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Fuzzy approach to innovative programs development in conditions of partial and full uncertainty

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Abstract: *In the article the authors develop their research aimed at the use of fuzzy logic and fuzzy set theory to model the solution of economic problems. In particular, there are considered approaches to formation of innovative programs and the choice of a set of innovative projects, and their components, under varying degrees of uncertainty. Among the major selection criteria were identified such as financial capacity, payback period, profitability, social significance, regulatory compliance, degree of novelty, size of the market, opportunity of international cooperation, financing flexibility, flexibility of project and others. Algorithms using fuzzy linguistic expert assessment of the main criteria that characterize the innovative programs are proposed. At the same time can be taken into account the level of competence of experts as well as the requirements of the regional authorities and the degree of uncertainty. The proposed solutions are based on the multi-criteria convolutions of criteria estimates, max-min approach and computational analysis of the relations of domination. Are given examples of calculations for the pessimistic and optimistic approaches to the solution. Also described approach of rigorous dominance, interval dominance and not dominance in the case of considerable uncertainty, allows establish the relative degree of efficiency and a measure of preference for several innovative projects. The described theoretical approach can be successfully extended to other situations need formalized solving of multicriterial choice problems on the set of alternatives in conditions of different degrees of uncertainty in the economy.*

Key-words: *innovative program, economic uncertainly, fuzzy modeling, linguistic assessment ,multi-criteria convolution, fuzzy set, multicriterial choice problem*

1. Introduction

It is obvious that to achieve success within the framework of any regional innovation program need to be considered objective conditions of implementation for this program (Antonescu, 2008; Bobylev et al, 2008; Grillo and Landabaso, 2011). Among these basic conditions are existing regional assets; the level of

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innovation development; the level of cooperation between the innovation participants (Radosevic, 2002; Wamser et al, 2013). Therefore projects and hence the programs should be appropriately selected according to the conditions of implementation (Ganter and Hecker, 2014; Benita et al, 2016). That is, they should be well compatible with innovative potential of the region, as shown in Figure 1.

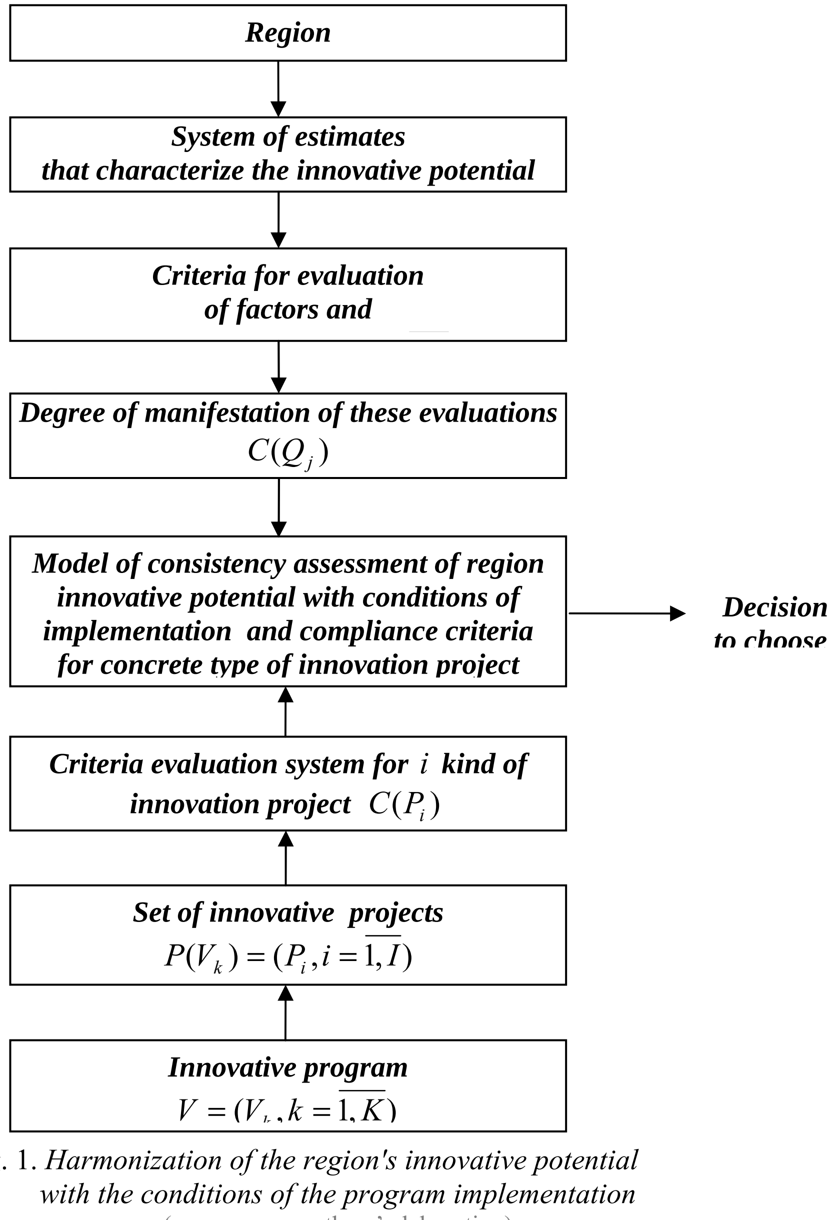

Fig. 1. *Harmonization of the region's innovative potential with the conditions of the program implementation*
(source: own authors' elaboration)

In the process of development and implementation of regional innovation programs need to assess all possible effects (Chernov et al, 2010; Kisiel et al, 2011).

Because the success depends on the effectiveness of all the projects included in this program, then starter set of projects should qualify both on eligibility criteria and on the territorial implementation of the capabilities and limitations.

