Formalization of Requirements for Spatial Development Investment Projects

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Abstract—One of the most important tasks in economy is to assess the economic efficiency of investment projects. Evaluation of the effectiveness of investment projects is of utmost importance at the pre-investment stage of the life cycle. However, the amount and nature of information available at this stage does not allow for the full application of traditional performance assessment methods based on discounting future cash flows (DCF-methods). However, these methods can be used by analyzing the information entity of each of the criteria underlying DCF-methods. At the same time, a set of these criteria is necessary but not enough, because during the stage of selection of investment projects by potential investors and decisions on their inclusion in financing programs, the stage of environmental screening plays a special role. At the same time, the main task is to define environmental criteria, which in most cases are not quantifiable, which leads to the need to process qualitative information. And besides, when assessing the effectiveness of investment projects, some criteria have the nature of limitations. In effect, criteria and restrictions are requirements that determine the needs of interested parties (stakeholders) – users, consumers, suppliers, developers, and businesses themselves. Therefore, the article uses the concepts of requirements-criteria and requirements-restrictions. The article presents a formal tool for describing various requirements and how to integrate them into a single model for assessing the effectiveness of investment projects at the pre-investment stage. As a formal tool for describing various requirements, the mathematical apparatus of fuzzy set theory and the methodology of system analysis of hierarchical structures are used. The use of fuzzy set theory as an instrumental basis for describing various requirements is although it does not eliminate the subjective nature of the concepts with which decision makers deal, it gives them the means to describe these subjective concepts in a rational way. The use of the proposed method of formalizing requirements and the formation of an assessment of the effectiveness of investment projects based on it is demonstrated on a model example.

Keywords—Discounted Cash Flow - methods (DFM-methods), environmental criteria, stakeholders, requirements-criteria, requirements-restrictions, fuzzy sets, degree of belonging to fuzzy set, system analysis of hierarchical structures, scripting method, subjective scale of qualitative gradations, latent vector, eigenvalue of pairwise comparison matrix, operation of crossing fuzzy sets (conjunction rule), weighted intersection of fuzzy sets.

I. INTRODUCTION

Universally known, that one of the most important tasks in economy is to assess the economic effectiveness of investment projects (IP) implemented in various fields of activity, including within the framework of spatial development of territories [1, 2, 3]. How far-sighted, rational, economically sound and efficient investment decisions depend to a large extent not only on the future of specific enterprises, firms, regions, but also on the future of the country's economy as a whole, since their functioning affects the behavior of other actors in the economic community, socio-economic and natural environment [4]. At the same time, it should be emphasized critical importance of IP performance assessment in the pre-investment phase, because it is on the quality of this assessment that the success of the subsequent IP implementation depends: this step selects from the list of alternative IPs the most efficient, which allows you to abandon the "non-viable" project. However, the amount and nature of information available at this stage does not allow full application of traditional IP performance assessment methods based on discounting future cash flows (DCF-methods): NPV – Net Present Value, PI – Profitability Index, IRR – Internal Rate of Return, DPP – Discount Payback Period. Besides, should be noted, in the process of analyzing an IP, only in rare cases will there be a situation when it is simultaneously acceptable from the position of all the criteria under consideration. As a rule, different criteria will give different IP ordering (ranking) and show different make-reject decisions. Therefore, there is a problem of selecting one leading criterion or prioritizing their use [2].

In this regard, many solid firms such as IBM, GE, «Royal Dutch Petroleum», calculate and analyze all criteria, since each of them provides additional relevant information that makes up their "information entity" [1, 5,6]: NPV is important because it shows the project-generated increase in shareholder...
Criteria and restrictions are requirements that determine the needs of interested parties (stakeholders) – users, consumers, suppliers, developers and the business itself, – which are necessary for them [11]. Good set stakeholder requirements may provide a brief and non-technical description of what will be developed at a level that is available for understanding high management. In this regard, it should be noted that in order to provide such an understanding, requirements are in most cases written in the "normal" language, which introduces its problems, namely, the need to fully and unequivocally identify problems and record needs without using the usual and professional language [11]. This circumstance fully applies to investment projects for the spatial development of territories, the user requirements for which are often formed by ordinary citizens living in the relevant territory and whose interests affect the investment project. Agreed requirements provide the basis for system development planning and acceptance upon completion. Requirements are necessary when compromises have to be made, and they are vital when changes have to be made in the development process, which is virtually inevitable for any of the projects. Thus, in order to obtain a comprehensive assessment of IP performance at the pre-investment stage, it is necessary to have a formal tool for describing various requirements and means for integrating them into a single assessment model. The result of such integration should be a single comprehensive assessment of IP performance, in which each private criterion used characterizes only a separate aspect of the implementation of the investment proposal. In this article as a formal tool for describing various requirements for spatial development investment projects, the mathematical apparatus of fuzzy set theory and the methodology of system analysis of hierarchical structures are used [8, 12]. At the same time, we will distinguish between requirements-criteria and requirements-restrictions. The use of fuzzy set theory as an instrumental basis for describing various requirements is that although it does not eliminate the subjective nature of the concepts that decision makers deal with, it gives them the means to describe these subjective concepts in a rational way [13, 14]. For the first time the mathematical apparatus of fuzzy set theory was proposed in Bellman and Zade's article [15] for problems of multi-criterion choice. It demonstrated the possibilities of presenting criteria and constraints through fuzzy sets that combine elements of subjective preferences. At the same time, the procedure for integrating criteria and constraints into a single evaluation model is considered as a problem of aggregating (combining) fuzzy sets by conducting theoretical-multiple operations on them. Bellman and Zade proposed using a conjunction rule with n criteria and m constraints as an aggregation operation.

