Decision Support System Regarding the Possibility of Financing Cross-Border Cooperation Projects

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Abstract

Research was conducted on the current task of developing a decision-making support system regarding the possibility of financing cross-border cooperation projects under the conditions of guaranteeing the national security of partner countries during project implementation, as well as designing innovative software as a means of technical support for managers of cross-border project competitions. In this study, an information model for forecasting the level of process control during project implementation was developed for the first time. Based on theoretical-multiple generalization, the factors affecting the implementation of the project are classified, namely: factors of internal and external influences; risk-oriented influencing factors; the effects of human factors; and factors guaranteeing the national security of the partner countries during project implementation. Also, for the first time, a fuzzy model for evaluating cross-border cooperation projects was developed regarding the possibility of their financing, considering the future level of management of processes during implementation. The model has been verified and tested on real and test data. An approbation example of the calculation is given. The conducted research will be a useful decision-making support tool for managers of cross-border project tenders under the conditions of guaranteeing the national security of partner countries during project implementation.

Keywords

Cross-border cooperation projects, National security, Fuzzy set, Expert evaluation, Decision-making

1. Introduction

Cross-border cooperation projects promote mutual understanding and cooperation between bordering countries, thereby contributing to stability. Cross-border cooperation creates new opportunities for economic development, by promoting trade, investment, and infrastructure development in border regions. Such projects often involve the joint construction and modernization of transport, energy, and other types of infrastructure that help improve access to services and markets. In addition, these projects help countries to solve common problems together, such as environmental issues, border security, migration, and other border challenges.

Nevertheless, cross-border cooperation projects require significant investments and joint efforts from partner countries. However, decision-making regarding the financing of such projects is associated with risks regarding the national security of the participating countries. Taking these risks into account in the decision-making process becomes critically important for ensuring the success of cross-border cooperation projects and preventing possible negative consequences for the national security of countries. Therefore, the development of a decision support system that takes these aspects into account is extremely relevant and will contribute to effective management in the implementation of cross-border projects.

Cross-border cooperation is carried out by the procedures of the European Commission. The documents related to this activity cover many aspects of evaluation of all sizes. The effectiveness of the implemented programs is limited in terms of potential analytical gaps [1].

The purpose of the presented research is to develop a decision-making support system regarding the possibility of financing cross-border cooperation projects under the conditions of guaranteeing the

CMIS-2024: Seventh International Workshop on Computer Modeling and Intelligent Systems, May 3, 2024, Zaporizhzhia, Ukraine
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national security of partner countries during project implementation, as well as designing innovative software as a means of technical support for managers of cross-border project competitions.

The above argues and confirms the relevance of the conducted research on the development of a decision-making support system regarding the possibility of financing cross-border cooperation projects. The relevance of this study proves the need to develop information models for evaluating cross-border cooperation projects and mathematical models for knowledge processing, using the theory of fuzzy sets and approaches to intellectual analysis of knowledge. In addition, the relevance of this study is reinforced by the European data strategy [2], which provides for the achievement of certain goals by 2030. One of the main goals of this strategy is to create an advanced model society in the European Union that uses data to solve problems in both business and the public sector.

2. Overview of domestic and foreign research studies

Cross-border cooperation reflects one of the forms of support for the development of regions and arises because of the strategic activity of various participants, which involves trust, mutual understanding, and the desire to cooperate. Durand and Decoville [3] consider cross-border integration in Europe as a complex and multidimensional process that has different effects on regions. Their various models show that there is no single best strategy for cross-border cooperation within the EU. Scott [4] argues for the socio-political significance of borders in Europe and beyond, arguing that the border perspective reflects the boundaries between communities and groups through ideologies, political institutions, attitudes, and agencies. Cross-border cooperation initiatives, institutional cooperation, and political support are also important [5]. Crescenzi and Iammarino [6] emphasize the need to review the current processes of regional development and argue that regional development is accompanied by different concepts, empirical evidence, and political approaches that influence decision-making processes.

Obstacles to the development of cross-border cooperation exist in several dimensions. Internal barriers affect the social goals of cooperation the most, and they can be overcome through the policies of municipalities and entrepreneurs [7]. External barriers are characteristic of peripheral regions, which are distant from national and regional decision-making centers, and lead to many negative consequences. Cross-border cooperation can be an effective tool for overcoming them. For the possibility of evaluating such projects, modern information and analytical systems are needed, which embody decision-making support systems for evaluating projects and supporting the controllability of processes during their implementation.

Methods based on the theory of fuzzy mathematics can provide analytical support for quality decision-making processes at any level of management [8]. For the successful development of regions, it is necessary to develop innovative tools and knowledge systems that will support their sustainability, especially in periods of intensive support from EU funds to ensure information security and in the interests of the national security of the partner countries implementing the project.

New decision support systems are technologies that focus on data and knowledge analysis, including the UN Sustainable Development Goals. Today, such technologies are developing rapidly, and especially great attention is paid to mathematical models of knowledge representation. The construction of such models is based on objective information about the object, but it can also be based on incomplete information, since in the process of creating the model, data obtained from experts are used, which reflect the significant features of the object under study and are formulated in natural language. Therefore, to display knowledge, it is worth using the theory of fuzzy sets [9-10] and modern approaches to the use of intellectual analysis of knowledge in decision support systems [11].