2. General formulation of the problem

Suppose that there is an innovative program $V=\{V_k;k=\overline{1,K}\}$. Are considered several innovative projects $P(V_k)=\{P_i\ ;i\ =\overline{1,I}\ \}$, competing for inclusion in the investment program of V_k kind and are subject to multi-criteria analysis. Projects - applicants must pass the selection under the terms of the implementation: $R_{IP}:Q\longrightarrow C\left(Q_j\right)$.

It is necessary ordering of the elements of the set $P(V_k)$ by existing systems of qualitative and quantitative evaluation criteria $C\left(P(V_k)\right)=\left\{C(P_i);i=\overline{1,I}\right\}$ for $P(V_k)\in V_k$: $R_{P(V_k)}:P(V_k)\longrightarrow C(P(V_k))$. Then the degree of preference for innovative projects can be determined from a composite output rule: $R_{IP}\circ R_{P(V_k)}\xrightarrow{\mu}P(V_k)\xrightarrow{\mu}V_k$.

Let denote as $W[Q(V_k)]$ the cardinality of the region's innovative capacity assessments, which can be considered as the appropriate conditions for implementing the program V_k, and the cardinality of the set of project evaluations within the framework of program V_k through $W[Q(P(V_k))]$.

Then, proceeding from the need to harmonize the conditions for the realization of a particular type of innovative project with estimates of the region's innovation potential, the decision to reject or to inclusion the project in an innovative program will depend on the implementation of the following non-strict inequality $W[Q(V_k)]\geq W[Q(P(V_k))]$ for all $P(V_k)\in V_k$.

To estimate exists a finite set of quantitative and qualitative criteria $\Re$, on which two subsets defined: $U(P)=\{U_S:s=\overline{1,S}\}$, that makes, for example, the regional administration authorized agency. And because there is no universal system of evaluation criteria, then second subset $W(P)=(W_r:r=\overline{1,R})$ proposed by experts. After that, from this set of experts should choose a variety of the most important criteria for the assessment of innovative projects $C\left(P(V_k)\right)=\left\{C(P_i);i=\overline{1,I}\right\}$ for $P(V_k)\in V_k$. Denote as $E=\{E_n;n=\overline{1,N}\}$ a number of experts who evaluate a set of selection criteria for innovative project.

According to problem, N experts must provide a qualitative and quantitative estimation on S and R criteria, from which we will then select a group of more meaningful $C(V_k)$: $F_1:E\xrightarrow{\mu}U(P)$ и $F_2:E\xrightarrow{\mu}W(P)$.

The expert must compare each criterion from the set with the quantitative indicator, according to which namely it will occur the place in the system $C(V_k)$. Then for criteria set we can set the linguistic evaluation: $L_{U_s}\ (s=\overline{1,S})$, whose value can be variant of answers $L_{U_{sg}}\ (g=\overline{1,G^{U_s}})$, where G^{U_s} is the number of variants of estimation on U_S and $L_{W_r}\ (r=\overline{1,R})$ with a value $L_{W_rz}(z=\overline{1,Z^{W_r}})$, where Z^{W_r} is the number of variants of estimation on W_r. For a description of these assessments can be applied corresponding fuzzy sets.

Fuzzy evaluation, summarizing the experts' opinion, can be obtained as the intersection of fuzzy sets corresponding to expert evaluations: if the level of competence of all experts is the same:

$$\mu\tilde{E}\left(u_{sg}\right)=\bigcap_{g=1}^{G^{U_s}}\mu\tilde{E}\left(u_{sg}\right)=min\left(\mu\tilde{E}\left(u_{sg}\right)\right);s=\overline{1,S},g=\overline{1,G^{U_s}},$$

$$\mu\tilde{E}\left(w_{rz}\right)=\bigcap_{z=1}^{Z^{W_r}}\mu\tilde{E}\left(w_{rz}\right)=min\left(\mu\tilde{E}\left(w_{rz}\right)\right);r=\overline{1,R},z=\overline{1,Z^{W_r}};$$

if the level of competence of all experts is various (β_n coefficient of expert competence):

$$\mu\tilde{E}\left(u_{sg}\right)=\bigcap_{g=1}^{G^{U_s}}\mu\tilde{E}\left(u_{sg}\right)^{\beta_n}=min\left(\mu\tilde{E}\left(u_{sg}\right)^{\beta_n}\right);s=\overline{1,S},g=\overline{1,G^{U_s}},\ \sum_{n=1}^{N}\beta_n=1;$$

$$\mu\tilde{E}\left(w_{rz}\right)=\bigcap_{z=1}^{Z^{W_r}}\mu\tilde{E}\left(w_{rz}\right)^{\beta_n}=min\left(\mu\tilde{E}\left(w_{rz}\right)^{\beta_n}\right);r=\overline{1,R},z=\overline{1,Z^{W_r}},\ \sum_{n=1}^{N}\beta_n=1.$$

Thus, for each set of criteria: $U(P)=\{U_S : s=\overline{1,S}\}$ и $W(P)=(W_r : r=\overline{1,R})$ from the answers of υ expert are formed matrixes $\left\|u_{sg}^{\upsilon}\right\|$ and $\left\|w_{rz}^{\upsilon}\right\|$:

$$u_{sg}^{\upsilon}=\begin{cases}1, & if \quad (u_{sg})\in C(V_k)\\ 0, & in \quad other \quad case\end{cases} \text{ and } w_{rz}^{\upsilon}=\begin{cases}1, & if \quad (w_{rz})\in C(V_k)\\ 0, & in \quad other \quad case\end{cases}.$$

