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# A decision-making support model for financing start-up projects by venture capital funds on a crowdfunding platform

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## ABSTRACT

The main goal of this study is to develop a comprehensive decision support model for financing start-up projects by venture capital funds on a crowd-investment platform. The model is aimed at supporting decision-making processes by venture capital funds regarding the financing of expensive start-up projects on crowdfunding platforms. The decision support model will prevent biased conclusions of crowdfunding platform experts regarding the evaluation of start-up projects, and venture capital funds will be able to manage the decision support process at all stages of evaluation. The research results were verified and tested using the example of evaluating a real start-up project to make a decision on its financing by a venture capital fund. The study outcomes may be beneficial for all sides of the explored fields - from regulatory authorities through traditional investors to start-up initiatives - to carry out investment activities and to develop optimal strategies.

**Keywords:** Start-up project, venture fund, crowdfunding platform, intellectual analysis of knowledge, fuzzy sets

## 1. Introduction

The business financing market currently uses crowdfunding platforms in addition to traditional forms of business financing. Crowdfunding represents a new alternative for business financing, and thus, it has been the subject of the research interests of many multidisciplinary teams in recent years. The use of crowdfunding platforms has experienced exponential growth in recent years (Busse, 2019). Crowdfunding is used by entrepreneurs as a controversial method for start-up financing alongside other alternative forms of venture capital financing, such as business angels and venture capital (Langley & Leyshon, 2017). The most productive countries are represented by highly developed

economies, but there are initiatives that have started investigating the use of crowdfunding in other countries as well (**Baber & Fanea-Ivanovici, 2022**). Its position as an alternative source of financing also supports the emergence of new challenges and opportunities for its use. This also activates the development of the theoretical base related to terminological aspects, ethical questions, and so forth. Despite the long-term research interest in crowdfunding, it can be concluded that the systematization and preparation of the complex decision-making structures of the crowdfunding concept have remained unexplored thus far. Many research studies appeal to the need to define the classification of crowdfunding as well as to compare it with other financing methods, with the aim of a more detailed investigation of the decision-making processes within the triadic relationship of the involved actors (**Cai et al. 2021; Bonini & Capizzi, 2019; Bessièrè et al. 2020**).

The available research studies focus more on the investigation of individual factors in individual categories than on the investigation of their mutual relations and their effects on elementary decision-making processes. The predominant focus of the research studies is on the influence of the various factors on the overall success of campaign financing rather than on the decision-making process itself. Additionally, there is an absence of investigations into the differences in the factors in research studies, as well as investigations into their influence and dependence. Some authors (**Allon & Babich (2020); Josefy et al. (2017)**) note that it is not possible to evaluate the factors separately because the outcome decision depends on their interactions; **Wang et al. (2020)** also confirm these facts explicitly. A correct understanding of the results of the decision-making processes requires the examination of not only the individual factors and the overall result of the campaign financing success but also the entire decision-making process in its individual stages and the examination of the influence of the individual stages and the factors included in them. These consistent facts represent a significant research gap, and thus, they were the motivation for carrying out our research.

The quality of the database is also a significant problem in decisionmaking processes. The limitations related to the use of secondary data can be effectively eliminated by several experimental methods, including observations of decision-making processes in monitored environments, in-depth interviews, and investigations of group goals. Since crowdfunding has become an increasingly common source of financing for various groups of entrepreneurs (B2B, B2C, and so on), it is also important to qualitatively examine the reasons for the involvement of entrepreneurs in crowdfunding.

To understand the dynamics of venture capital management, it is necessary to constantly investigate and analyze the decision-making processes of the individual actors involved, as well as their interdependencies in these triadic relationships (**Bessièrè et al. 2020; Motylska-Kuźma, 2020; Di Pietro et al. 2021**). This calls for further research and empirical support of the results. Many experts claim that using a wider spectrum of research methods in the decision-making processes would create a better understanding of the causal relationships between the individual components too.

Regarding the mentioned base, the main goal of the study was also defined, and the optimal database and methodological platform were selected.

The main goal of this study is to develop a comprehensive decision support model for financing start-up projects with venture capital funds on a crowdfunding platform. The model is aimed at supporting the decision-making processes of venture capital funds regarding the financing of expensive start-up projects on crowdfunding platforms. It is planned that the selection of start-up projects for financing by venture funds will be offered by the crowdfunding platform on a commercial basis in the context of B2B and e-commerce. Then, we have the business processes of three objects: start-ups that want to implement the project and make money from it; venture capitalists who want to finance a profitable

project; and a crowdfunding platform that wants to receive income from a start-up, a venture fund, and from popularization on the internet.

The key result of the article is a comprehensive approach to the practical use and validity of decision-making regarding the evaluation and selection of start-up projects, with the aim of financing them by venture capital funds on crowdfunding platforms. This will reduce the risks of financial operations and increase the security of venture funds, and for crowdfunding platforms, improve the quality of their activities (**Kozuba et al., 2019**).

The output of the model will be a quantitative assessment of the startup project and a linguistic interpretation of the possibility of its financing. The acquired knowledge and the fuzzy model can be transferred to the evaluation of start-up projects outside the European Union, and the problem-solving methodology itself can be repeated by other scientists, experts of venture funds, project analysts of crowdfunding platforms, and other interested persons.

a scientific hypothesis of the presented research is proposed as follows. If the start-up project is successfully implemented, then it is possible to claim a highly comprehensive assessment of its financing, obtained based on a built decision support model that takes into account the target needs of venture capital funds and expert advice.

The results of the study will be a valuable platform not only for all interested actors in triadic relations but also for policy-makers as well as creators of national and regional development strategies to support the development of the business environment and thus to increase national and international competitiveness. The results of the study will also support the construction of a benchmarking platform and the implementation of comparative analyses.

## **2. Literature review**

In the available professional and scientific literature, crowdfunding is considered an increasingly applied mechanism for obtaining financial resources, even if its practical use remains limited in some types of business. Through systematic analysis of the existing research studies, it is possible to obtain an interesting interdisciplinary overview of crowdfunding mechanisms and to identify rudimentary development trends. Sector specifics can represent new dimensions of research, and thus, they can create space for necessary comparative sector analyses (**Chandna, 2022; Hoegen et al. 2018; Leboeuf & Schwienbacher, 2018**). A special group is represented by the B2B, B2C, and the other sectors. Many authors recommend a separate investigation of crowdfunding platforms for B2B and B2C because of their significant sector specificities (**Alam, 2021; Cawsey & Rowley, 2016; Jovanović et al. 2019; Kärkkäinen et al. 2016**). It is obvious that most of the research in the field of crowdfunding is focused on campaigns. Research on B2B and B2C companies reaching for equity-based crowdfunding is spread at a lower level.