As for the application of the theory of fuzzy mathematics for the tasks of evaluating project cross-border activities, the following can be distinguished. For example, source [12] describes the task of evaluating and selecting projects using the hybrid technique of multi-criteria evaluation in a fuzzy environment, based on financial factors. As a result, projects are ranked from most important to least important. In [13], a study aimed at building an integrated framework for assessing the sustainability of public-private partnership projects using the extended VIKOR method in a fuzzy image environment is considered. In work [14], a fuzzy multi-criteria evaluation model of heterogeneous cross-border cooperation projects was developed. The model is aimed at ensuring the sustainable development of neighboring regions, considering the goals of the announced competition.

All these studies are designed in such a way that the evaluation process takes place now and cannot predict what will happen during the implementation of the project. Thus, to date, there is no comprehensive study that makes it possible to evaluate cross-border cooperation projects, while predicting the level of process control during project implementation and using the approaches of intellectual analysis of knowledge.

3. Decision support system regarding the possibility of financing cross-border cooperation projects

3.1. Formal problem statement and input data

Consider a project (or a set of projects) of cross-border cooperation P. Such projects are presented as project applications for competitive selection, with the aim of their financing and implementation. The project application is evaluated by the expert (experts) E of the competitive selection. All projects of cross-border cooperation P are divided into three groups G, considering the strategic goal of the programs and specific thematic goals: G_1 – micro-projects; G_2 – regular projects; G_3 – large infrastructure projects [14]. The projects will be evaluated using the information model for evaluating cross-border cooperation projects regarding the possibility of their financing – K_{FO} [14]. Also, project applications will be evaluated using the information model for predicting the level of process control during project implementation – K_{PR}. Processed input data according to information models are calculated using a fuzzy model for evaluating cross-border cooperation projects regarding the possibility of their financing, considering the future level of process control during project implementation – M_{TP}.

Formally, the decision support system regarding the possibility of financing cross-border cooperation projects is proposed to be presented in the form of an operator:

$$\mathrm{X}(P, E, G, K_{FO}, K_{PR}, M_{TP}) \rightarrow \Upsilon(y_{TP}, TP). \quad (1)$$

Where X is an operator that, based on the input data $P, E, G, K_{FO}, K_{PR}, M_{TP}$ matches the set of output values Υ. Two values are obtained at the output: y_{TP} – generalized assessment of the level of the possibility of financing cross-border cooperation projects; TP is the linguistic level of the possibility of financing cross-border cooperation projects, considering the future level of manageability of their implementation processes.

The following management subjects are defined for the presented research. Experts are persons who have functional responsibilities for evaluating cross-border cooperation projects based on project applications submitted within the framework of the competition. System analysts are individuals who configure all project evaluation processes in the decision support system. Decision-making persons (DM) are persons who make further management decisions regarding the selection of cross-border cooperation projects for their financing.

Next, a structural diagram of the decision-making support system regarding the possibility of financing cross-border cooperation projects is presented (Fig. 1).

Fig. 1. shows the structural diagram of the decision support system. The cross-border cooperation project P is submitted for evaluation by expert E. After that, the evaluation takes place using the information model K_{FO}, considering which group G the project belongs to. The expert also evaluates the project using an information model for predicting the level of process control during project implementation – K_{PR}. The obtained data according to information models form the research knowledge base. After that, the obtained data are processed with the help of a three-stage fuzzy model for evaluating cross-border cooperation projects regarding the possibility of their financing, considering the future level of process control during project implementation – M_{TP}. On the one hand, an assessment of the project regarding the possibility of its financing ($m(P)$), is obtained, and on the other hand, the quantitative levels $\varphi_1, \varphi_2, \varphi_3, \varphi_4$, which determine the controllability of the processes during the implementation of the project according to the studied factors.

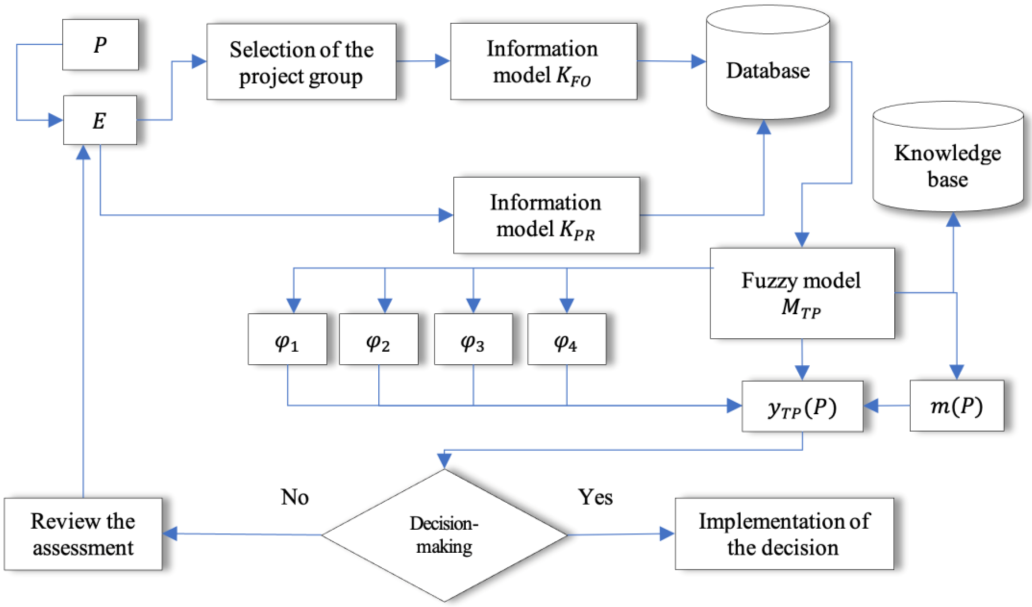

Figure 1: Structural diagram of the decision support system

After that, a generalized quantitative assessment of the possibility of financing the cross-border cooperation project ($y_{TP}(P)$) is obtained. The acquired knowledge forms the research knowledge base. Next, the DM analyzes the received initial evaluations and makes a decision or reviews the evaluation together with experts.