As a result, we can introduce new quantities $\chi_{sg}=\sum_{\upsilon=1}^{N}u_{sg}^{\upsilon}$ and $\varepsilon_{rz}=\sum_{\upsilon=1}^{N}w_{rz}^{\upsilon}$, indicating the number of votes cast for the criterion u_i and w_i, against the decision $\wp_{sg}=\chi_{sg}-\chi_{gs}=2\chi_{sg}-1$ and $\ell_{rz}=\varepsilon_{rz}-\varepsilon_{rz}=2\varepsilon_{rz}-1.$

The value of membership function is defined as follows:

$$\mu(u_s)=\sum_{i=1}^{n}\lambda_s\wp_{sg}, \quad \lambda_s\geq 0, \quad \sum_{s=1}^{S}\lambda_s=1,$$

$$\mu(w_r)=\sum_{i=1}^{n}\gamma_r\ell_{rz}, \quad \gamma_r\geq 0, \quad \sum_{r=1}^{R}\gamma_r=1.$$

Then to obtain $C(V_k)$ compositional deduction rule can be represented as follows:

$$R: E_n\rightarrow C(V_k)\Leftrightarrow F_1\circ F_2\xrightarrow{\mu}C(V_k),$$

$$\mu C_j(P_i)=\max\min(\mu\tilde{E}(u_{sg});\mu\tilde{E}(w_{rz})).$$

3. Variants of solutions at various uncertainty levels

Since the selection of innovative projects carried on a competition basis, then the selection process can be accompanied by different levels of uncertainty (Chernov et al, 2015; Chernov et al, 2016): partial uncertainty (incompleteness of the information associated with fuzzy preference relations) with comparison and selection using the experts point estimates; full uncertainty, when in the initial stage the experts set coarse or inaccurate estimation of the future system according to characterizing its criteria, which in the process of the project realization will gradually refined (Godoe et al, 2014; Alfaro et al, 2015). In this case, it is advisable to use interval estimates.

For the first case multi-criteria analysis of the of innovative projects leads to streamline the set of elements $P(V_k)$ according to the criteria $C(V_k)$:

$R_{P(V_k)} : P(V_k) \xrightarrow{\mu} C(V_k)$.

For each set linguistic evaluations and the corresponding fuzzy sets can be built: $L_{P(V_k)} = \left\{ L_{P_{ij}} \right\}; L_C = \left\{ L_{C_{mh}} \right\}; L_E = \left\{ L_{E_{np}} \right\}$, where the fuzzy set: $\mu_C(P(V_k)) \in [0,1]$, and also term sets of values of linguistic variables: $T = \{T_i\}$.

The level of estimation $P_i \in P(V_k), i = \overline{1,I}$ by criterion $C_j; j = \overline{1,M}$ characterized by the number $\mu C_j(P_i) \in [0,1]$. Hence, the greater the number $\mu C_j(P_i)$, so much the better an innovative project. On universal set $P(V_k)$ criteria $C_j \in C\left(V_k\right)$ can be represented in the form of fuzzy sets $\tilde{C}_j$ in the following way: $\tilde{C}_j = \left\{ \mu_{C_j}\left(P_1\right)/P_1, \mu_{C_j}\left(P_2\right)/P_2 \quad \ldots \quad \mu_{C_j}\left(P_I\right)/P_I \right\}$, where $\mu_{Cj}\left(P_i\right)$ degree of element membership $P_i\ ; i = \overline{1,I}$ to the fuzzy set $\tilde{C}_j$.

Then for equilibrium criteria a rule to select the best project can be written as the intersection of the corresponding fuzzy sets.

Because the operation of intersection of fuzzy sets corresponding to the minimum operations performed on their membership functions, we have:

$$P^{pes} = \mu C_j\left(P_i\right) = \bigcap_{j=1}^{M} \mu C_j\left(P_i\right) = \min_{j=\overline{1,M}} \mu C_j\left(P_i\right); \quad i = \overline{1,I}$$

In case of not equilibrium criteria degrees of membership for fuzzy sets are defined as:

$$P^{pes} = \mu C_j(P_i) = \bigcap_{j=1}^{M} \mu C_j(P_i)^{\alpha_j} = \min_{j=\overline{1,M}} \mu C_j(P_i)^{\alpha_j}; \quad i = \overline{1,I},$$

where α_j is coefficient of relative importance or rank of criteria Cj and $\alpha_1 + \alpha_2 + \ldots + \alpha_M = 1$.

As the best is selected alternative P_i which has the highest value of membership function:

$$P^{opt} = \mu C_j(P_i) = \bigcup_{j=1}^{M} \mu C_j(P_i) = \max_{j=\overline{1,M}} \mu C_j(P_i) \quad i=\overline{1,I} \cdot P^{opt} = \max\min \mu C_j(P_i)$$

Then, the level of non-compliance project evaluations on all criteria will be equal:

$$\overline{P^{opt}} = 1 - P^{opt} = 1 - \mu C_j(P_i).$$

The uncertainty of specified estimates can be determined as follows:

$$H = P^{opt} \cap \overline{P^{opt}} = \mu C_j(P_i) \cap \overline{\mu C_j(P_i)} = \min\left\{\mu C_j(P_i), \overline{\mu C_j(P_i)}\right\}.$$

For comparison of fuzzy sets $H, P^{opt}, \overline{P^{opt}}$, i.e. for ordering projects and obtain the best alternative, for which $P^{opt} \xrightarrow{\mu} 1$, H and $\overline{P^{opt}} \xrightarrow{\mu} 0$, we use the weighted power of these sets, computed on the basis of α - decompositions by the formula: $U_i = \sum_j \frac{x_{ij}}{n_j} d\alpha_i$ where:

$d\alpha_i$ i-й α-level, $d\alpha_i = \alpha_i - \alpha_{i-1}$;

x_{ij} - argument of membership functions is such that $\mu(x_{ij}) \geq \alpha_i$;

n_j - number of values x_{ij}. Total power $U = \sum_i U_i$.