**Jovanović et al. (2019)** investigated the differences between the financing decisions for startups located in the B2B and B2C markets. The results of the study pointed to the fact that there are indeed differences in investment between B2B and B2C companies, and therefore, it is necessary to investigate their different success factors. Additionally, the studies by **Duraković & Cosic (2019)**, **Angerer et al. (2017)** and **Lukkarinen & Schwienbacher (2023)** confirm this. In both cases (B2B and B2C markets), the involvement of the investor as lead user is of great importance for the decision to invest. The use of crowdfunding strategies also depends on their acceptance by entrepreneurs (**Kappal & Rastogi, 2020; Vismara, 2018; Wang et al. 2020**). Some studies declare that the main reason for its

rejection by entrepreneurs is the fear of disclosure as well as the fear of visible failure (**Gleasure, 2015; Loher, 2017; Bonini & Capizzi, 2019**). Crowdfunding is also an active tool for securing sector financing (**Wu et al. 2022**). An example of this is the use of crowdfunding campaigns to finance climate change mitigation processes on farms. **Kragt et al. (2021)** solved this issue and stated that farmers have very little knowledge about crowdfunding as an alternative financing method. According to the authors, optimally designed campaigns could mitigate the effects of climate change on farms. These findings are followed by the study by **Meng et al. (2021)**, whose goal was to evaluate crowdfunding alternatives within investment projects for clean energy. Suitable financing alternatives were identified through the new *MCDM* model. Financial ecology creates an additional space for the development of decision-making systems and the use of crowdfunding, but studies that map the initial motivations of entrepreneurs to engage in crowdfunding are absent (**Junge et al. 2022; Gallemore et al. 2019; Lam & Law, 2016**).

**Kärkkäinen et al. (2012)** draw attention to the fact that the environment for crowdsourcing is different within B2B and B2C. The authors investigated crowdsourcing in the B2B innovation process and found evidence of its use in all three phases of the innovation process: front-end, product development, and commercialization. The authors identified a significant role of social media in B2B crowdsourcing. Social media transforms group behavior, and thus, it transfers decision-making power between the subjects of crowdfunding platforms (**Alam, 2021; Cawsey & Rowley, 2016; Bakici, 2020**).

**Mamonov and Malaga (2019)** state that there is not enough evidence on which factors have the greatest impact on the success of fundraising through online equity crowdfunding platforms. Their findings show that online equity crowdfunding platforms are complementary platforms to traditional venture funding sources. This can make the decision-making processes and revealing the success factors more difficult (**Hoegen et al. 2018, Zhang et al. 2017**). **Di Pietro et al. (2021)** carried out an in-depth analysis of 60 European equity crowdfunded ventures with the aim of specifying the barriers to crowd openness for new ventures. The authors identified several organizational barriers: lack of trust, information, and lack of resources. The study also offers several solutions for their elimination. One of them is the creation of coordination technology, mapping of the network of investors, as well as their expertise and proactive communication. Crowd stratification is an important factor.

**Pargachevskaya et al. (2019)** evaluate that there are currently several approaches by researchers to crowdfunding as a tool to attract investment. The authors also specified various crowdfunding risks that exist between project investors and sponsors using crowdfunding to attract investment. Although crowdfunding risks are a part of many research studies, their systematic investigation and quantification of the impact on the outcomes of decision-making processes is absent (**Wasiuzzaman, 2021; Montford & Goldsmith, 2016; Renwick & Mossialos, 2017**). The difference in criteria, the availability of comparative platforms, and the necessary database have a significant impact on the decision-making processes of crowdfunding projects. It is also important to perceive the importance of the criteria by investors as well as evaluators and thus to understand their causal relationships. For this reason, structural analyses are also very often applied - for instance, *MIC MAC* and others.

**Wang et al. (2020)** investigated how the emphasis of text stories influences fundraising outcomes. The study helps to understand the importance of the textual content, the published profile of the entrepreneur, and the social connections for the success of the evaluation of the crowdfunding project. According to the authors, entrepreneurs have to decide between the two types of strategies aimed at emphasizing text content - of the entrepreneur's profile or the creativity of ideas.

**Petruzzelli et al. (2019)** focused on the link between crowdfunding and sustainability, which is understudied. According to the authors, it is essential to reveal the dynamics of the relationship

between crowdfunding and sustainability by an examination of the following dimensions - project creator, campaign supporters, crowdfunding platform, and the outcome of the crowdfunding campaigns. This fact is confirmed by several studies (**Laurell et al., 2019; Petruzzelli et al., 2019; Vismara, 2019**). However, sustainability as a target criterion of crowdfunding can create multiple decision variants and thus support the use of multiple decision-making and optimization methods (**Laurell et al., 2019; Siebeneicher & Bock, 2022**).

Communication policy is also strongly related to the aspects of sustainability and its connection with crowdfunding campaigns. The study by **Ribeiro-Navarrete et al. (2021)** is devoted to the research dimension that investigates communication policies and the quality of investor experience based on information obtained from crowdlending platforms. The authors applied fuzzy-set qualitative comparative analysis to investigate investor satisfaction with these platforms. According to the authors, a strong communication policy based on the frequent updates of the platform, sending information to investors, the offer of mobile applications, and the availability of updated detailed information about the project increases the interest of investors and the level of satisfaction with these platforms. These findings confirm the strong variability of the factors affecting investor satisfaction with crowdfunding platforms.

Many other factors affecting crowdfunding platforms have not yet been sufficiently explored, while many authors have also drawn attention to their mutual influence. This will introduce even greater uncertainty and risks into the decision-making processes and hence the need to investigate them by an application of the appropriate methodological processes (**Pargachevskaya et al. 2019; Leboeuf & Schwienbacher, 2018**). Their correct choice and application can create a strong competitive advantage for B2B platforms. Proof of this is the study by **Bakici (2020)**, in which the authors investigated the competitive and social nature of these B2B platforms to support permanent engagement.

