} 0 & 0,1 & 0,2 & 0,3 & 0,4 & 0,5 & 0,6 & 0,7 & 0,8 & 0,9 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0,92 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0,92 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{matrix} \right\|$$

$$\overline{\widetilde{D}}_9 = \begin{matrix} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{matrix} \left\| \begin{matrix} 0 & 0,1 & 0,2 & 0,3 & 0,4 & 0,5 & 0,6 & 0,7 & 0,8 & 0,9 & 1 \\ 0,99 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,92 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,92 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,92 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{matrix} \right\|$$

$$\overline{\widetilde{D}}_{10} = \begin{matrix} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{matrix} \left\| \begin{matrix} 0 & 0,1 & 0,2 & 0,3 & 0,4 & 0,5 & 0,6 & 0,7 & 0,8 & 0,9 & 1 \\ 0,99 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,92 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,92 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,92 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{matrix} \right\|$$

$$\overline{\widetilde{D}}_{11} = \begin{matrix} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{matrix} \left\| \begin{matrix} 0 & 0,1 & 0,2 & 0,3 & 0,4 & 0,5 & 0,6 & 0,7 & 0,8 & 0,9 & 1 \\ 0,99 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,92 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,92 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,92 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{matrix} \right\|$$

$$\overline{\widetilde{D}}_{12} = \begin{matrix} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{matrix} \left\| \begin{matrix} 0 & 0,1 & 0,2 & 0,3 & 0,4 & 0,5 & 0,6 & 0,7 & 0,8 & 0,9 & 1 \\ 0,8 & 0,99 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,8 & 0,99 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,8 & 0,99 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,8 & 0,99 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{matrix} \right\|$$

$$\overline{\widetilde{D}}_{13} = \begin{matrix} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{matrix} \left\| \begin{matrix} 0 & 0,1 & 0,2 & 0,3 & 0,4 & 0,5 & 0,6 & 0,7 & 0,8 & 0,9 & 1 \\ 0,8 & 0,9 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,8 & 0,9 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,8 & 0,9 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0,8 & 0,9 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{matrix} \right\|$$

$$\overline{\widetilde{D}}_{14} = \begin{matrix} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{matrix} \left\| \begin{matrix} 0 & 0,1 & 0,2 & 0,3 & 0,4 & 0,5 & 0,6 & 0,7 & 0,8 & 0,9 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{matrix} \right\|$$

$$\overline{\widetilde{D}}_{15} = \begin{matrix} \\ u_1 \\ u_2 \\ u_3 \\ u_4 \end{matrix} \left\| \begin{matrix} 0 & 0,1 & 0,2 & 0,3 & 0,4 & 0,5 & 0,6 & 0,7 & 0,8 & 0,9 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{matrix} \right\|$$

$$\overline{\tilde{D}}_{16}=\begin{matrix} \\ u_1\\ u_2\\ u_3\\ u_4\end{matrix}\left\|\begin{matrix}0&0,1&0,2&0,3&0,4&0,5&0,6&0,7&0,8&0,9&1\\1&1&1&1&1&1&1&1&1&1&1\\1&1&1&1&1&1&1&1&1&1&1\\1&1&1&1&1&1&1&1&1&1&1\\1&1&1&1&1&1&1&1&1&1&1\end{matrix}\right\|$$

$$\overline{\tilde{D}}_{17}=\begin{matrix} \\ u_1\\ u_2\\ u_3\\ u_4\end{matrix}\left\|\begin{matrix}0&0,1&0,2&0,3&0,4&0,5&0,6&0,7&0,8&0,9&1\\0,8&0,81&1&1&1&1&1&1&1&1&1\\0,8&0,81&1&1&1&1&1&1&1&1&1\\0,8&0,81&1&1&1&1&1&1&1&1&1\\0,8&0,81&1&1&1&1&1&1&1&1&1\end{matrix}\right\|$$

As a result we'll obtain general functional solution:

$$\overline{\tilde{D}}=\overline{\tilde{D}}_1\cap\overline{\tilde{D}}_2\cap\ldots\cap\overline{\tilde{D}}_{17},$$

that is

$$\mu_{\overline{\tilde{D}}}(u,i)=\min_{j=\overline{1,17}}\mu_{\overline{\tilde{D}}_j}(u,i) \tag{22}$$

$$\overline{\tilde{D}}=\begin{matrix} \\ u_1\\ u_2\\ u_3\\ u_4\end{matrix}\left\|\begin{matrix}0&0,1&0,2&0,3&0,4&0,5&0,6&0,7&0,8&0,9&1\\0,88&0,98&1&1&1&1&1&1&1&1&1\\0,92&1&1&1&1&1&1&1&1&1&1\\0,92&1&1&1&1&1&1&1&1&1&1\\0,92&1&1&1&1&1&1&1&1&1&1\end{matrix}\right\|. \tag{23}$$