In the second case of full of uncertainty each criterion $C(P(V_k))$ can be specify in the interval form, which characterizes each individual version of the project P_i, accordingly, $C(P(V_k)) = \left[\underline{C(P(V_k))}; \overline{C(P(V_k))}\right]$, where $\underline{C(P(V_k))}$ the lower boundary of the evaluation interval, $\overline{C(P(V_k))}$- the upper boundary of the interval. That is, the point estimate can be considered a special case of interval estimates, when $\underline{C(P(V_k))} = \overline{C(P(V_k))}$.

For the system $P(V_k)$ can be determined the interval membership function:

$$\mu_{C_j}(P_i) = \left\{ \left[\underline{\mu_{C_1}(P_i)}; \overline{\mu_{C_1}(P_i)} \right]; \left[\underline{\mu_{C_2}(P_i)}; \overline{\mu_{C_2}(P_i)} \right], \ldots, \left[\underline{\mu_{C_M}(P_i)}; \overline{\mu_{C_M}(P_i)} \right] \right\}.$$

Comparison of pair of projects $(P_i, P_{i-1}) \in P(V_k)$ by fuzzy criteria C_j gives us an estimate by intervals: $\mu_{C_j}(P_i, P_{i-1}) = \left[\underline{\mu_{C_j}(P_i, P_{i-1})}; \overline{\mu_{C_j}(P_i, P_{i-1})}, j = \overline{1, M} \right].$

The corresponding degrees of superiority are introduced by natural means:

$$\underline{\Delta_j(P_i, P_{i-1})} = \underline{\mu_{C_j}(P_i, P_{i-1})} - \overline{\mu_{C_j}(P_i, P_{i-1})},$$

$$\overline{\Delta_j(P_i, P_{i-1})} = \overline{\mu_{C_j}(P_i, P_{i-1})} - \underline{\mu_{C_j}(P_i, P_{i-1})},$$

$$\overline{\Delta_j(P_i, P_{i-1})} \geq \underline{\Delta_j(P_i, P_{i-1})}.$$

Then the project P_i interval preference over project P_{i-1} is determined by membership functions $\mu^{in}{}_{Cj}(P_i, P_{i-1}) \in [-1, 1]$, which form the evaluation matrix for the entire set of projects $\left\| \mu^{in} C_j(P_i, P_{i-1}) \right\|$, and are defined as follows:

$$\mu^{in}{}_{Cj}(P_i, P_{i-1}) = \frac{\mu_{Cj}(P_i, P_{i-1}) - \mu_{Cj}(P_i, P_{i-1})}{t_j} =$$

$$= \frac{\left[\underline{\mu_{Cj}(P_i, P_{i-1})}; \overline{\mu_{Cj}(P_i, P_{i-1})} \right] - \left[\underline{\mu_{Cj}(P_i, P_{i-1})}; \overline{\mu_{Cj}(P_i, P_{i-1})} \right]}{t_j} =$$

$$= \left[\min \left\{ \underline{\underline{\mu_{Cj}(P_i, P_{i-1})} - \underline{\mu_{Cj}(P_i, P_{i-1})}; \overline{\mu_{Cj}(P_i, P_{i-1})} - \overline{\mu_{Cj}(P_i, P_{i-1})}} \right\}; \right.$$

$$\max\left\{\underline{\mu_{C_j}(P_i,P_{i-1})}-\underline{\mu_{C_j}(P_i,P_{i-1})};\overline{\mu_{C_j}(P_i,P_{i-1})}-\overline{\mu_{C_j}(P_i,P_{i-1})}\right\}\Big]\Big/t_j$$

where: - $\mu^{in}{}_{Cj}(P_i,P_{i-1})$ – interval domination P_i over P_{i-1} ;

- t_j – width for the evaluation interval for j partial interval criterion.

If we introduce the ratio of the strictly interval domination $\mu_{DC_j}(P_i,P_{i-1})$, then for j partial interval criterion we will have:

$$\mu_{DC_j}(P_i,P_{i-1})=\mu^{in}{}_{Cj}(P_i,P_{i-1})-\mu^{in}{}_{Cj}(P_{i-1},P_i)=$$
$$\left[\underline{\mu^{in}C_j(P_i,P_{i-1})};\overline{\mu^{in}C_j(P_i,P_{i-1})}\right]-\left[\underline{\mu^{in}C_j(P_{i-1},P_i)};\overline{\mu^{in}C_j(P_{i-1},P_i)}\right].$$

As an addition $\mu_{DC_j}(P_i,P_{i-1})$ can be entered $\mu_{NDC_j}(P_i,P_{i-1})$ as interval not dominance of P_i over P_{i-1} :

$$\mu_{NDCj}(P_i,P_{i-1})=\begin{cases}1, if \ \ \mu_{DC_j}(P_i,P_{i-1})\le 0\\ 1-\mu_{DC_j}(P_i,P_{i-1}), if \ \ \mu_{DC_j}(P_i,P_{i-1})>0\end{cases}.$$

Consequently, for $\mu_{DC_j}(P_i,P_{i-1})$ и $\mu_{NDC_j}(P_i,P_{i-1})$ is possible to build a matrix of interval estimates $\left\|\mu_{DC_j}(P_i,P_{i-1})\right\|$ и $\left\|\mu_{NDC_j}(P_i,P_{i-1})\right\|$, which include the combined sets of interval solutions.

If through $\overset{*}{\mu}_D(P_i,P_{i-1})$ denote the membership functions, which shows the degree of efficiency and project preferences measure, then $\overset{*}{\mu}_{DC_j}(P_i,P_{i-1})=\min\overset{*}{\mu}_{NDC_j}(P_i,P_{i-1})$. And the higher $\overset{*}{\mu}_D(P_i,P_{i-1})$, the more preferable is considered project: if $\overset{*}{\mu}_D(P_i,P_{i-1})=1$, then P_i is the best project, but if 0, then it is the worst.