II. METHODS

In this article as a formal tool for describing various requirements for spatial development investment projects, the mathematical apparatus of fuzzy set theory and the methodology of system analysis of hierarchical structures are used.

III. MAIN PART

We set out a method for formalizing the requirements for investment projects of spatial development of territories, based on the mathematical apparatus of fuzzy set theory and the methodology of system analysis of hierarchical structures.
Let it be evaluated as *investment* projects \( IP_1, ..., IP_m \) and choose the best of them in terms of \( n \) requirements-criteria \( K = \{ K_1, ..., K_n \} \) and \( l \) requirements-restrictions \( G = \{ G_1, ..., G_l \} \).

In this case, two cases are possible:

1. Requirements-criteria and requirements-restrictions have the same degree of importance for decision maker;
2. Requirements-criteria and requirements-restrictions have different degrees of importance for decision makers.

*First case.* Present each requirement with fuzzy sets defined on a universal set of investment projects. They will be denoted, as well as the names of the requirements, but we will write them in italics together with bold:

\[
K_1 = \{ IP_1/\mu_{K_1}(IP_1), IP_2/\mu_{K_1}(IP_2), ..., IP_m/\mu_{K_1}(IP_m) \},
\]

\[
K_l = \{ IP_1/\mu_{K_l}(IP_1), IP_2/\mu_{K_l}(IP_2), ..., IP_m/\mu_{K_l}(IP_m) \},
\]

According to these scenarios are generated relevant assessments \( IP \) according to the criterion \( K_i \).

<table>
<thead>
<tr>
<th>Criterion ( K_i )</th>
<th>Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optimistic</strong></td>
<td>( W^{\text{max}} (IP/K_i) )</td>
</tr>
<tr>
<td><strong>Pessimistic</strong></td>
<td>( W^{\text{min}} (IP/K_i) )</td>
</tr>
<tr>
<td><strong>Real</strong></td>
<td>( W(IP/K_i) )</td>
</tr>
</tbody>
</table>

Appropriate degrees of affiliation \( IP_i \) fuzzy set \( K_i \) we will get as follows:

\[
\mu_{K_i}(IP_i) = (W(IP/K_i) - W^{\text{min}}(IP/K_i))/(W^{\text{max}}(IP/K_i) - W^{\text{min}}(IP/K_i)).
\]

To obtain estimates \( \mu_V(IP_i) \) relating to fuzzy sets, meeting qualitative requirements-criteria, it is proposed to use the following procedure. Let's assume, for all qualitative criteria requirements, it is sufficient to have a subjective scale having the following qualitative gradations:

- «low» – \( L \);
- «low medium» – \( LM \);
- «medium» – \( M \);
- «high medium» – \( HM \);

\[
\text{• «high»} \rightarrow H.
\]

Let the considered IP from the point of view of this scale received according to some criterion \( K_i \) the following qualitative evaluations:

\[
IP_1 \rightarrow M; \ IP_2 \rightarrow LM; ... \ IP_m \rightarrow HM.
\]

To obtain quantitative estimates IP from the position of the criterion \( K_i \), it is necessary to display a subjective scale with qualitative gradations on a numerical scale in a mutually unambiguous way. For this purpose, we will use the methodology AHP.

Calculated eigenvector \( W = (w_1, w_2, w_3, w_4, w_5) \), corresponding to the maximum eigenvalue of the matrix of paired comparisons of qualitative gradations, will determine their mapping to a numerical scale as follows (table 2.).