3.2. Information model for evaluating cross-border cooperation projects regarding the possibility of their financing

The process of evaluating cross-border projects is a complex task, due to their implementation by applicants and partners from different countries, which have different goals and address different problems. By analyzing various programs, projects, and challenges of cross-border cooperation, it is possible to generalize the evaluation criteria. Usually, the strategic goal of such programs should be achieved by financing and implementing projects that are determined by the specific thematic goals of the program. The criteria for evaluating projects divided into three groups were summarized: micro-projects, regular projects, and large infrastructure projects.

All criteria for evaluating projects are set out in the form of questions to which the applicant must provide a descriptive answer in his project application. The expert evaluates the project application and determines the appropriate score from the interval [1; 10] to assess the quality of the description. Where 10 points is considered the highest level of quality of the description, this or that criterion. The criteria for evaluating cross-border cooperation projects regarding the possibility of their financing for the K_{FO} information model is described in detail in the work [14] based on official sources [15-16]. Thus, without reducing generality, for this study, we will use the same evaluation indicators presented by the authors in [14].

3.3. Information model for predicting the level of process control during project implementation

To improve the quality of project application evaluation, it is necessary to forecast the possibility of project implementation by partners, considering the conditions affecting this complex process. It is proposed to look at this task from the point of view of determining the level of controllability of the processes of a complex system. Let us know the complex functioning system of the implementation of some cross-border cooperation project P. We know the set of factors F that affect the controllability of the processes of such a complex system. The main goal of the system is the implementation of the project within the established terms. For this applied problem, a theoretical-multiple generalization of the factors that most strongly influence the level of process control during project implementation was carried out. It is proposed, but not limited, to classify the factors into four main groups, the influence of which is the most significant on the implementation of the project, for example f_1 – factors of internal and external influences; f_2 – risk-oriented influencing factors; f_3 – effects of human factors; f_4 – factors guaranteeing the national security of the partner countries during project implementation. This classification is quite general, but nevertheless, it fully reveals the methodology of the task of assessing controllability in complex systems, and each group of factors complements each other. Of course, many factors are open, when considering an applied problem, assigning factors to one of the groups depends on the competence of system analysts.

Next, the proposed classes of influence factors are considered in more detail.

f_1 – factors of internal and external influences. To predict the level of controllability of processes during the implementation of a cross-border cooperation project, it is first of all necessary to assess this possibility, taking into account internal and external influences.

Internal (external) influences on the implementation of the cross-border cooperation project are events or phenomena in the internal (external) environment that pose a threat to the security of achieving the goal, as they go beyond the permissible estimates of the indicators of the object under study. Therefore, the group of internal and external influences can include goals, tasks, structures, technologies, and people, as well as the external management environment of direct influence and indirect influence.

For example, the following open set of evaluation criteria is proposed for the group of factors of internal and external influences f_1:

F_1^1 – Partners have a realistic and balanced budget that corresponds to their actual participation.

F_2^1 – The financial plan is realistic and effective.

F_3^1 – Project objectives correspond to the needs analysis and are covered by the main objective of the program or challenge.

F_4^1 – All activities in the project are aimed at achieving its tasks and main goal.

F_5^1 – The project has a real need, determined by the clear needs of the public.

F_6^1 – The level of influence on the implementation of the draft legislation and the political situation.

F_7^1 – The level of influence on the implementation of the project of socio-cultural factors, such as cultural characteristics, language barriers, and other social factors.

f_2 – risk-oriented influencing factors. The level of safety of human activities improves every day due to the improvement of technologies, intelligent analysis of data and knowledge, artificial intelligence management systems, etc. At the same time, the standards for the protection of information security in the management of international cooperation projects have become higher. Such standards are based on the principles of guaranteeing the national security of partner countries in the implementation of projects. However, we face many risks that could potentially jeopardize the success of the cross-border cooperation project if they are not adequately managed. One of the key components of measuring the risk of project implementation is the generation of scenarios for the development of the main risk factors.

To date, general principles and signs of risk classification have not been formed, there are practically no developments on the generalization and formalization of risk classification that can be applied to cross-border cooperation projects. For example, the following open set of evaluation criteria for a risk-oriented group of influence factors is proposed f_2:

F_1^2 – The project contains a comprehensive and detailed analysis of risks, as well as a plan for their elimination.

F_2^2 – Risks of change in the political environment of the partner countries, conflicts, and instability, the possibility of a change of government, which may affect the implementation of the project.

F_3^2 – Risks related to the possibility of changes in the world economy, tax, or customs policy and will have a significant impact on the implementation of the project.

F_4^2 – Risks of public dissatisfaction during project implementation.

F_5^2 – Risks of negative impact of the project on the environment and/or environmental pollution.

F_6^2 – Risks of conflicts regarding rights and obligations between project partners.

f_3 – effects of human factors. In the process of professional training, professional activity and acquired experience, the individual qualities of management subjects are transformed into a complex system of important professional qualities that ensure the successful formation of professional skills and their reliability, especially in extreme operating conditions. Therefore, there is an interdependence between the personal properties of management subjects, professional activity (professional training), the level of development of professional qualities and the ability of a person to integrative realization in the process of professional activity. The complex integrative complex of the formation of important professional qualities is not additive according to the individual qualities of the subject of management. The mastery of rigid algorithms of professional activity and the optimal level of development of important professional qualities in the subject of management determines the adequacy of decision-making in extreme conditions.