Besides, projects should qualify under the terms of the implementation of innovation project: $Q_{H_s,F_g,R_e,T_v} = \{ H_s = \overline{1,S};\ F_g = \overline{1,G};\ R_e = \overline{1,E};\ T_y = \overline{1,Y} \}$, where H_s, F_g, R_e, T_v restrictions related to human resources, financial, material and technical basis, the implementation period.

If for the innovation program V_k exists the following restrictions: $H_{V_k}, F_{V_k}, R_{V_k}, T_{V_k}$, and for its may be noted the value of possible additional attracted funds $\varepsilon_h, \nu_f, \varphi_r, \xi$, then for each i project planned values will be $\alpha_s h_{P_{i_{V_k}}}, \beta_g f_{P_{i_{V_k}}}, \gamma_e r_{P_{i_{V_k}}}, \omega_y t_{P_{i_{V_k}}}$, where $\alpha_s, \beta_g, \gamma_e, \omega_y$ accordingly the degree of importance of the human resource, financial, material and technical basis and term of implementation for this type of project, and the deviation from the planned value $\zeta_{h,f,r,t}$ (with the plus sign if more than the planned and minus when optimizing), hence: $\mu_{C_j}(P_i) \longrightarrow \max$,

$$\sum_{i=1}^{I} \alpha_s h_{P_i} \times P_i + \zeta_h \le H(V_k) + \varepsilon_h, \alpha_s h_{P_i} \ge 0, \sum_{s=1}^{S} \alpha_s = 1;$$

$$\sum_{i=1}^{I} \beta_g f_{P_i} \times P_i + \zeta_f \le F(V_k) + \nu_f, \beta_g f_{P_i} \ge 0, \sum_{g=1}^{G} \beta_g = 1;$$

$$\sum_{i=1}^{I} \gamma_e r_{P_i} \times P_i + \zeta_r \le R(V_k) + \varphi_r, \gamma_e r_{P_i} \ge 0, \sum_{e=1}^{E} \gamma_e = 1;$$

$$\sum_{i=1}^{I} \omega_y t_{P_i} \times P_i + \zeta_t \le T(V_k) + \xi_r, \omega_y t_{P_i} \ge 0, \sum_{y=1}^{Y} \varpi_y = 1.$$

Thus, the multi-criteria analysis of innovative projects leads to ordering elements of sets $P(V_k)$ not only by already defined evaluation criteria $C(V_k)$, but also by the conditions of implementation Q_{H_s,F_g,R_e,T_y}.

4. Formation of common criteria set

Let us assume during the formation of an innovative program of development were presented 6 projects (and besides 2 are at an early development phase, hence they have a high degree of uncertainty), which apply for inclusion in the investment program. The selection is carried out according to expert estimates, whose number in this case is five: $E = \{E_n; n = \overline{1,5}\}$ (they have the same competences). Suppose that the regional authorities have provided to experts set of criteria for evaluating projects, but experts considered it not complete in this case and each of them offered his additions. As a result, has been formed two potential sets of criteria (Ling, 2010), from which experts are choosing more meaningful for these types of projects: $C(P_i) \equiv U \oplus W, i = \overline{1,6}$ (Table 1).

$U(P_i)$	$W(P_i)$
1) degree of novelty	1) description of the project
2) financial capacity	2) experience of developers
3) resource intensity	3) compliance with standards
4) payback period	4) opportunity of international cooperation
5) size of the market	5) financing flexibility
6) profitability	6) flexibility of project
7) reliability	7) innovative environment
8) degree of risk	8) fields of application
9) regulatory compliance	
10) social significance	

(Source: own authors' research classification)

Table 1. *Criteria for evaluation of projects*

Further were obtained estimates (one of three levels – low, medium, high - specified in binary form) of each expert by each criterion for the first (Table 2) and second sets (Table 4). After was calculated a generalization of the results as a whole for all the experts for the first (Table 3) and second (Table 5) sets.

E_n/№	**term**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
№1	low	0	0	0	0	0	0	1	0	0	0
	medium	0	0	1	0	0	0	0	1	1	0
	high	1	1	0	1	1	1	0	0	0	1
№2	low	0	0	0	0	0	0	1	0	0	0
	medium	1	0	1	0	1	0	0	0	1	0
	high	0	1	0	1	0	1	0	1	0	1

E_n/№	term	1	2	3	4	5	6	7	8	9	10
№3	low	0	0	0	0	0	0	0	0	0	0
	medium	0	0	0	0	1	0	1	0	1	0
	high	1	1	1	1	0	1	0	1	0	1
№4	low	0	0	0	0	0	0	1	0	0	0
	medium	0	0	1	0	0	0	0	0	0	0
	high	1	1	0	1	1	1	0	1	1	1
№5	low	0	0	0	0	0	0	1	0	0	0
	medium	1	0	0	0	0	0	0	1	1	0
	high	0	1	1	1	1	1	0	0	0	1

(Source: own authors' research, expert survey)

Table 2. *The results of the expert survey on a set of criteria* $U(P_i)$

term	1	2	3	4	5	6	7	8	9	10
low	0	0	0	0	0	0	4	0	0	0
	0	0	0	0	0	0	0.8	0	0	0
medium	2	0	3	0	2	0	1	2	4	0
	0.4	0	0.6	0	0.4	0	0.2	0.4	0.8	0
high	3	5	2	5	3	5	0	3	1	5
	0.6	1	0.4	1	0.6	1	0	0.6	0.2	1

(Source: own authors' calculations)