<table>
<thead>
<tr>
<th>Gradation</th>
<th>L</th>
<th>LM</th>
<th>M</th>
<th>HM</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W )</td>
<td>( w_1 )</td>
<td>( w_2 )</td>
<td>( w_3 )</td>
<td>( w_4 )</td>
<td>( w_5 )</td>
</tr>
</tbody>
</table>

After the relevant assessments are generated \( \mu_V(IP_i) \) for each fuzzy set, can be stated, fuzzy sets are formed.

The rule of choosing the best IP according to the Bellman and Zad approach can be represented as the intersection of these fuzzy sets:

\[
D = K_1 \cap ... \cap K_n \cap G_1 \cap ... \cap G_l.
\]

It is known, the operation of crossing fuzzy sets corresponds to the operation of taking a minimum on a set of degrees of belonging of elements to these sets:

\[
\mu_{D}(IP_i) = \min (\mu_V(IP_i)), i = 1, ..., m.
\]
Therefore, the best IP will be the IP* investment project that has the most ownership function value:

\[ IP^* = \text{Argmax}(\mu_{D}(IP_i)), \quad i = 1, \ldots, m. \]

Second case. Criteria and restrictions are of different importance for decision makers. In this case, the best IP selection rule can be represented as weighted intersection fuzzy sets:

\[ D = K_1^{α_1} \cap \ldots \cap K_n^{α_n} \cap G_1^{μ_{DPP1}} \cap \ldots \cap G_5^{μ_{DPP5}}, \]

where \( α_i = p \cdot w_i \)

\( w_i \) – weights of relative importance of the corresponding requirements,

\( p \) – scaling coefficient, equal to the sum of requirements-criteria and requirements-restrictions (in this case \( p = n+1 \));

Coefficients’ relative importance requirements \( wi \) can be defined, using methodology AHP.

Let us describe the proposed method of formalizing requirements and the formation of an IP performance assessment based on it on the following model example.

Example. Let it be necessary to evaluate five investment projects (IP1, ..., IP5) and assess their effectiveness in terms of three criteria NPV, IRR, PI and two restrictions of specified indicators DPP and INV (qualitative requirement-restriction «Impact on the environment»).

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Example. Let it be necessary to evaluate five investment projects (IP1, ..., IP5) and assess their effectiveness in terms of three criteria NPV, IRR, PI and two restrictions of specified indicators DPP and INV (qualitative requirement-restriction «Impact on the environment»).

First case. Requirements-criteria and requirements-restrictions have the same degree of importance for decision makers.

Present IP estimates for each requirement-criteria and requirement-constraints with fuzzy sets:

\[ \text{NPV} = \{ IP_1/\mu_{DPP1}(IP_1), IP_2/\mu_{DPP2}(IP_2), \ldots, IP_5/\mu_{DPP5}(IP_5) \}, \]

\[ \text{IRR} = \{ IP_1/\mu_{DPP1}(IP_1), IP_2/\mu_{DPP2}(IP_2), \ldots, IP_5/\mu_{DPP5}(IP_5) \}, \]

\[ \text{PI} = \{ IP_1/\mu_{DPP1}(IP_1), IP_2/\mu_{DPP2}(IP_2), \ldots, IP_5/\mu_{DPP5}(IP_5) \}, \]

\[ \text{DPP} = \{ IP_1/\mu_{DPP1}(IP_1), IP_2/\mu_{DPP2}(IP_2), \ldots, IP_5/\mu_{DPP5}(IP_5) \}, \]

\[ \text{INV} = \{ IP_1/\mu_{DPP1}(IP_1), IP_2/\mu_{DPP2}(IP_2), \ldots, IP_5/\mu_{DPP5}(IP_5) \}. \]

Functions \( \mu_{D}(IP_i) \), in essence, there are estimated IP in terms of some requirement-criteria and requirement-limitations \( V = \text{NPV}, \text{IRR}, \text{PI}, \text{DPP}, \text{INV} \).