The success of the implementation of cross-border cooperation projects depends on the professionalism of the partners. Therefore, the systemic vision of formative influences on decision-making by the management subject contains a number of information subsystems, namely: the level of knowledge, skills, abilities, educational and qualification characteristics, psychophysiological, individual-psychological, social-psychological. Thus, the following are proposed as criteria for the influence of human factors on the level of manageability of project implementation processes:

F_1^3 – Insufficient qualifications and experience of project managers.

F_2^3 – The possibility of inefficient project management and insufficient control over the execution of works.

F_3^3 – Insufficient qualification of executors and subjects who will directly participate in project implementation.

F_4^3 – The possibility of conflicts between project participants.

F_5^3 – Ability to interact ineffectively with partners, including communication, collaboration, and conflict management.

f_4 – factors guaranteeing the national security of the partner countries during project implementation. Guaranteeing the national security of partner countries during the implementation of a cross-border cooperation project is a set of measures and strategies aimed at ensuring the protection and stability of each of the participating countries in the process of implementing joint projects. This includes various aspects of security such as political, economic, social, cyber security, border security, and others. The main goal is to prevent any threats that may arise because of the implementation of the project and preserve the interests and security of each of the participating countries. This may include measures to monitor and respond to potential threats, joint security arrangements, information sharing, joint training, and the development of joint security strategies. For example, the following open set of evaluation criteria for factors guaranteeing the national security of partner countries is proposed f_4:

F_1^4 – Resistance to geopolitical and international risks is the project's ability to withstand geopolitical tensions and international challenges that may arise during its implementation.

F_2^4 – Effective use of resources is an analysis of the effectiveness of the use of financial, technical, and human resources of the project to maximize effectiveness and minimize risks.

F_3^4 – Protection against cyber threats and cyber-attacks is an assessment of cyber security measures and the protection of information systems of the project against potential cyber threats and cyber-attacks.

F_4^4 – Availability of mechanisms that ensure transparency and openness in the project implementation process, including access to information for interested parties and the public.

F_5^4 – Risk and conflict management is an assessment of risk and conflict management strategies to prevent and minimize possible threats to national security.

F_6^4 – Raising Education and Awareness is an assessment of education and awareness of national security issues among participating partner countries.

All criteria of influencing factors are expertly evaluated using one of the terms, the next proposed term-set of linguistic variables $L = \{L;\quad BA;\quad A;\quad AA;\quad H\}$. Linguistic variables characterize the predicted level of the indicator during project implementation, where: L is "low"; BA is "below average"; A is "average"; AA is "above average"; H is "high". Also, experts put a quantitative value from the interval [1; 100], which characterizes the expert's confidence in his assessment – $\mu(F_e^g), g = \overline{1,4}$, $e = \overline{1, m_g}$, m_g – the number of criteria in group g.

The set of criteria does not cover all aspects of cross-border cooperation, which can take place within the framework of various programs and initiatives. Therefore, the set of criteria is flexible, the formal presentation of a fuzzy evaluation model does not depend on their number, and depending on the specific program and its purpose, the DM may add other indicators for evaluation.

3.4. Fuzzy model for evaluating cross-border cooperation projects regarding the possibility of their financing, considering the future level of process control during project implementation

Next, a three-stage mathematical fuzzy model for evaluating cross-border cooperation projects is presented.

The first stage is finding an aggregated assessment of cross-border cooperation projects regarding the possibility of their financing.

Without reducing the generality, in the future we will consider one project of cross-border cooperation P, which belongs to one of the groups G. Such a project underwent an expert evaluation according to the information model – K_{FO}, and received points for each evaluation criterion: $O_1, O_2, \dots, O_m$; $O_i \in [1;\ 10]$, $i = \overline{1,m}$, де m-where m is the number of criteria for the corresponding evaluation group G.

So, as for each question, experts set a score from the interval [1; 10] regarding the level of quality of the project application, then first you need to normalize the evaluations according to the criteria. Normalization is proposed using intellectual analysis of knowledge and membership functions. The choice of membership functions rests with the system analyst. Here it is suggested to use membership functions of the "large value" type. This type is given by S-like membership functions, for example, a quadratic S-spline is given by the following analytical formula:

$$\mu(O_i) = \begin{cases} 0, & O_i \le 1; \\ 2\frac{(O_i-1)^2}{81}, & 1 < O_i \le 5; \\ 1 - 2\frac{(10-O_i)^2}{81}, & 6 < O_i < 10, \\ 1, & O_i \ge 10. \end{cases}, i = \overline{1,m}. \quad (2)$$

Thus, a transition was made from quantitative point estimates to normalized and compared ones, $\mu(O_i) \in [0;\ 1]$.

For each criterion $\{K_1, K_2, \dots, K_m\}$, the DM sets the weighting coefficients $\{v_1, v_2, \dots, v_m\}$ from some interval [1; 10]. Next, normalized weighting factors for each criterion are determined:

$$w_i = \frac{v_i}{\sum_{i=1}^{m} v_i}, i = \overline{1,m}; w_i \in [0;1]. \quad (3)$$

It is noted that if there is no need to enter weighting coefficients, the weights of the criteria are considered balanced.