Table 3. *Result of processing the expert opinions on the criteria* $U(P_i)$

E_n/№	term	1	2	3	4	5	6	7	8
№1	low	1	0	0	0	0	0	1	0
	medium	0	0	1	0	0	0	0	1
	high	0	1	0	1	1	1	0	0
№2	low	0	0	0	0	0	0	1	0
	medium	1	0	0	1	0	0	0	0
	high	0	1	1	0	1	1	0	1
№3	low	1	0	0	0	0	0	0	0
	medium	0	1	0	1	0	0	1	0
	high	0	0	1	0	1	1	0	1
№4	low	1	0	0	0	0	0	1	0
	medium	0	1	1	1	0	0	0	0
	high	0	0	0	0	1	1	0	1
№5	low	0	1	0	0	0	0	1	0
	medium	1	0	0	1	0	0	0	1
	high	0	0	1	0	1	1	0	0

(Source: own authors' research, expert survey)

Table 4. *The results of the expert survey on a set of criteria* $W(P_i)$

term	1	2	3	4	5	6	7	8
low	3	1	0	0	0	0	4	0
	0.6	0.2	0	0	0	0	0.8	0
medium	2	2	3	4	0	0	1	3
	0.4	0.4	0.6	0.8	0	0	0.2	0.6
high	0	2	2	1	5	5	0	2
	0	0.4	0.4	0.2	1	1	0	0.4

(Source: own authors' calculations)

Table 5. *Result of processing the expert opinions on the criteria* $W(P_i)$

Based on the results of generalization, for evaluating six innovative projects is possible to select the following set of criteria $C_j(P_i)$: financial capacity, payback period, profitability, social significance, regulatory compliance, degree of novelty, size of the market, opportunity of international cooperation, financing flexibility, flexibility of project, $j = \overline{1,10}, i = \overline{1,6}$.

5. Example of numerical calculations with lower uncertainty

We shall have deemed the following linguistic evaluations of compliance with the criteria, shown in Table 6.

Linguistic evaluations	Corresponding fuzzy numbers
very low [VL]	(0.1, 0. 2 , 0.3)
low [L]	(0.25 , 0.35 , 0.55)
medium [M]	(0.4 , 0.5, 0.65)
high [H]	(0.6 0.7 0.85)
very high [VH]	(0.8 ,0.9 , 1)

(Source: own authors' suppose based on expert survey)

Table 6. *Variants of linguistic evaluations*

Then, for the first four projects with greater certainty, it is possible to obtain estimates and parameters weighting coefficients for each project, shown in Table 7.

Projects / criteria	weight w	P_1	weight w	P_2	weight w	P_3	weigh t w	P_4
financial capacity C_1	0.1	H≡0.6	0.12	M≡0.45	0.14	H≡0.8	0.1	VH≡0.8
payback period C_2	0.1	M≡0.5	0.13	H≡0.75	0.15	VL≡0.3	0.1	L≡0.3
profitability C_3	0.15	VH≡0.8	0.2	VH≡0.85	0.13	VH≡0.8	0.2	VH≡0.95
social significance C_4	0.08	M≡0.65	0.04	M≡0.5	0.09	L≡0.35	0.09	M≡0.6
regulatory compliance C_5	0.08	H≡0.7	0.04	H≡0.8	0.06	H≡0.8	0.1	H≡0.75
degree of novelty C_6	0.12	M≡0.65	0.15	H≡0.8	0.11	M≡0.6	0.08	L≡0.4
size of the market C_7	0.1	L≡0.4	0.11	L≡0.4	0.04	VH≡0.8 5	0.06	H≡0.8
international cooperation opportunity C_8	0.06	L≡0.25	0.09	VH≡0.9	0.12	M≡0.5	0.08	L≡0.45
financing flexibility C_9	0.11	M≡0.6	0.07	VH≡0.8	0.07	H≡0.7	0.12	H≡0.75
flexibility of project C_{10}	0.09	H≡0.7	0.05	L≡0.35	0.09	VL≡0.2 5	0.07	VL≡0.3

(Source: own authors' research, expert survey)

Table 7. *Variants of linguistic evaluations*

When not equilibrium criteria of fuzzy set's grade of membership pessimistic (intersection), and optimistic (combination) evaluations are defined as follows:

$$P_1^{pes} = \bigcap_{j=1}^{10} \mu_{C_j}(P_1) = \min\left[0.6^{0.1}, 0.5^{0.1}, 0.8^{0.15}, 0.65^{0.08}, 0.7^{0.08}, 0.65^{0.12}, 0.4^{0.1}, 0.25^{0.06}, 0.6^{0.11}, 0.7^{0.09}\right] =$$

$$= \min[0.95; 0.93; 0.97; 0.96; 0.97; 0.95; 0.91; 0.92; 0.95; 0.97] = 0.91$$

$$P_1^{opt} = \max[0.95; 0.93; 0.97; 0.96; 0.97; 0.95; 0.91; 0.92; 0.95; 0.97] = 0.97$$

$$P_2^{pes}=\bigcap_{j=1}^{10}\mu_{C_j}(P_2)=\min\left[0.45^{0.12},0.75^{0.13},0.85^{0.2},0.5^{0.04},0.8^{0.04},0.8^{0.15},0.4^{0.11},0.9^{0.09},0.8^{0.07},0.35^{0.05}\right]=$$

$$=\min[0.91;0.96;0.97;0.97;0,99;0.97;0.90;0.99;0.98,0.95]=0.90$$

$$P_2^{opt}=\max[0.91;0.96;0.97;0.97;0,99;0.97;0.90;0.99;0.98,0.95]=0.99$$

$$P_3^{pes}=\bigcap_{j=1}^{10}\mu_{C_j}(P_3)=\min\left[0.8^{0.14},0.3^{0.15},0.8^{0.13},0.35^{0.09},0.8^{0.06},0.6^{0.11},0.85^{0.04},0.5^{0.12},0.7^{0.07},0.25^{0.09}\right]=$$