The complexity of investigating competitive trajectories associated with the use of crowdfunding is also pointed out by **De Crescenzo et al. (2020)**. According to the authors, the equity crowdfunding market is still underresearched, and the analysis of factors influencing the emergence of unforeseen circumstances is essential. This is confirmed by the studies of **Motyłska-Kuźma (2020), Kaminski et al. (2019)**, and **Gedda et al. (2016)**. The authors applied fuzzy-set qualitative comparative analysis to investigate the factors affecting the outcomes of the equity crowdfunding market campaign. The results of the study confirmed the fact that success versus failure of crowdfunding is associated with various combinations of conditions that influence them and that require constant investigation.

The authors declare that better results can be achieved through the hybrid *MCDM* model by a combination of *DEMATEL* and *TOPSIS*. **Anglin et al. (2022)** conducted a holistic survey of how story elements influence fundraising in crowdfunding campaigns. Additionally, in this study, the authors applied fuzzy set qualitative comparative analysis to evaluate the investigated configurations that bring funding performance. Despite the many declared benefits of crowdfunding, continued research is needed in this area with the aim of developing complementary systems to eliminate the risks associated with this financial platform (**Bessière et al. 2020; Bonini & Capizzi, 2019**).

The complexity of the decision-making processes, the increase in the number of new criteria and their unclear causal relationships encourage the use of multidisciplinary approaches to evaluate the effectiveness of crowdfunding platforms. **Gupta et al. (2022)** employed this multidisciplinary approach to identify the various benefits of crowdfunding. The first authors applied the buckley fuzzy-AHP technique for this multidisciplinary approach. The results of the analyses confirmed that the most important advantages are obtaining financial resources, cost structure, customer relations, building demand, creating business ecosystems, team development, product life cycle, and market intelligence.

The fuzzy model approach was also applied by **Wu et al. (2022)** when investigating the key success factors of crowdfunding by evaluating several criteria. The authors focused on crowdfunding platforms for microgrid project investments. They proposed a novel fuzzy decisionmaking model with two phases, in which they applied a multistepwise weight assessment ratio approach based on q-rung orthopair fuzzy sets (q-ROFSs). The outcomes of the analyses confirmed that security is the most important factor in crowdfunding platforms for smart-grid project investors. **Tuo et al. (2019)** examine crowdfunding projects by applying asymmetric analytics to identify the different configurational paths to delivery performance. The authors performed a qualitative comparative analysis exploring the data from the Kickstarter crowdfunding platform. The study has several implications for crowdfunding stakeholders. Additionally, **Zhang et al. (2017)** analyze the financing performance of crowdfunding projects in an asymmetric way and employ qualitative comparative analysis (QCA). Using the QCA application, the authors wanted to highlight the configurational impact on financing performance from an asymmetrical perspective. **De Crescenzo et al. (2022)** note that there is a lack of research aimed at evaluating the importance of the external entities participating in the co-financing of projects that at the same time eliminate the problems of information asymmetry. The authors applied fuzzy-set qualitative comparative analysis (fsQCA) to investigate the two types of factors enabling the elimination of the problem related to information asymmetry: content communication and third-party support. The study highlights the role of third-party investors in crowdfunding projects. The issue of information asymmetry in crowdfunding projects is also investigated by **Li et al. (2021)**. These authors also applied the fuzzy-set qualitative comparative analysis (fsQCA) approach to the evaluation of the complexity of lead investors indicated by information disclosure in equity crowdfunding. They draw attention to the need to investigate the decision-making model of individuals disadvantaged by information asymmetry. **Rau et al. (2009)** proposed a negotiation framework for automating B2B processes through fuzzy approaches. They carried out several experiments, whose results demonstrate that fuzzy approaches can effectively help in B2B transactions. **Kärkkäinen et al. (2016)** perceive the power of crowdsourcing in the innovation processes of B2B companies. The authors found evidence of the use of crowdsourcing platforms in the development of B2B innovations in all phases of the front-end innovation process, product development, and commercialization. A strong role of social media in B2B crowdsourcing innovation has been identified. **Simula and Vuori (2012)** examine the innovation dimension in B2B through crowdsourcing. They see the support of innovation processes for B2B in the generation of ideas with internal and external crowds. The authors identify the main obstacles for the effective application of crowdsourcing in the B2B sector with the aim of solving existing B2B problems and supporting their innovation processes.

Social media plays an important role not only in the innovative development of B2B companies but also in the development of collaboration between B2B companies and customers. This is evidenced by the outcomes of the studies by **Alam (2021)** and **Cawsey & Rowley (2016)**, in which the use of social media in the development of new B2B financial services is investigated. New ways of interaction with customers between B2B companies should work alongside traditional ways of interaction with customers. **Kaminski et al. (2019)** investigated whether there is a long-term relationship between crowdfunding and venture capital investments. They found that successful crowdfunding campaigns lead to an increase in venture capital investments. Even experimenting with a product at an early stage and bringing it to market through crowdfunding can support financial managers in decisionmaking processes. **Gedda et al. (2016)** tried to find the optimal platform for funders and entrepreneurs. The funders' favored crowdfunding model named the equity model, which is not established - in combination with the grouped nonfinancial crowdfunding models of preorder or sponsoring of the best crowdfunding platforms. **Babich et al. (2020)** focused on investigating the evolution of crowdfunding, where their research goal was to determine how crowdfunding interacts with

traditional sources of financing such as bank financing and venture capital financing. The authors concluded that the goals of entrepreneurs are much more complex than just maximizing revenue from crowdfunding campaigns. This research also initiates the need for a deeper investigation of how crowdfunding influences entrepreneurs and how crowdfunding platforms fit into the traditional sources of funding startups (banks, venture capital companies). Competition from investors significantly reduces value for venture capital providers, who may withdraw from transactions (**Bonini & Capizzi, 2019; Bessière et al. 2020; Gedda et al. 2016**). The dynamics of the development of financing platforms through the FinTech crowd funding mechanism in the USA, Asia, and Europe were investigated by **Wonglimpiyarat (2018)**. The outcomes of their study result in many recommendations, mainly for developing economies with regard to start-up financing. The study identified several barriers at the operational and political levels.

The research studies on the given issue are quite heterogeneous, which is influenced by the different research trajectories, as well as the focus of the research teams and the available database. Their outcomes confirm the facts stated in the introduction section of our study - an absent investigation of the effects of the various factors on the decisionmaking process itself, a predominant isolated investigation of the factors, and a preference for an investigation of the effects of the factors on overall success.