In the next step, the evaluation of cross-border cooperation projects is aggregated regarding the possibility of their financing using a convolutional approach. For this, the DM can choose one of the convolutions, considering its considerations [14]:

$$m_1(P) = \frac{1}{\sum_{i=1}^{m} \frac{w_i}{\mu(O_i)}}. \quad (4)$$

$$m_2(P) = \prod_{i=1}^{m} (\mu(O_i))^{w_i}. \quad (5)$$

$$m_3(P) = \sum_{i=1}^{m} w_i \cdot \mu(O_i). \quad (6)$$

$$m_4(P) = \sqrt{\sum_{i=1}^{m} w_i \cdot (\mu(O_i))^2}. \quad (7)$$

$i = \overline{1,m}$. Thus, aggregated assessments of cross-border cooperation projects regarding the possibility of their financing are obtained, which completes the first stage of solving the task.

In addition to the convolutional approach, other more traditional methods can also be used, such as the method of weighted summation of ranking; the method of analysis of hierarchies; the method of direct comparison, and others. It is noted that convolution methods have advantages over traditional methods in cases where complex alternatives need to be evaluated using multiple criteria and trade-offs between different objectives must be considered. This can be especially important in large or complex projects where large volumes of data need to be processed and complex interdependencies between different criteria need to be dealt with. Convolution methods allow considering trade-offs between different criteria, which can be important when making decisions in complex situations. They allow you to find the most optimal solutions that consider certain compromises and prevent extreme options.

The second stage is the finding of aggregated predicted estimates of factors influencing the level of manageability of project implementation processes.

Each criterion of influence factors is evaluated by an expert using one of the L terms and the expert's confidence in issuing the term estimate – $\mu(F_e^g)$. Therefore, the input data of the cross-border cooperation project P is a set of estimates $\lambda_e^g = \{L_e^g; \mu(F_e^g)\}$, $g = \overline{1,4}$, $e = \overline{1, m_g}$.

Fuzzification of fuzzy linguistic reasoning of experts is carried out, which will make it possible to compare the obtained data regarding the impact on the predicted level of controllability of processes during project implementation. For each linguistic variable, a value from the interval [0;1] is determined: L – $[a_1;a_2]$, BA – $[a_3;a_4]$, A – $[a_5;a_6]$, AA – $[a_7;a_8]$, H – $[a_9;a_{10}]$. For example: L – [0; 0,2], BA – [0,2; 0,4], A – [0,4; 0,6], AA – [0,6; 0,8], H – [0,8; 1]. After that, based on the linguistic variable and the confidence of the expert's reasoning regarding their assignment, one normalized score is calculated:

$$\vartheta_e^g = a_t + \frac{1}{100} \cdot \mu(F_e^g) \cdot (a_{t+1} - a_t). \tag{8}$$

Where a_t is the interval value for the linguistic variable L_e^g, $t = \overline{1,9}$. ϑ_e^g is the normalized numerical value of the criterion for the influence factor on the predicted level of process control during project implementation, which is adjusted for the confidence of the expert's reasoning $g = \overline{1,4}$, $e = \overline{1, m_g}$.

Next, there is one aggregated predicted assessment within the influence factors f_1, f_2, f_3, f_4. In this case, for each criterion within the influence factors g there are weighting factors g $\{\alpha_{g1}, \alpha_{g2}, \dots, \alpha_{gm_g}\}$ from the interval [1; 10]. Similarly, within the influence factors g, normalized weighting factors for each criterion are determined:

$$\beta_{ge} = \frac{\alpha_{ge}}{\sum_{e=1}^{m_g} \alpha_{ge}}, g = \overline{1,4}, e = \overline{1, m_g}, \beta_{ge} \in [0; 1]. \tag{9}$$

After that, one predicted aggregated estimate is calculated within the influence factors f_1, f_2, f_3, f_4 of the level of process control during project implementation:

$$\varphi_g = \sum_{e=1}^{m_g} \beta_{ge} \cdot \vartheta_e^g, g = \overline{1,4}. \tag{10}$$

The obtained estimates $\varphi_g \in [0; 1]$ characterize the quantitative level that determines the predicted controllability of the processes during the implementation of the project according to the studied influence factors. The larger the value of $\varphi_g \in [0; 1]$, the better the predicted level of process control during project implementation.

So, at the end of the second stage, aggregated predicted estimates $\varphi_1, \varphi_2, \varphi_3, \varphi_4$ of factors affecting the level of controllability of project implementation processes were obtained in relation to the opinions of expert E.

The third stage is to find generalized quantitative estimates and linguistic levels of the possibility of financing cross-border cooperation projects, considering factors influencing the level of manageability of project implementation processes.

For an adequate interpretation of the dependence of assessments of cross-border cooperation projects on the possibility of their financing and considering the quantitative forecast level, which determines the controllability of processes during the implementation of the project on the studied factors, the following function of belonging is built:

$$\Delta_g = \begin{cases} 0, & m(P) < 0; \\ (m(P))^{\varphi_g}, & 0 \le m(P) \le 1; \quad g = \overline{1,4}. \\ 1, & m(P) > 1. \end{cases} \tag{11}$$

Thus, estimates $\Delta_1, \Delta_2, \Delta_3, \Delta_4 \in [0; 1]$ are obtained, which characterize the level of the possibility of financing the project of cross-border cooperation in terms of factors affecting the control of processes during the implementation of this project.