Suppose for certainty that these valuations received the following values (table 3).

| Table III. Estimates IP by requirements NPV, IRR, PI, DPP, INV |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                | IP1             | IP2             | IP3             | IP4             | IP5             |
| NPV            | 0.3             | 0.2             | 0.6             | 0.7             | 0.5             |
| IRR            | 0.6             | 0.5             | 0.5             | 0.3             | 0.4             |
| PI             | 0.5             | 0.6             | 0.2             | 0.4             | 0.6             |
| DPP            | 0.6             | 0.4             | 0.7             | 0.5             | 0.4             |
| INV            | 0.7             | 0.3             | 0.4             | 0.8             | 0.7             |

Based on available estimates, the following fuzzy sets can be determined:

\[ \text{NPV} = \{ IP_1/0.3, IP_2/0.2, IP_3/0.6, IP_4/0.7, IP_5/0.5 \}, \]

\[ \text{IRR} = \{ IP_1/0.6, IP_2/0.5, IP_3/0.5, IP_4/0.3, IP_5/0.4 \}, \]

\[ \text{PI} = \{ IP_1/0.5, IP_2/0.6, IP_3/0.2, IP_4/0.4, IP_5/0.6 \}, \]

\[ \text{DPP} = \{ IP_1/0.6, IP_2/0.4, IP_3/0.7, IP_4/0.5, IP_5/0.4 \}, \]

\[ \text{INV} = \{ IP_1/0.7, IP_2/0.3, IP_3/0.4, IP_4/0.8, IP_5/0.7 \}. \]

From here, the rule of choosing the best IP can be represented as the intersection of these fuzzy sets:

\[ D = \text{NPV} \cap \text{IRR} \cap \text{PI} \cap \text{DPP} \cap \text{INV}. \]

It is known, the operation of crossing fuzzy sets corresponds to the operation of taking a minimum on a set of degrees of belonging of elements to these sets:

\[ \mu_{D}(IP_i) = \min (\mu_{D}(IP_i)). \]

\[ V = (\text{NPV}, \text{IRR}, \text{PI}, \text{DPP}, \text{INV}), \quad j = 1, \ldots, 5. \]

Therefore, the best IP will be the IP* investment project that has the most ownership function value:

\[ \mu_{D}(IP^*) = \max (\mu_{D}(IP_j)), \quad j = 1, \ldots, 5. \]

Find values \( \mu_{D} \) for each IP:

\[ \mu_{D}(IP_1) = \min (0.3, 0.6, 0.5, 0.6, 0.7) = 0.3, \]

\[ \mu_{D}(IP_2) = \min (0.2, 0.5, 0.6, 0.4, 0.3) = 0.2, \]

\[ \mu_{D}(IP_3) = \min (0.6, 0.5, 0.2, 0.7, 0.4) = 0.2, \]

\[ \mu_{D}(IP_4) = \min (0.7, 0.3, 0.4, 0.5, 0.8) = 0.3, \]

\[ \mu_{D}(IP_5) = \min (0.5, 0.4, 0.6, 0.4, 0.7) = 0.4. \]

From here we get:

\[ \mu_{D}(IP^*) = \max (0.3, 0.2, 0.2, 0.3, 0.4) = 0.4. \]

Therefore, the most effective is IP3 = IP*.

Second case. Requirements-criteria and requirements-restrictions have the same degree of importance for decision makers.

In this case, the best IP selection rule can be represented as weighted intersection fuzzy sets:

\[ D = \text{NPV}^{α_1} \cap \text{IRR}^{α_2} \cap \text{PI}^{α_3} \cap \text{DPP}^{α_4} \cap \text{INV}^{α_5}. \]

where \( α_i = p \cdot w_i, w_i – \) weights of relative importance of relevant criteria and limitations,

\( p \) – scaling coefficient, equal to the sum of criteria and restrictions (in this case \( p = 5 \));

\( V^a \) – the result of the construction of a fuzzy set \( V \) to degree \( a \).
Coefficients relative importance of criteria \( w_i \) can be defined using methodology AHP.

Let's assume, the expert built the following matrix of paired comparisons of criteria and constraints (NPV, IRR, PI, DPP, INV) relative to the leading target (table 4).

**TABLE IV. MATRIX OF PAIRED COMPARISONS OF CRITERIA AND CONSTRAINTS ON THE TARGET**

<table>
<thead>
<tr>
<th>Purpose</th>
<th>NPV</th>
<th>IRR</th>
<th>PI</th>
<th>DPP</th>
<th>INV</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>IRR</td>
<td>1/2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>PI</td>
<td>1/4</td>
<td>1/2</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>DPP</td>
<td>1/6</td>
<td>1/3</td>
<td>1/4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>INV</td>
<td>1/7</td>
<td>1/5</td>
<td>1/3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

We find the maximum eigenvalues, IS coefficients, OS and eigenvector corresponding to the maximum eigenvalue represented above the matrix of paired comparisons.