Because of all the above facts, it was decided to carry out an innovative study on the development of a mathematical model of decisionmaking support, which increases the degree of reasonableness of decision-making regarding the financing of start-up projects, takes into account the target needs of experts of venture funds, and focuses on the unbiased evaluation of start-up projects, as it uses the apparatus of the theory of fuzzy sets, thereby increasing the security of financing such projects and crowdfunding platforms' quality of activity (**Kozuba et al., 2019**).

This document is presented as follows. Part 2 describes a formal formulation of the problem and a mathematical model of decision support for financing start-up projects by venture capital funds on the crowdfunding platform. In Part 3, a simulation experiment is presented that enables the verification of the model, and an approbation example of evaluating a real start-up project on a crowdfunding platform is offered. In Part 4, the results of the research are discussed, the advantages, disadvantages, and limitations of the developed mathematical model are given, and the rationality of the obtained results and their reliability are substantiated. Next, the conclusions and results obtained for the first time are presented, as well as opportunities for improving the research through future work and improvements.

### 3. Materials and methods

Let us have a start-up project  $S$ , or a set of such projects, placed on some crowdfunding platform  $CP$ , for financing by venture funds. The complex model of decision-making support will be presented as a collection of the following models:  $M_S$  - the fuzzy model for assessing the importance of the innovative idea of start-up projects;  $M_R$  - the fuzzy model for assessing the risks of implementing a start-up project;  $M_H$  - the hybrid model for assessing the competence of the start-up project team;  $M_U$  - the model for combining data and deriving the level of decisionmaking regarding the financing of start-up projects. The mathematical model of the assessment problem is:

$$M(M_S, M_R, M_H, G, M_U) \rightarrow f \quad (1)$$

As a result, we obtain the output estimate  $f = (\mu_V; CA)$ , which is a comprehensive estimate of wY regarding the financing of a start-up project, which takes into account the target needs of venture funds  $G$  and expert advice, as well as the linguistic level  $CA$  of the security of financing such projects.

It is proposed to introduce the following management subjects: experts - persons of the crowdfunding platform who analyze and evaluate the start-up project based on the provided questionnaire information about the project, as well as additional other information from various sources; venture funds (venture capitalists) are business entities that intend to finance a start-up project, usually on the terms of a share of the company; project analysts are individuals who customize the entire evaluation process, taking into account the needs of venture funds.

The structural diagram of the decision-making support model for financing start-up projects by venture funds is shown in **Fig. 1**.

**Fig. 1** reflects the structural scheme of the assessment of start-up projects by venture funds on the crowdfunding platform based on developed models, available input data, and target needs of the venture fund. After a comprehensive assessment of the start-up project, the output will be a quantitative assessment and the level of security of financing the start-up project. The venture fund decides on the financing of the start-up project. If the solution does not satisfy the venture fund, then there is an opportunity to attract additional data, revise the target needs or move on to consider another project.

The stages of designing a mathematical model of decision-making support are presented in terms of the above mathematical models. Without reducing generality, the model will be evaluated on a single project. In the case of multiple start-up projects, the assessment is repeated. After that, a ranking series of alternative options for start-up projects are built for their selection and financing by a venture capital fund.

$M_5$ - The fuzzy model for assessing the importance of the innovative idea of start-up projects.

For this model, a set of criteria for evaluating the importance of the innovative idea of start-up projects is proposed -  $K_S = (K_{S1}, K_{S2}, \dots, K_{Sm})$ . Each criterion represents a certain question, with a proposed set of answers and proposed points for them. The expert needs to evaluate and assign a score based on the option that is close to the truth for each start-up  $S$ . Moreover, if there is no correct answer in the proposed questionnaire, then the expert adjusts the assigned score to obtain a value close to the truth. Below is a set of criteria for evaluating the innovative idea of start-up projects, which is open and, if necessary, project analysts can add other indicators that are of interest to venture funds or when considering highly specialized start-up projects. Without reducing generality, the model will be evaluated on a single project. In the case of multiple start-up projects, the assessment is repeated. After that, a ranking series of alternative options for start-up projects are built for their selection and financing by a venture capital fund.

$K_{S1}$ - is the proposed innovative idea of the start-up project a product or service: the idea under development (5 points); the idea has marketing research and a business plan (8 points); working prototype (15 points); implemented a start-up project, and received the first income (25 points).

$K_{S2}$ -does the proposed innovative idea of the start-up project belong to the industry: the start-up is relevant for customers of the public (10 points); the start-up belongs to the industry that is at the peak of popularity (15 points); start-up refers to a field that is just developing, and there are forecasts for popularization in the future (18 points); startup refers to the most popular field among investors (20 points).

$K_{53}$ - Does the proposed innovative idea of the start-up project matter: make life comfortable and pleasant for the public (10 points); helps people or enterprises in the implementation of labor activities (15 points); directly supports one or more UN sustainable development goals (20 points); able to save human life (urgently needed in the market) (25 points).

$K_{54}$ - it is predicted that the start-up project will compete with businesses in its sector in terms of annual revenues: up to 5 million USD dollars (5 points); 5 million — 15 million USD dollars (15 points); 15 million — 20 million USD dollars (20 points); more than 20 million USD dollars (25 points).