$$=\min[0.97;0.83;0.97;0,90,0.98;0.94;0.98;0.92;0.97;0.88]=0.83$$

$$P_3^{opt}=\max[0.97;0.83;0.97;0,90,0.98;0.94;0.98;0.92;0.97;0.88]=0.98$$

$$P_4^{pes}=\bigcap_{j=1}^{10}\mu_{C_j}(P_4)=\min\left[0.8^{0.1},0.3^{0.1},0.95^{0.2},0.6^{0.09},0.75^{0.1},0.4^{0.08},0.8^{0.06},0.45^{0.08},0.75^{0.12},0.3^{0.07}\right]=$$

$$=\min[0.98;0.89;0.99;0.95;0.97;0.93;0.99;0,93;0.96;0.91]=0.89$$

$$P_4^{opt}=\max[0.98;0.89;0.99;0.95;0.97;0.93;0.99;0,93;0.96;0.91]=0.99$$

Then the level of non-compliance for project evaluations on all criteria will be equal:

$$\overline{P_1^{opt}}=1-P_1^{opt}=1-0.93=0.07\,;\ \overline{P_2^{opt}}=1-P_2^{opt}=1-0.99=0.01\,;$$

$$\overline{P_3^{opt}}=1-P_3^{opt}=1-0.98=0.02\,;\ \overline{P_4^{opt}}=1-P_4^{opt}=1-0.99=0.01\,.$$

Most often for selecting the best alternative by multiple criteria used max-min approach, where: $P^{optimum}=\max\min\mu C_j\left(P_i\right)$.

So, finally we will have:

$$R=\begin{matrix} \\ P_1 \\ P_2 \\ P_3 \\ P_4\end{matrix}\begin{bmatrix} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 & C_{10} \\ 0.95 & 0.93 & 0.97 & 0.96 & 0.97 & 0.95 & 0.91 & 0.92 & 0.95 & 0.97 \\ 0.91 & 0.96 & 0.97 & 0.97 & 0.99 & 0.97 & 0.90 & 0.99 & 0.98 & 0.95 \\ 0.97 & 0.83 & 0.97 & 0.90 & 0.98 & 0.94 & 0.98 & 0.92 & 0.97 & 0.88 \\ 0.98 & 0.89 & 0.99 & 0.95 & 0.97 & 0.93 & 0.99 & 0.93 & 0.96 & 0.91\end{bmatrix}\begin{matrix}\min_j \\ 0.91 \\ 0.90 \\ 0.83 \\ 0.89\end{matrix}$$

$$P^{optimum}=0.91$$

Thus, according to the pessimistic and optimistic estimates and the method of max-min convolution projects by preferability can be ordered as follows:

1) $P_3^{pes} \prec P_4^{pes} \prec P_2^{pes} \prec P_1^{pes}$;

2) $P_1^{opt} \prec P_3^{opt} \prec P_2^{opt} = P_4^{opt}$;

3) $P_3^{optimum} \prec P_4^{optimum} \prec P^{optimum}{}_2 \prec P_1^{optimum}$.

6. Example of numerical calculations with greater uncertainty

As noted above in the formation of an innovative program six projects were presented, but two of which are at an early stage of development. The latter have a high degree of uncertainty and their criteria better to set in the interval form, characterizing each separate variant of project.

Evaluation of these projects is carried out according to three criteria: financial capacity, payback period, profitability (see Table 8).

projects / criteria	Projects P_1	Projects P_2	Width of the evaluation interval t_j
financial capacity C_1	[40; 75]	[45; 65]	100
payback period C_2	[3;6]	[4;5]	10
profitability C_3	[120; 145]	[125;140]	150

(Source: own authors' research, expert survey)

Table 8. *Variants of linguistic evaluations*

In order to establish the dominance interval of P_1 above P_2 by partial integral criterion we define the membership function as follows:

$$\mu^{in} C_1(P_1,P_2) = \frac{\mu_{C_1}(P_1,P_2) - \mu_{C_1}(P_1,P_2)}{t_1} = \frac{\left[\underline{\mu_{C_1}(P_1,P_2)}; \overline{\mu_{C_1}(P_1,P_2)}\right] - \left[\underline{\mu_{C_1}(P_1,P_2)}; \overline{\mu_{C_1}(P_1,P_2)}\right]}{t_1} =$$

$$= \frac{\left[\min\left[\underline{\mu_{C_1}(P_1,P_2)} - \underline{\mu_{C_1}(P_1,P_2)}; \overline{\mu_{C_1}(P_1,P_2)} - \overline{\mu_{C_1}(P_1,P_2)}\right]; \max\left[\underline{\mu_{C_1}(P_1,P_2)} - \underline{\mu_{C_1}(P_1,P_2)}; \overline{\mu_{C_1}(P_1,P_2)} - \overline{\mu_{C_1}(P_1,P_2)}\right]\right]}{t_1}$$

$$= \frac{[40;75]-[45;65]}{100} = \frac{[\min \underline{[40-45;75-65]}; \max \overline{[40-45;75-65]}]}{100} = [-0,05;0,1] \cdot$$

$$\mu^{in} C_2(P_1,P_2) = \frac{[3;6]-[4;5]}{10} = \frac{[\min \underline{[3-4;6-5]}; \max \overline{[3-4;6-5]}]}{10} = [-0,1;0,1]$$

$$\mu^{in}C_3(P_1,P_2)=\frac{[120;145]-[125;140]}{150}=\frac{[\min[\underline{120-125;145-140}];\max\overline{[120-125;145-140]}]}{150}=$$