Let DM set the weighting coefficients $\{p_1, p_2, p_3, p_4\}$ for each influence factor f_1, f_2, f_3, f_4 from the interval [1; 10]. Next, to obtain a generalized quantitative assessment of the possibility of financing a cross-border cooperation project, a weighted average convolution is used, while the weighting coefficients are normalized:

$$y_{TP}(P) = \frac{1}{p_1 + p_2 + p_3 + p_4}(p_1 \cdot \Delta_1 + p_2 \cdot \Delta_2 + p_3 \cdot \Delta_3 + p_4 \cdot \Delta_4). \tag{12}$$

In the end, TP is derived - the linguistic level of the possibility of financing cross-border cooperation projects, considering the future level of management of their implementation processes. For this, the obtained estimate $y_{TP}(P)$ is compared to one variable of the term sets $TP = \{tp_1, tp_2, \dots, tp_5\}$ with the following content: $y_{TP}(P) \in (0{,}89; 1]$ – tp_1 = “high level regarding the possibility of financing a cross-border cooperation project”; $y_{TP}(P) \in (0{,}77; 0{,}89]$ – tp_2 = “level regarding the possibility of financing a cross-border cooperation project – higher average”; $y_{TP}(P) \in (0{,}65; 0{,}77]$ – tp_3 = “average level regarding the possibility of financing a cross-border cooperation project”; $y_{TP}(P) \in (0{,}54; 0{,}65]$ – tp_4 = “low level regarding the possibility of financing a cross-border cooperation project”; $y_{TP}(P) \in [0; 0{,}54]$ – tp_5 = “very low level regarding the possibility of financing a cross-border cooperation project”.

Demarcations between levels rely on the system analyst, using own experience and real data from cross-border cooperation projects.

It is noted that this study used the evaluations of one expert to evaluate the project. It is known that several experts $E = \{e_1; e_2; \dots; e_q\}$ work in tender commissions. In this case, the evaluation procedure is repeated q times. At the output of the project P, q estimates are obtained: $\left(y_{TP}(P)\right)_1, \left(y_{TP}(P)\right)_2, \dots, \left(y_{TP}(P)\right)_q$. Then it is necessary to derive one aggregated estimate for the cross-border cooperation project, considering the opinions of all experts. To do this, you can use the intelligent analysis of knowledge using multidimensional membership functions or the convolutional approach described above.

4. Results

The decision-making support system regarding the possibility of financing cross-border cooperation projects was tested and verified on real and test data. Real data were obtained from the organization that implements cross-border cooperation projects, namely: the Agency for Regional Development and Cross-Border Cooperation of Transcarpathia (Ukraine). For the possibility of reproducing the research by other scientists, an example of the evaluation of a regular project of cross-border cooperation is shown below: P - Visual control of the functioning of checkpoints (PBU1/0240) [16]. The main goal of the project is the use of unmanned aerial vehicles intended for monitoring violations of the airspace of the state border, water bodies, and forests, which can take aerial photography and conduct search activities.

Next, a three-stage evaluation using a mathematical fuzzy model of evaluation of cross-border cooperation projects is presented.

The first stage.

Suppose that the cross-border cooperation project P underwent expert evaluation according to the information model – K_{FO}, and received points for each evaluation criterion. After obtaining point estimates according to the criteria (O), it is necessary to normalize them ($\mu(O)$), using formula (2). Also, DM sets the weighting coefficients (v) for each evaluation criterion. Next, the normalized weighting coefficients (w) for each criterion are determined according to formula (3). All obtained and calculated data are presented in Table 1.

Table 1
Input and normalized evaluations according to project evaluation criteria P

Name of the group	Criterion	v	w	O	$\mu(O)$
Financial and operational capacity	K_1^2	10	0.078	8	0.9012
	K_2^2	9	0.07	8	0.9012
	K_3^2	8	0.062	10	1
	K_4^2	9	0.07	9	0.9753
Cross-border approach	K_5^2	9	0.07	7	0.7778
	K_6^2	10	0.078	8	0.9012
	K_7^2	9	0.07	7	0.7778
	K_8^2	9	0.07	9	0.9753
Sustainability	K_9^2	8	0.062	9	0.9753

	K_{10}^2	8	0.062	5	0.3951
	K_{11}^2	9	0.07	7	0.7778
Action and communication plan	K_{12}^2	7	0.054	8	0.9012
	K_{13}^2	8	0.062	10	1
	K_{14}^2	9	0.07	7	0.7778
	K_{15}^2	7	0.054	9	0.9753

In the next step, the evaluation of cross-border cooperation projects is aggregated regarding the possibility of their financing. Let the DM choose the average convolution according to formula (6): $m_3(P)$ =0.868.

The second stage.

In the second stage, an expert assessment takes place according to the information model for predicting the level of process control during project implementation – K_{PR}. The received input data of the evaluated project are shown in Table 2. Further, based on the linguistic variable (L) and the confidence of the expert's judgments ($\mu(F)$) regarding their assignment, one normalized evaluation (ϑ) is calculated according to formula (8).

Let DM determine the weighting coefficients α from the interval [1; 10] for each criterion within the influence factors g. Similarly, within the influence factors g, normalized weight coefficients β are determined for each criterion according to the formula (9). All calculation results are given in Table 2.

After that, one predicted aggregated estimate is calculated within the influence factors of the level of process control during project implementation: φ_1=0.73; φ_2=0.765; φ_3=0.876; φ_4=0.712.

The third stage.

At the final stage, generalized quantitative estimates and linguistic levels of the possibility of financing cross-border cooperation projects are found, considering the factors influencing the level of manageability of project implementation processes. First, the dependencies of estimates of cross-border cooperation projects are calculated according to formula (11) regarding the possibility of their financing and taking into account the quantitative forecasted level, which determines the controllability of the processes during the implementation of the project according to the studied factors: Δ_1=0.902; Δ_2=0.898; Δ_3=0.884; Δ_4=0.904.