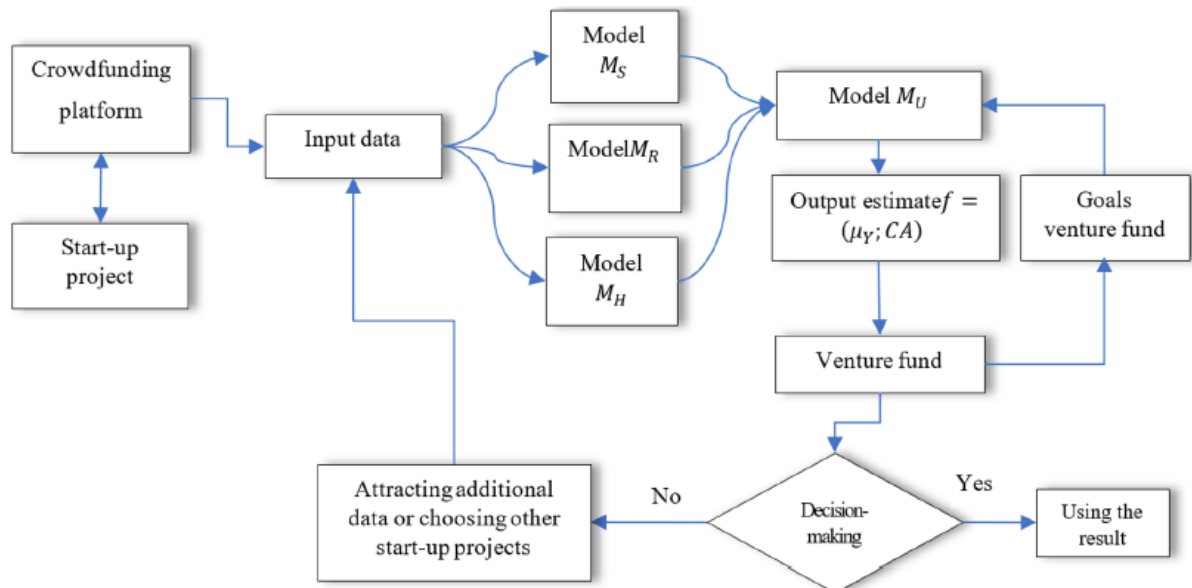


Fig. 1. Structural diagram of the decision support model.

$K_{55}$ - it is predicted that the start-up project will have main competitors in its sector: large companies conducting electronic commerce and investing a lot of money in marketing (5 points); other start-up projects (15 points); the proposed innovation does not have a direct competitor, but there is a risk that customers will find a substitute for this need (20 points); another start-up project, but there are not so many specialists who know how to implement it (25 points).

$K_{56}$ - the team has a strategic partner: existing letters of support regarding the needs of the start-up (5 points); availability of several signed partnership agreements (10 points); contracts on commercial partnership and licensing are signed with dozens of companies (15 points); there are several large partners with a conquered international market (20 points).

$K_{57}$ - other start-up projects in this field that received venture capital at the fundraising stage:

less than USD 1 million (5 points); from 1 to 2 million USD dollars (7 points); from 2 to 5 million USD (10 points); from 5 to 10 million USD dollars (15 points); more than 10 million USD dollars (20 points).

$K_{58}$ - the presence of a corporate lawyer: a medium-sized law firm with experience in cooperation with innovative projects (8 points); a large law firm at the national level (15 points); an international law firm recognized in the venture community (20 points).

$K_{59}$ - the presence of an intellectual property specialist: a medium-sized firm with experience in cooperation with innovative projects or technology transfer (10 points); a large national-level company

that works with a large number of innovative projects (15 points); one of the recognized intellectual property law firms operating at the national or international level (25 points).

After evaluation, a set of numerical variables  $O_s = (O_{s1}, O_{s2}, \dots, O_{sm})$  is obtained according to the criteria  $K_s = (K_{s1}, K_{s2}, \dots, K_{sm})$ . We will offer the model in the form of a step-by-step algorithm.

**Step 1.** Fuzzification of input data.

Fuzzification of input data is carried out with the help of intellectual analysis of knowledge [3] and membership functions according to criteria. An S-shaped membership function is used to normalize the data:

$$\vartheta_j(O_{sj}, a_j, b_j) = \begin{cases} 0, & O_{sj} \leq a_j; \\ 2 \left( \frac{O_{sj} - a_j}{b_j - a_j} \right)^2, & a_j < O_{sj} \leq \frac{a_j + b_j}{2}; \\ 1 - 2 \left( \frac{b_j - O_{sj}}{b_j - a_j} \right)^2, & \frac{a_j + b_j}{2} < O_{sj} < b_j; \\ 1, & O_{sj} \geq b_j. \end{cases} \quad (2)$$

where  $a_j$  is the minimum,  $b_j$  is the maximum number of points that a start-up project can score according to the  $K_{sj}$  criterion, and  $O_{sj}$  is the number of points received according to the  $j$ -th criterion ( $j = \overline{1, m}$ ).

**Step 2.** Taking into account the wishes of venture capital funds.

For each criterion, the venture fund expresses its own considerations, which should be the evaluations according to the criteria. Such considerations will be denoted by the vector  $T = (t_1, t_2, \dots, t_m)$  according to the criteria  $K_{sl}$  ( $l = \overline{1, m}$ ) and, respectively. Next, for each value, the membership function is calculated according to Formula (2), which we denote by  $\tau = (\tau_1, \tau_2, \dots, \tau_m)$ , where  $\tau_j = \vartheta_j$ , ( $j = \overline{1, m}$ ).

**Step 3.** Evaluation of the start-up in relation to the wishes of venture capital funds.

Regarding the desire of venture funds and the obtained results for each  $K_s$  criterion, the distance relative to the real value and the desired value is calculated:

$$\varepsilon_j = |\vartheta_j(O_{sj}) - \tau_j|, j = \overline{1, m}. \quad (3)$$

Since  $\vartheta_j(O_{sj}) \in [0; 1]$  and  $\tau_j \in [0; 1]$ , then it is natural to assume that when the discrepancy between the real value and the desire for venture funds is greater than 0,4, then such a start-up is not suitable for a venture fund. The value of 0.4 was obtained from experimental studies and based on the experience of the authors of the article, who are experts and members of the jury of start-up competitions. With this in mind, it is appropriate to use a Z-linear membership function to compare data:

$$\delta_j = \begin{cases} 1, & 0 < \varepsilon_j \leq 0, 1; \\ \frac{4 - 10\varepsilon_j}{3}, & 0, 1 < x \leq 0, 4; , j = \overline{1, m}. \\ 0, & x > 0, 4. \end{cases} \quad (4)$$

Then, for each criterion  $K_s$ , we obtain the value  $\delta_j$ , which characterizes the relative value of the wishes of venture capital funds to the corresponding criterion. If the value is close to 1, then the obtained estimates for the start-up project fully satisfy the wishes of venture funds.