**TABLE V. PRIORITY OF CRITERIA AND LIMITATIONS ON THE LEADING OBJECTIVE**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Latent vector ((W_i))</th>
<th>MAX eigenvalue</th>
<th>IS</th>
<th>OS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV</td>
<td>0,438</td>
<td>5,269</td>
<td>0,067</td>
<td>0,060</td>
</tr>
<tr>
<td>IRR</td>
<td>0,252</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PI</td>
<td>0,192</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DPP</td>
<td>0,060</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INV</td>
<td>0,059</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

By analyzing the values of the IC coefficients, the OS can be concluded that the matrix is agreed and, therefore, the judgments of experts regarding the importance of criteria and restrictions can be considered quite logical, and the results ("weights" of criteria and restrictions) are sufficiently justified.

The results of the obtained calculations are presented in table 5.

**TABLE VI. BUILD DEGREES OF IP BELONGING TO FUZZY SET D**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>&quot;Weight&quot; criterion ((w_i))</th>
<th>(a_i)</th>
<th>(IP_1)</th>
<th>(IP_2)</th>
<th>(IP_3)</th>
<th>(IP_4)</th>
<th>(IP_5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV</td>
<td>0,438</td>
<td>2,189</td>
<td>0,072</td>
<td>0,029</td>
<td>0,327</td>
<td>0,458</td>
<td>0,219</td>
</tr>
<tr>
<td>IRR</td>
<td>0,252</td>
<td>1,259</td>
<td>0,526</td>
<td>0,418</td>
<td>0,418</td>
<td>0,220</td>
<td>0,316</td>
</tr>
<tr>
<td>PI</td>
<td>0,192</td>
<td>0,958</td>
<td>0,515</td>
<td>0,613</td>
<td>0,214</td>
<td>0,416</td>
<td>0,613</td>
</tr>
<tr>
<td>DPP</td>
<td>0,060</td>
<td>0,301</td>
<td>0,857</td>
<td>0,759</td>
<td>0,898</td>
<td>0,812</td>
<td>0,759</td>
</tr>
<tr>
<td>INV</td>
<td>0,059</td>
<td>0,293</td>
<td>0,901</td>
<td>0,703</td>
<td>0,765</td>
<td>0,937</td>
<td>0,901</td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
<td></td>
<td>0,072</td>
<td>0,029</td>
<td>0,214</td>
<td>0,220</td>
<td>0,219</td>
</tr>
</tbody>
</table>
Thus, fuzzy set $D$ has an appearance:

$$D = \{IP1/0.072, IP2/0.029, IP3/0.214, IP4/0.220, IP5/0.219\}.$$  

The best IP can be determined from the condition:

$$\mu_D(IP^*) = \max (0.072; 0.029; 0.214; 0.220; 0.219) = 0.220.$$  

Since the maximum is for the fourth IP, we get the result: $IP^* = IP4$.

Thus, taking into account the importance of the relevant requirements-criteria and requirements-restrictions for decision-makers, the result has changed: without taking into account the importance, the investment project IP5 was recognized as the most preferable, and given the importance, the investment project IP4 was the most preferable.

IV. CONCLUSION

In this article a formal tool for describing various requirements (requirements-criteria and requirements-limitations) for spatial development investment projects and means of their integration into a single model for assessing the effectiveness of investment projects at the pre-investment stage of the project life cycle is presented. A feature of spatial development investment projects is the fact that various requirements for them are formed based on the goals and interests of interested parties (stakeholders) – users, consumers, suppliers, developers and the business itself. Therefore, in general, the set of requirements includes both quantitative and qualitative requirements-criteria, along with requirements-restrictions. In order to obtain a comprehensive assessment of IP performance at the pre-investment stage, it is necessary to have a formal tool for describing various requirements and means for integrating them into a single assessment model. The result of such integration should be a single comprehensive assessment of IP performance, in which each private criterion used characterizes only a separate aspect of the implementation of the investment proposal. As a formal tool for describing various requirements, the mathematical apparatus of fuzzy set theory and the methodology of system analysis of hierarchical structures are used. The use of fuzzy set theory as an instrumental basis for describing various requirements is that it, although it does not eliminate the subjective nature of the concepts with which persons deal with the decision maker, but gives them the means to describe these subjective concepts in a rational way. The use of the proposed method of formalizing requirements and the formation of an assessment of the effectiveness of investment projects at the pre-investment stage of the life cycle is demonstrated on a model example. At the same time, two cases were considered: the first case – requirements-criteria and requirements-restrictions have the same degree of importance for decision-makers and the second – requirements-criteria and requirements-restrictions have different degrees of importance for decision-makers. As the calculations showed, the priority (importance) of the corresponding requirements-criteria and requirements-restrictions for decision-makers is important for the assessment.

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