For calculation of satisfaction of each alternative we'll applyrule of composition outlet (16), where E_j – is the level of alternative satisfaction j; G_j – is the image of alternative j in the form of fuzzy subset from $U=(u_1, u_2, u_3, u_4)$, where G_j issinglet on: $\mu_{G_j}(u)=0, u\neq u_j, \mu_{G_j}(u)=1, u=u_j$; D – is functional decision.

Then

$$\mu_{\overline{\tilde{E}}_j}(i)=\max_{u\in U}\left(min\left(\mu_{G_j}(u),\mu_{\overline{\tilde{D}}}(u,i)\right)\right) \tag{24}$$

With other words, $\overline{\tilde{E}}_j$is$j$-line in $\overline{\tilde{D}}$matrix.

Now let's apply comparison of fuzzy subsets $\overline{\tilde{E}}_j(j=\overline{1,4})$in the single interval I=[0, 1], using level sets.

For the first alternative (j=1)

$$\overline{\tilde{E}}_1=\{0,88/0\,;0,98/0,1\,;1/0,2\,;1/0,3\,;1/0,4\,;1/0,5\,;1/0,6\,;1/0,7\,;1/0,8\,;0,9/0,9\,;0,75/1\}$$

let's use level $\overline{\tilde{E}}_{j\alpha}$. Their power$M\left(\overline{\tilde{E}}_{j\alpha}\right)$is found on the formula (10) from section 3:

$$M\left(\overline{\tilde{E}}_{j\alpha}\right)=\sum_{x_i\in\overline{\tilde{E}}_{j\alpha}}\frac{x_i}{n}, \tag{25}$$

where n – is number of points in $\overline{\tilde{E}}_{j\alpha}$.

Level sets: 0≤α≤0,75; d_α=0,75

$$\overline{\tilde{E}}_{1\alpha}=\{0;0,1;0,2;0,3;0,4;0,5;0,6;0,7;0,8;0,9;1\};\ M\left(\overline{\tilde{E}}_{1\alpha}\right)=0,5;$$

0,75<α≤0,88; d_α=0,13

$$\overline{\tilde{E}}_{1\alpha}=\{0;0,1;0,2;0,3;0,4;0,5;0,6;0,7;0,8;0,9\};\ M\left(\overline{\tilde{E}}_{1\alpha}\right)=0,45;$$

0,88<α≤0,98; d_α=0,1

$$\overline{\tilde{E}}_{1\alpha}=\{0,1;0,2;0,3;0,4;0,5;0,6;0,7;0,8;0,9\};\ M\left(\overline{\tilde{E}}_{1\alpha}\right)=0,5;$$

0,98<α≤1; d_α=0,02

$$\overline{\tilde{E}}_{1\alpha} = \{0{,}1; 0{,}2; 0{,}3; 0{,}4; 0{,}5; 0{,}6; 0{,}7; 0{,}8\};\ M\left(\overline{\tilde{E}}_{1\alpha}\right) = 0{,}45;$$

$$F\left(\overline{\tilde{E}}_1\right) = \frac{1}{\alpha_{max}} \int_0^{\alpha_{max}} M\left(\overline{\tilde{E}}_{1\alpha}\right) d_\alpha = \frac{1}{1} \int_0^1 M\left(\overline{\tilde{E}}_{1\alpha}\right) d_\alpha =$$
$$= \frac{1}{1}(0{,}5 \cdot 0{,}75 + 0{,}45 \cdot 0{,}13 + 0{,}5 \cdot 0{,}1 + 0{,}45 \cdot 0{,}2) = 0{,}512$$