**Step 4.** Entering weighting factors according to evaluation criteria.

Let the venture funds have their own considerations about the importance of the coefficients for each criterion. We denote such coefficients  $(\alpha_1, \alpha_2, =, \alpha_m)$ , from the interval [1; 10]. To compare the data, we determine normalized weighting factors:

$$\bar{\alpha}_j = \frac{\alpha_j}{\sum_{j=1}^m \alpha_j}, j = \overline{1, m}; \bar{\alpha}_j \in [0, 1]. \quad (5)$$

Apparently  $\sum_{j=1}^m \bar{\alpha}_j = 1$

**Step 5.** Data defuzzification.

For data defuzzification, an aggregated quantitative estimate is constructed using a convolutional approach:

$$e_{S1} = \frac{1}{\sum_{j=1}^m \frac{\bar{\alpha}_j}{\delta_j}} - \text{pessimistic convolution}; \quad (6)$$

$$e_{S2} = \prod_{j=1}^m (\delta_j)^{\bar{\alpha}_j} - \text{cautious convolution}; \quad (7)$$

$$e_{S3} = \sum_{j=1}^m \bar{\alpha}_j \cdot \delta_j - \text{average convolution}; \quad (8)$$

$$e_{S4} = \sqrt{\sum_{j=1}^m \bar{\alpha}_j \cdot (\delta_j)^2} - \text{optimistic convolution}. \quad (9)$$

The obtained estimate  $e_s \in [0; 1]$  characterizes the value of the level of importance of the innovative idea of the start-up project. The higher the score, the better the start-up project fits the goals of the venture fund.

The model reduces the subjectivity of expert evaluations and takes into account the wishes of venture funds regarding evaluations by criteria.

$M_R$  - The fuzzy model for assessing the risks of implementing a startup project

We suggest using the methodology described by the authors in the article (**Polishchuk et al., 2019**) to derive an aggregated assessment of the risks of implementing a start-up project. The model reveals the vagueness of input estimates based on input hybrid data and makes it possible to combine expert knowledge and quantitative information on risk assessment of start-up project implementation at the initial stages while reducing the subjectivity of experts evaluating them. For such hybrid data, the following term set of linguistic variables  $T=\{\text{high level; level above average; average level; level below average; low level}\}$ . In addition, for each criterion, the expert expresses his confidence in the validity of his reasoning in assigning him a linguistic assessment, which is expressed in quantitative form from the interval  $[0; 1]$ . At the output of the model, a quantitative normalized estimate is the output.

$M_H$  - The hybrid model for assessing the competence of the start-up project team.

One of the important factors influencing the successful implementation of a start-up project is the human factor. Incompetent actions of the development team and their leaders lead to failure to achieve project goals. Achieving competent decisions in the project management process depends on the quality of the start-up project team.

When evaluating a start-up project team, it becomes necessary to analyze competencies, work experience, and other additional indicators that affect the success of a start-up. In this case, a formalized toolkit is proposed that allows venture capital funds to take into account their considerations regarding start-up team members.

Similarly, an open set of evaluation criteria for members of the startup project team  $K_H = (K_{H1}, K_{H2}, \dots, K_{Hm})$  is offered. Each criterion represents some question for which the expert sets a score from the interval  $[a; b]$ . We denote such quantitative estimates as  $u(K_j \in [a; b], j = \overline{1, m})$ . Below is an open set of criteria for their addition by project analysts.

$K_{H1}$  - the previous experience of the applicant's project activity, which coincides with the project direction.

$K_{H2}$  - stability of the team in relation to the members and the leader.

$K_{H3}$  - having successful work experience as a team leader (member) in similar projects.

$K_{H4}$  - available, both a priori and empirical education of the leader on the topic of the start-up project.

$K_{H5}$  - existing systematic participation of the team in professional events for the project.

$K_{H6}$  - presence in the team of interchangeable specialists capable of performing innovative project tasks to achieve the main project goal.

$K_{H7}$  - the presence of a project partner with a similar business or significant influence in the sector of implementing a start-up project.

$K_{H8}$  - availability of sufficient time to implement the project presented by the start-up, according to the declared development terms.

The hybrid model is proposed in the form of the following algorithm.

**Step 1.** Fuzzification of input data.

For fuzzification of the input data  $u(K_{Hj}), j = \overline{1, m}$  of the start-up project team, the membership function in the form of a harmonic S-spline is used:

$$\gamma_j = \begin{cases} 0, & u(K_{Hj}) < a; \\ \frac{1}{2} + \frac{1}{2} \cos \left( \frac{u(K_{Hj}) - b}{b - a} \cdot \pi \right), & a \leq u(K_{Hj}) \leq b; \\ 1, & u(K_{Hj}) > b. \end{cases} \quad (10)$$

The concept of building membership functions implies the following meaning: the higher the score, the more likely the team is to successfully implement the project, and the value of the membership function tends to unity.

**Step 2.** Considering the importance of evaluation criteria.

Similarly, venture funds have their own considerations regarding the importance of each evaluation criterion  $\{P_1, P_2, \dots, P_m\}$  from the interval, for example  $[1;10]$ . For data comparison, normalized weighting factors are determined:

$$\overline{p}_j = \frac{P_j}{\sum_{j=1}^m P_j}, j = \overline{1, m}. \quad (11)$$

**Step 3.** Deriving an aggregated assessment of the competence of the start-up project team.

The aggregate assessment of the competence of the start-up project team is calculated using a weighted average convolution:

$$m_3 = \sum_{j=1}^m \overline{p}_j \cdot \gamma_j. \quad (12)$$

**Step 4.** Combining the aggregated assessment of the competence of the start-up project team and the expert.

The expert has empirical experience of what the combination of the start-up project team should be to complete project tasks and achieve project goals. Such considerations of the expert are proposed to be presented in the form of linguistic variables:  $L_1$  {the composition of the team of very strong competence, which is capable of successfully implementing a start-up project};  $L_2$ {composition of a team of strong competence, capable of successfully implementing a start-up project};  $L_3$ {the team's competencies are average, and the ability to successfully implement a start-up project depends on many external factors};  $L_4$ {competencies of the team are low, potentially unable to successfully implement this start-up project};  $L_5$ {competencies of the team are very low in relation to this start-up project}. For an adequate interpretation of the dependence of the output estimates  $m_3$  and expert opinion  $L$ , the following membership function is proposed:

$$e_H = \begin{cases} 0, & m_3 \leq 0; \\ (m_3)^\theta, & 0 < m_3 < 1; \\ 1, & m_3 \geq 1. \end{cases} \quad (13)$$

where  $\theta$  is the threshold of the possibility of successful implementation of a start-up project, the value of which changes depending on the expert opinion  $L$ . It is proposed that this threshold will be adjusted by the project analyst in the process of learning on real data that will be obtained during the operation of the crowdfunding platform. Therefore, at this stage of the research, it was established by experiment that  $\theta = -\frac{2}{9} - \frac{1}{5}$  for  $L_1$ ;  $\theta = -\frac{7}{9} - \frac{3}{5}$  for  $L_2$ ;  $\theta = -\frac{4}{9}$  for  $L_3$ ;  $\theta = -\frac{5}{9} - \frac{9}{5}$  for  $L_4$ ; and  $\theta = -\frac{11}{5}$  for  $L_5$ .