Let DM set the weighting coefficients {9,9,8,10} for each influence factor from the interval [1; 10]. Next, to obtain a generalized quantitative assessment of the possibility of financing a cross-border cooperation project, a weighted average convolution is used, according to formula (12): $y_{TP}(P) = \frac{1}{9+9+8+10}(9 \cdot 0.902 + 9 \cdot 0.898 + 8 \cdot 0.884 + 10 \cdot 0.904) = 0.8$

In conclusion, TP is derived - the linguistic level of the possibility of financing cross-border cooperation projects, considering the future level of manageability of their implementation processes: $y_{TP}(P) \in (0{,}89; 1] - tp_1$ = “high level regarding the possibility of financing a cross-border cooperation project”.

For the practical implementation of the decision-making support system regarding the possibility of financing cross-border cooperation projects, software in the C# programming language was developed. The main window of the software is shown in Fig. 2. Such software will be a useful tool for tender managers of cross-border projects, to increase the validity of decision support.

Table 2
Input and normalized estimates according to the information model – K_{PR}

A group of factors	Criterion	α	β	L	$\mu(F)$	ϑ
	F_1^1	9	0.143	AA	80	0.76
	F_2^1	8	0.127	H	90	0.98
	F_3^1	10	0.159	H	70	0.94
f_1	F_4^1	9	0.143	BA	90	0.38
	F_5^1	10	0.159	A	80	0.56
	F_6^1	9	0.143	AA	70	0.74
	F_7^1	8	0.127	AA	90	0.78
f_2	F_1^2	10	0.182	A	70	0.54
	F_2^2	9	0.164	H	80	0.96

	F_3^2	10	0.182	H	90	0.98
	F_4^2	8	0.145	BA	60	0.32
	F_5^2	9	0.164	AA	80	0.76
	F_6^2	9	0.164	H	90	0.98
	F_1^3	9	0.2	H	90	0.98
	F_2^3	9	0.2	H	70	0.94
f_3	F_3^3	10	0.222	AA	80	0.76
	F_4^3	10	0.222	AA	90	0.78
	F_5^3	7	0.156	H	80	0.96
	F_1^4	10	0.179	H	70	0.94
	F_2^4	9	0.161	H	60	0.92
f_4	F_3^4	10	0.179	H	70	0.94
	F_4^4	10	0.179	A	80	0.56
	F_5^4	9	0.161	AA	90	0.78
	F_6^4	8	0.143	H	90	0.98

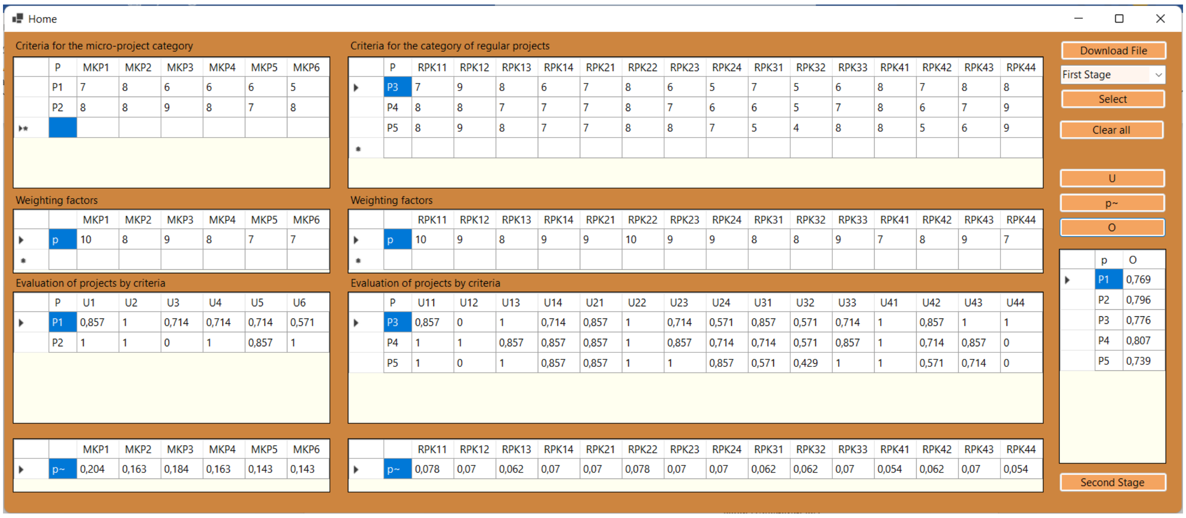

Figure 2: The main window of the decision support system

To check the adequacy and determine the effectiveness of the proposed decision-making support system regarding the possibility of financing cross-border cooperation projects, the results of project evaluation were compared with test regulatory approaches, namely: the VIKOR method, the TOPSIS method, and the ELECTRE method [13]. For this, five projects of cross-border cooperation were evaluated with the involvement of 9 experts [14]. The experts gave their opinions on whether the selected project, based on normative methods and the proposed method in the work, would suit them. At the same time, each expert gave their priorities and importance for evaluation criteria based on multi-criteria evaluation models. As a result, a different combination of alternative solutions was obtained for various experts. Also, to improve the quality of the evaluation, each expert put a quantitative number of "reliability" of his reasoning, from the interval [0; 1]: 0 if the chosen assessment approach did not suit the expert at all, 1 – on the contrary, it suited the expert as much as possible. "the chosen method suits the expert" was chosen as the comparative criterion. Despite the slight differences in the evaluation by the normative methods and the proposed approach, the results were identical. So, this testifies to the adequacy of the proposed approach. At the same time, the average accuracy regarding the satisfaction of experts in choosing alternative projects was higher: by 8.86% compared to the VIKOR method; by 10.12% compared to the TOPSIS method; and by 4.34% compared to the ELECTRE method. Then it can be concluded that the satisfaction of experts in the selection of projects according to the proposed approach is higher by 8% compared to the average arithmetic result of the selected normative methods of multi-criteria evaluation.