For the second alternative (j=2)

$$\overline{\tilde{E}}_2 = \{0{,}92/0\,; 1/0{,}1\,; 1/0{,}2\,; 1/0{,}3\,; 1/0{,}4\,;\ 1/0{,}5\,; 1/0{,}6\,;\ 1/0{,}7\,; 1/0{,}8\,; 0{,}9/0{,}9\,;\ 0{,}75/1\};$$

$$F\left(\overline{\tilde{E}}_2\right) = 0{,}525$$

For the third alternative (j=3)

$$\overline{\tilde{E}}_3 = \{0{,}92/0\,; 1/0{,}1\,; 1/0{,}2\,; 1/0{,}3\,;\ 1/0{,}4\,; 1/0{,}5\,;\ 1/0{,}6\,; 1/0{,}7\,;\ 1/0{,}8\,; 0{,}9/0{,}9\,; 0{,}75/1\};$$

$$F\left(\overline{\tilde{E}}_3\right) = 0{,}525$$

For the fourth alternative (j=4)

$$\overline{\tilde{E}}_4 = \{0{,}92/0\,;\ 1/0{,}1\,;\ 1/0{,}2\,; 1/0{,}3\,; 1/0{,}4\,; 1/0{,}5\,; 1/0{,}6\,; 1/0{,}7\,;\ 1/0{,}8\,;\ 0{,}9/0{,}9\,; 0{,}75/1\};$$

$$F\left(\overline{\tilde{E}}_4\right) = 0{,}525$$

Analagously calculation of “low” FBforresultingIFST2 has been carried out

ford$_1$: $\mu_{\underline{\tilde{M}}_1}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{3,1}}(u); \underline{\tilde{M}}_1 = \{0{,}225/u_1\,; 0{,}25/u_2\,; 0{,}225/u_3\,; 0{,}25/u_4\};$

ford$_2$: $\mu_{\underline{\tilde{M}}_2}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{3,2}}(u);\ \underline{\tilde{M}}_2 = \{0{,}225/u_1\,;\ 0{,}05/u_2\,; 0{,}25/u_3\,; 0{,}025/u_4\};$

ford$_3$: $\mu_{\underline{\tilde{M}}_3}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{3,3}}(u); \underline{\tilde{M}}_3 = \{0/u_1\,; 0/u_2\,; 0/u_3\,; 0/u_4\};$

ford$_4$: $\mu_{\underline{\tilde{M}}_4}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{3,4}}(u); \underline{\tilde{M}}_4 = \{0/u_1\,;\ 0/u_2\,; 0/u_3\,; 0/u_4\};$

ford$_5$: $\mu_{\underline{\tilde{M}}_5}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{1,1}}(u); \underline{\tilde{M}}_5 = \{0{,}35/u_1\,;\ 0{,}35/u_2\,;\ 0{,}35/u_3\,;\ 0{,}35/u_4\};$

ford$_6$: $\mu_{\underline{\tilde{M}}_6}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{1,2}}(u); \underline{\tilde{M}}_6 = \{0/u_1\,;\ 0/u_2\,;\ 0{,}12/u_3\,; 0/u_4\};$

ford$_7$: $\mu_{\underline{\tilde{M}}_7}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{1,3}}(u); \underline{\tilde{M}}_7 = \{0/u_1\,;\ 0/u_2\,;\ 0/u_3\,;\ 0{,}12/u_4\};$

ford$_8$: $\mu_{\underline{\tilde{M}}_8}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{2,4}}(u); \underline{\tilde{M}}_8 = \{0{,}08/u_1\,;\ 0/u_2\,;\ 0/u_3\,; 0{,}12/u_4\};$

ford$_9$: $\mu_{\underline{\tilde{M}}_9}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{2,3}}(u); \underline{\tilde{M}}_9 = \{0{,}008/u_1\,;\ 0{,}08/u_2\,;\ 0{,}08/u_3\,;\ 0{,}08/u_4\};$

ford$_{10}$: $\mu_{\underline{\tilde{M}}_{10}}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{2,2}}(u); \underline{\tilde{M}}_{10} = \{0/u_1\,; 0/u_2\,; 0/u_3\,;\ 0/u_4\};$

ford$_{11}$: $\mu_{\underline{\tilde{M}}_{11}}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{2,1}}(u); \underline{\tilde{M}}_{11} = \{0/u_1\,; 0/u_2\,; 0/u_3\,;\ 0/u_4\};$

ford$_{12}$: $\mu_{\underline{\tilde{M}}_{12}}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{5,3}}(u); \underline{\tilde{M}}_{12} = \{0/u_1\,;\ 0/u_2\,;\ 0/u_3\,; 0/u_4\};$

ford$_{13}$: $\mu_{\underline{\tilde{M}}_{13}}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{5,2}}(u); \underline{\tilde{M}}_{13} = \{0{,}2/u_1\,;\ 0{,}2/u_2\,;\ 0{,}2/u_3\,;\ 0{,}2/u_4\};$