The designed hybrid model uses the analysis of the reasoning of experts in relation to the proposed criteria and general linguistic considerations regarding the possibility of successful implementation of a start-up project; at the same time, it reveals the vagueness of the input estimates and increases the degree of validity of making further management decisions based on the obtained results.

$M_u$ — The model for combining data and deriving the level of decision-making regarding the financing of start-up projects.

A feature of the decision-making support model for financing startup projects by venture funds on the crowdfunding platform is that venture funds have the opportunity to express their target needs  $G = \{G_S; G_R; G_H\}$  regarding the importance of the innovative idea of start-up projects, the possibility of covering a certain level of project implementation risk and the level of competence of the start-up project team.

For each of the goals, a characteristic function is introduced that will interpret the relationship between the linguistic expression of venture funds and the quantitative normalized assessment. This will make it possible to adjust the obtained aggregated estimates  $e_S, e_R, e_H$  according to the models  $M_S, M_R, M_H$  with the target needs of those subjects that finance the start-up project.

Next, we will consider the model of combining data and deriving the level of decision-making regarding the financing of start-up projects in terms of goals  $G = \{G_S; G_R; G_H\}$ .

$G_S$ — Target need regarding the importance of the innovative idea of start-up projects.

The following statements regarding the target needs are offered:  $g_{S1}$  — the start-up project is at the level of only an innovative idea;  $g_{S2}$  — the start-up project is at the level of an innovative idea that has good prospects for EU development goals;  $g_{S3}$  — the start-up project has a promising innovative idea and an alpha version of the prototype;  $g_{S4}$  — potential customers have evaluated the start-up project and are testing the product;  $g_{S5}$  — a promising innovative idea and a ready-made tested product. According to the above statements, the following characteristic function is proposed:

$$g_S = \begin{cases} 0,2 & \text{if } g_{S1}; \\ 0,4 & \text{if } g_{S2}; \\ 0,6 & \text{if } g_{S3}; \\ 0,8 & \text{if } g_{S4}; \\ 1 & \text{if } g_{S5}. \end{cases} \quad (14)$$

The values of the characteristic function are not reference and can be changed by project analysts during the functioning of the crowdfunding platform and testing the model on real data.

$G_R$ - The target need for project implementation risk management.

In the process of activity, venture capital funds will gain experience and knowledge of risk management. Therefore, the statement regarding the target needs is offered according to the degree of risk admissibility:  $g_{R1}$  — the ability to bear only the neglected (insignificant) risk of project implementation;  $g_{R2}$  — the possibility of bearing an acceptable risk of project implementation;  $g_{R3}$  — the ability to bear the maximum permissible risk of implementation. The more opportunities a venture fund has, the more it is able to finance the project at the stage of its implementation when certain risks occur. The characteristic function is as follows:

$$g_R = \begin{cases} 0,6 & \text{if } g_{R1}; \\ 0,8 & \text{if } g_{R2}; \\ 1 & \text{if } g_{R3}; \end{cases} \quad (15)$$

$G_H$ - The target need for the competence of the start-up project team.

Similar to the previous one, each venture fund has its own considerations regarding the competence of the start-up project team, their experience, and knowledge of the presented innovation. Therefore, the statement regarding the target needs is offered by the level of competences:  $g_{H1}$  — the average level of competence of the start-up project team regarding the presented innovation;  $g_{H2}$  — the level of competence of the start-up project team regarding the presented innovation is above average;  $g_{H3}$  — high level of competence of the start-up project team regarding the presented innovation. The characteristic function will have the form:

$$g_H = \begin{cases} 0,6 & \text{if } g_{H1}; \\ 0,8 & \text{if } g_{H2}; \\ 1 & \text{if } g_{H3}; \end{cases} \quad (16)$$

Furthermore, for the aggregation of  $e_u$  and  $g_u$  values,  $u = \{S; R; H\}$  it is proposed to use intellectual analysis of knowledge based on multidimensional membership functions. For example, let us model uncertainties of the “average value” type based on a cone-shaped membership function:

$$\Delta_u = \begin{cases} 1 - \frac{1}{2} \cdot \sqrt{(e_u - 1)^2 + (g_u - 1)^2}, & \text{if } \frac{1}{2} \cdot \sqrt{(e_u - 1)^2 + (g_u - 1)^2} < 1, \\ 0, & \text{in the other case.} \end{cases} \quad (17)$$

Since the calculation takes place in the space of normalized values, then the value of the center of the base of the cone is a unit vector, and the scaling according to the coordinates of the vector  $(e_u; g_u)$  is set to  $(2; 2)$ . With such a given base and scaling, the obtained output estimates from a mathematical

point of view will be from the interval  $\Delta_S \in [0,3597; 1]$ ,  $\Delta_R \in [0,4615; 1]$ ,  $\Delta_H \in [0,4615; 1]$ . In terms of content, output assessments combine a real comprehensive assessment of a startup project and considerations of venture capital funds.

By combining the values of  $\Delta_S$ ,  $\Delta_R$ ,  $\Delta_H$ , a comprehensive estimate of  $\mu_Y$  is obtained for the financing of a start-up project, which takes into account the target needs of venture capital funds. To obtain a comprehensive estimate of  $\mu_Y$  and to derive the linguistic level of  $CA$  security of financing start-up projects, it is similarly proposed to use a cone-shaped membership function, but in a three-dimensional space. Here, the value of the center of the base of the cone will be a unit vector, and the scaling will be based on coordinates (3; 3; 3):

$$\mu_Y = \begin{cases} 1 - \mu, & \text{if } \mu < 1, \\ 0, & \text{in the other case.} \end{cases} \quad (18)$$

where

$$\mu = \frac{1}{3} \cdot \sqrt{(\Delta_S - 1)^2 + (\Delta_R - 1)^2 + (\Delta_H - 1)^2}$$

$\mu =$

Thus, a comprehensive estimate of  $J_Y$  is obtained regarding the financing of a start-up project from the interval  $[0,5025; 1]$ . The output comprehensive assessment is based on the assessment of the importance of the innovative idea of start-up projects, the assessment of the risks of the implementation of the start-up project, the assessment of the competence of the start-up project team, their experience, and knowledge, and it also takes into account the target needs of the venture fund.