$$=[-0.03,0.03]$$

Further, to determine the strictly interval dominance $\mu_D C_j(P_i, P_{i-1})$ is possible to apply the following formula:

$$\mu_D C_j(P_i,P_{i-1}) = \mu^{in}C_j(P_i,P_{i-1}) - \mu^{in}C_j(P_{i-1},P_i) =$$
$$\left[\underline{\mu^{in}C_j(P_i,P_{i-1})};\overline{\mu^{in}C_j(P_i,P_{i-1})}\right]-\left[\underline{\mu^{in}C_j(P_{i-1},P_i)};\overline{\mu^{in}C_j(P_{i-1},P_i)}\right],$$

hence:

$$\mu_D C_1(P_1,P_2) = [0.05;0.1]-[-0.1;0.05] = [\min\{\underline{-0.05-(-0.1);0.1-0.05}\};$$
$$\max\{\overline{-0.05-(-0.1);0.1-0.05}\} = 0.05$$

$$\mu_D C_2(P_1,P_2) = [-0.1;0.1]-[-0.1;0.1] = [\min\{\underline{-0.1-(-0.1);0.1-0.1}\};$$
$$\max\{\overline{-0.1-(-0.1);0.1-0.1}\} = 0$$

$$\mu_D C_3(P_1,P_2) = [-0.03;0.03]-[-0.03;0.03] = 0$$

As an adjunct $\mu_D C_j(P_i, P_{i-1})$ we have $\mu_{ND} C_j(P_i, P_{i-1})$ interval not dominance P_i above P_{i-1} :

$$\mu_{ND}C_j(P_i,P_{i-1}) = \begin{cases} 1, if\,\mu_D C_j(P_i,P_{i-1}) \le 0 \\ 1-\mu_D C_j(P_i,P_{i-1}), if\,\mu_D C_j(P_i,P_{i-1}) > 0 \end{cases}$$

The matrices of interval dominance $\mu^{in}C_1(P_1,P_2)$, strictly interval dominance $\mu_D C_1(P_1,P_2)$ and not dominance $\mu_{ND}C_1(P_1,P_2)$ will have the form and results shown in Table 9.

$\mu^{in}C_1(P_1,P_2)$		
	P_1	P_2
P_1	-	[-0.1; 0.05]
P_2	[-0.05;0.1]	-

$\mu^{in}C_2(P_1,P_2)$		
	P_1	P_2
P_1	-	[-0,1;0,1]
P_2	[-0,1;0,1]	-

$\mu^{in}C_3(P_1,P_2)$		
	P_1	P_2
P_1	-	[-0.03; 0.03]
P_2	[-0.03; 0.03]	-

$\mu_D C_1(P_1,P_2)$		
	P_1	P_2
P_1	-	0.05
P_2	-0.05	-

$\mu_D C_2(P_1,P_2)$		
	P_1	P_2
P_1	-	0
P_2	0	-

$\mu_D C_3(P_1,P_2)$		
	P_1	P_2
P_1	-	0
P_2	0	-

$\mu_{ND} C_1(P_1,P_2)$		
	P_1	P_2
P_1	-	0.95
P_2	1	-

$\mu_{ND} C_2(P_1,P_2)$		
	P_1	P_2
P_1	-	1
P_2	1	-

$\mu_{ND} C_3(P_1,P_2)$		
	P_1	P_2
P_1	-	1
P_2	1	-

(Source: own authors' calculations)

Table 9. *The matrices of interval dominance*

Value of $\overset{*}{\mu}_D(P_i,P_{i-1})$ shows degree of efficiency and measure of project preferences. It is determined as $\overset{*}{\mu}_D C_j(P_i,P_{i-1}) = \min \overset{*}{\mu}_{ND} C_j(P_i,P_{i-1})$. Accordingly, for the first project $\mu^*_D C_1(P_1) = 0.95;$ $\mu^*_D C_2(P_1) = \mu^*_D C_1(P_2) = 1$, and for the second project $\mu^*_D C_1(P_2) = \mu^*_D C_2(P_2) = \mu^*_D C_3(P_2) = 1$.

Because $\overset{*}{\mu}_D(P_i,P_{i-1})$ shows the degree of effectiveness and measure of projects preferences, then preference should be given to project P_2 the better in all criteria, being that P_1 insignificantly, but nevertheless inferior to the second project on the first criterion.

7. Conclusions

Thus, in the article the fuzzy approach to determine the best composition of innovative programs in conditions of full and partial uncertainty has been considered. Statement of a problem, combining the evaluation of innovative potential of the region and sets of proposed innovative projects is substantiated. The theoretical approaches to it solution in terms of using of linguistic variables and constructing membership functions in accordance with the theory of fuzzy sets are described. In this are applied expert estimates with the possibility of taking into account competence of experts.

Cases of partial and full of uncertainty were examined. In the first case, the incompleteness of the information associated with fuzzy preference relations. Then comparison and selection are made using experts point estimates. In the second case, at the initial stage experts define rough or inaccurate estimates of future system by its characterizing criteria. Then, in the process of project implementation they gradually are clarified. In this case are used interval estimates. For both algorithms numerical examples of calculations are presented.

At the same time proposed, described and numerically implemented the procedure for obtaining a generalized set of project evaluation criteria. It has the ability to integrate different weights of various criteria. As a result of calculations built a sequence of preferences for the considered projects. Also a more preferable set of projects for the case of strong uncertainty has been determined.

The proposed approach is quite justified mathematically and economically meaningful. It can be successfully used in the comparison of investment projects and opportunities. Also it can be used to solve other problems of multi-criteria selection of a set of alternatives of different origin under conditions of varying degrees of uncertainty, requirements and criteria.

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