5. Discussion

The work developed a decision support system regarding the possibility of financing cross-border cooperation projects under the conditions of guaranteeing the national security of the partner countries during the implementation of the project. The research used an adequate apparatus of fuzzy sets, intellectual analysis of experts' opinions, and the principles of a system approach, which together make it possible to increase the objectivity of expert evaluation and management decision-making.

The peculiarity of the study is that it allows to derivation of a generalized quantitative assessment and the linguistic level of the possibility of financing cross-border cooperation projects, considering the future level of manageability of project implementation processes. Based on the obtained initial data, knowledge about the possibility of financing cross-border cooperation projects is determined, which is aimed at increasing the degree of validity of decision-making regarding the selection of projects for the possibility of their financing. Such knowledge is aimed at protecting information security during the management of international cooperation projects based on guaranteeing the national security of partner countries implementing projects. The knowledge obtained in this study will be useful for various management subjects in the ecosystem of financing cross-border cooperation projects for the purpose of making management decisions.

The received expert data is processed with the help of a fuzzy model for evaluating cross-border cooperation projects regarding the possibility of their financing, considering the future level of controllability of processes during implementation. The openness of the set of criteria for evaluating projects and factors that affect the level of process management during project implementation allows adapting the decision-making support system to highly specialized projects.

The advantages of the decision support system are as follows: it uses the input linguistic variables and the confidence of the expert's reasoning regarding their assignment; increases the objectivity of assessment and the reliability of expert assessments; the level of process control during project implementation is predicted; the factors of guaranteeing the national security of the partner countries are considered during the implementation of the project. In addition, to check the adequacy and determine the effectiveness of the proposed decision support system, the results of the project evaluation were compared with test regulatory approaches. It was found that the satisfaction of experts in the selection of projects according to the proposed approach was higher by 8% compared to the average arithmetic result of the selected normative methods of multi-criteria evaluation.

For this study, the method of traditional fuzzy inference can also be applied. The main advantage of such a method is its ability to effectively manage vagueness and uncertainty in data, which allows you to make informed decisions under conditions of uncertainty. However, it is very important to correctly define the set of rules and input parameters to ensure adequate decision-making results. Such a set of rules should be built separately for each group of projects: micro-projects, regular projects, and large infrastructure projects. In addition, it is necessary to have enough data on successfully implemented projects for adequate construction of the knowledge base. Instead, the proposed three-stage fuzzy model does not require such efforts and can be easily implemented in the practical work of cross-border project tender managers.

A limitation of our study was the selection of criteria and factors whose impact on project implementation was considered the most significant, as well as the use of various types of membership functions and data fuzzification approaches, including convolutions to obtain overall estimates. Another limitation is the geographical coverage of the study and the selection of cross-border cooperation projects. That is when receiving more projects from different countries, it would be possible to better adjust the fuzzy model to obtain more accurate results. Instead, the application of the developed decision support system does not impose any restrictions on the country of origin of the cross-border project.

Such limitations may lead to ambiguity in the results, but at the same time, the effectiveness of the developed decision support system has been proven and confirmed by the reasonable use of mathematical theory and verification on both real and test data.

6. Conclusions

During the conducted research, for the first time, an information model was developed for forecasting the level of controllability of processes during project implementation. Based on theoretical-multiple generalization, the factors affecting the implementation of the project are classified, namely: factors of internal and external influences; risk-oriented influencing factors; the effects of human factors; and factors guaranteeing the national security of the partner countries during project implementation. Based on these factors, an open set of evaluation criteria of a total number of 24 was proposed. Also, for the first time, a fuzzy model of evaluation of cross-border cooperation projects was developed regarding the possibility of their financing, considering the future level of controllability of processes during implementation. The model consists of three stages: finding an aggregated assessment of cross-border cooperation projects regarding the possibility of their financing; finding generalized quantitative estimates and linguistic levels of the possibility of financing cross-border cooperation projects and considering factors influencing the level of manageability of project implementation processes. An approbation example of the calculation is given. For the practical implementation of the decision-making support system regarding the possibility of financing cross-border cooperation projects, software was developed, which will be a useful tool for managers of cross-border project tenders, to increase the validity of decision-making support.

The obtained results demonstrate the scientific and applied value of the conducted research. Further research of the problem is seen in the development of other mathematical models and software support for the evaluation of cross-border cooperation projects under the conditions of guaranteeing the national security of the partner countries during the implementation of the project.

Acknowledgements

It was funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V01-00059.
The scientific research and preparation of the article took place within the framework of the scientific project of young scientists "Protection of information security in the management of international cooperation projects based on guaranteeing the national security of Ukraine" (DB-921M) with financial support of the Ministry of Education and Science of Ukraine. This publication is also the result of the project „New possibilities and approaches of optimization within logistical processes “, supported by Operational Program Integrated Infrastructure (ITMS: 313011T567), and the Slovak Research and Development Agency project PP-COVID-20-0002.

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