ford$_{14}$: $\mu_{\underline{\tilde{M}}_{14}}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{5,1}}(u); \underline{\tilde{M}}_{14} = \{0/u_1\,;\ 0/u_2\,;\ 0/u_3\,;\ 0/u_4\};$

ford$_{15}$: $\mu_{\underline{\tilde{M}}_{15}}(u) = \underline{\mu}_{\tilde{\tilde{X}}_{5,1}}(u); \underline{\tilde{M}}_{15} = \{0/u_1\,; 0/u_2\,; 0/u_3\,;\ 0/u_4\};$

ford$_{16}$: $\mu_{\underline{\tilde{M}}_{16}}(u) = min\left(\underline{\mu}_{\tilde{\tilde{X}}_{4,2}}(u), \underline{\mu}_{\tilde{\tilde{X}}_{5,2}}(u)\right); \underline{\tilde{M}}_{16} = \{0/u_1\,; 0/u_2\,; 0/u_3\,;\ 0/u_4\};$

$$\text{ford}_{17}\text{: } \mu_{\underline{\tilde{M}}_{17}}(u) = min\left(\mu_{\underline{\tilde{\tilde{X}}}_{4,1}}(u), \mu_{\underline{\tilde{\tilde{X}}}_{5,3}}(u)\right); \underline{\tilde{M}}_{17} = \{0/u_1\,;\ 0/u_2\,; 0/u_3\,; 0/u_4\};$$

In formulae (1) upper line should be changed into the low one. Asaresultweget:

$$\underline{\tilde{E}_1} = \{0{,}65/0\,;\ 0{,}68/0{,}1\,;\ 0{,}74/0{,}2\,;\ 0{,}81/0{,}3\,;\ 0{,}9/0{,}4\,;\ 1/0{,}5\,;\ 1/0{,}6\,; 1/0{,}7\,; 1/0{,}8\,;\ 0{,}925/0{,}9\,; 0{,}775/1\};$$

$$F\left(\underline{\tilde{E}_1}\right) = 0{,}592;$$

$$\underline{\tilde{E}_2} = \{0{,}65/0\,; 0{,}68/0{,}1\,; 0{,}74/0{,}2\,; 0{,}81/0{,}3\,; 0{,}9/0{,}4\,; 1/0{,}5\,; 1/0{,}6\,; 1/0{,}7\,; 1/0{,}8\,; 1/0{,}9\,; 0{,}95/1\};$$

$$F\left(\underline{\tilde{E}_2}\right) = 0{,}61;$$

$$\underline{\tilde{E}_3} = \{0{,}65/0\,; 0{,}68/0{,}1\,; 0{,}74/0{,}2\,; 0{,}81/0{,}3\,; 0{,}9/0{,}4\,; 1/0{,}5\,; 1/0{,}6\,; 1/0{,}7\,;\ 1/0{,}8\,; 0{,}9/0{,}9\,; 0{,}95/1\};$$

$$F\left(\underline{\tilde{E}_3}\right) = 0{,}608;$$

$$\underline{\tilde{E}_4} = \{0{,}65/0\,; 0{,}68/0{,}1\,; 0{,}74/0{,}2\,; 0{,}81/0{,}3\,; 0{,}9/0{,}4\,; 1/0{,}5\,; 1/0{,}6\,; 1/0{,}7\,; 1/0{,}8\,; 1/0{,}9\,; 0{,}95/1\};$$

$$F\left(\underline{\tilde{E}_4}\right) = 0{,}614;$$

For more satisfaction let's accept alternative $u_j$for which average point value $F\left(\tilde{\tilde{E}}_j\right) = \frac{1}{2}\left(F\left(\overline{\tilde{E}}_j\right) + F\left(\underline{\tilde{E}}_j\right)\right)$ will be biggest. These values for alternatives u_1, u_2, u_3, $u_4$are equal to 0,552; 0,567; 0,566; 0,569. The biggest average value of satisfaction appeared at alternative u_4. Consequently, for$u_4$thebiggestreliability will be PALC and it must be repaired first.

5. Conclusion

Unlike the usual fuzzy sets (fuzzy sets of the first type (FST1), having one value function of belonging (FB), interval fuzzy sets of the second type (IFST2) have "upper" and "low" function of belongings. Essencially, such fuzzy sets are resulted by optimistic expert values to the pessimistic ones.

Application of IFST2 allows more fully to consider all expert information, not using average expert values on the basis of FS1T.

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