The following linguistic conclusions are offered to derive the  $CA$  linguistic level of the security of financing start-up projects by venture capital funds on the crowdfunding platform:  $CA_3$  - very low level;  $CA_2$  - low level;  $CA_3$  - average level;  $CA_4$  - high level;  $CA_5$  - very high level.

As a result of the verification of the decision support model on real (database of the competition "Start-up UzhNU") and test data, the levels for comparing the comprehensive assessment  $\mu_Y$  with the linguistic  $CA = \{CA_1, CA_2, CA_3, CA_4, CA_5\}$  are as follows:  $\mu_Y \in [0,5025; 0,6] - CA_1$ ;  $\mu_Y \in (0,6; 0,7] - CA_2$ ;  $\mu_Y \in (0,7; 0,8] - CA_3$ ;  $\mu_Y \in (0,8; 0,9] - CA_4$ ;  $\mu_Y \in (0,9; 1] - CA_5$ .

As a result, a linguistic level of security of start-up project financing is obtained, which takes into account the target needs of venture capital funds.

Of course, the given levels are not a priori, and DMs can always change them if necessary and adjust them for a specific crowdfunding platform. Model verification was performed on real data, which draws the attention of other researchers to the need for training on real data. In our case, the database of the student competition contains 109 projects that were completed during 2016-2022.

At the competitive selection, as a rule, several experts take part in the evaluation. Without reducing the generality, the developed model demonstrates the calculation procedure by one expert. In the case of multiple experts, this calculation procedure is repeated the corresponding number of times. After that, you can use the arithmetic mean approach to derive a single output score or enter the importance of the experts and use the weighted average convolution (12).

#### 4. Results

We will verify and test the results of the research on the example of the evaluation of the project “Innovative forms of intangible cultural heritage protection of Ukraine and support of local communities by creating a virtual pilot museum of gastronomic heritage” (**Showcase of Zakarpattia, 2022**), which has passed the expansion stage and will be presented in the form project start-up on a crowdfunding platform. This start-up project was implemented by the public organization “IMAGO Kultury” (Ukraine).

The evaluation was carried out according to the models  $M_S$ ,  $M_R$ ,  $M_H$ ,  $M_U$  by the authors of the article, who are members of the jury of start-up competitions, experts of various commissions for evaluating grants, and experts of scientific and technical (experimental) works of national academies of sciences. The input data for the evaluation are obtained from an expert on the crowdfunding platform who examines the start-up according to the evaluation criteria. Data on their target needs are taken from venture capital funds.

For the fuzzy model  $M_S$ , it is necessary to evaluate and assign a score to the questions based on the option that is close to the truth.

**Table 1** Input data for the model  $M_S$ .

	$K_{G1}$	$K_{G2}$	$K_{G3}$	$K_{G4}$	$K_{G5}$	$K_{G6}$	$K_{G7}$	$K_{G8}$	$K_{G9}$
$O_G$ - numerical variables	15	15	20	15	20	15	15	15	15
$T$ - wishes of venture funds	18	20	17	20	20	15	12	10	12
$a$ - the minimum number	5	10	10	5	5	5	5	8	10
$b$ - the maximum number	25	25	25	25	25	20	20	20	25
$\alpha$ - weighting factors	9	8	7	10	9	9	7	6	6

The venture fund needs to express its wishes regarding the evaluations according to the criteria and reasoning about the importance of the ratios. **Table 1** shows the number of points obtained for the corresponding criterion; wishes of venture capital funds regarding evaluations according to criteria ( $T$ ); the minimum ( $a$ )/maximum ( $b$ ) number of points that a start-up project can score according to the criterion; and weighting factors according to evaluation criteria ( $a$ ).

For the hybrid model  $M_H$ , the expert must answer the questions and set a point estimate  $u(K_H)$  from the interval, for example, [1; 20]. For venture funds, it is necessary to express their reasoning regarding the importance of coefficients for each criterion  $\{P_1, P_2, \dots, P_m\}$ . The input data are presented in **Table 2**.

The evaluation for the  $M_S$  model is given in the form of a developed algorithm.

**Step 1.** Fuzzification of input data is carried out using Formula (2):

$$\vartheta_1 = 0,5; \vartheta_2 = 0,222; \vartheta_3 = 0,778; \vartheta_4 = 0,5; \vartheta_5 = 0,875; \vartheta_6 = 0,778; \vartheta_7 = 0,778; \vartheta_8 = 0,653; \vartheta_9 = 0,222.$$

**Step 2.** Taking into account the wishes of venture capital funds.

For each value of  $T$ , the membership function is calculated according to Formula (2):  $\tau_1 = 0,755; \tau_2 = 0,778; \tau_3 = 0,436; \tau_4 = 0,875; \tau_5 = 0,875; \tau_6 = 0,778; \tau_7 = 0,436; \tau_8 = 0,056; \tau_9 = 0,036.$

**Step 3.** Evaluation of the start-up relative to the wishes of venture capital funds, according to Formula (3):  $\varepsilon_1 = 0,255$ ;  $\varepsilon_2 = 0,556$ ;  $\varepsilon_3 = 0,342$ ;  $\varepsilon_4 = 0,375$ ;  $\varepsilon_5 = 0$ ;  $\varepsilon_6 = 0$ ;  $\varepsilon_7 = 0,342$ ;  $\varepsilon_8 = 0,597$ ;  $\varepsilon_9 = 0,187$ . Next, the relative value of the wishes of venture capital funds to the corresponding criterion is calculated (4):  $\delta_1 = 0,48$ ;  $\delta_2 = 0$ ;  $\delta_3 = 0,19$ ;  $\delta_4 = 0,08$ ;  $\delta_5 = 1$ ;  $\delta_6 = 1$ ;  $\delta_7 = 0,19$ ;  $\delta_8 = 0$ ;  $\delta_9 = 0,71$ .

**Step 4.** Entering weighting factors according to evaluation criteria.

We determine the normalized weighting coefficients for (5):  $\bar{\alpha}_1 = 0,127$ ;  $\bar{\alpha}_2 = 0,113$ ;  $\bar{\alpha}_3 = 0,099$ ;  $\bar{\alpha}_4 = 0,141$ ;  $\bar{\alpha}_5 = 0,127$ ;  $\bar{\alpha}_6 = 0,127$ ;  $\bar{\alpha}_7 = 0,099$ ;  $\bar{\alpha}_8 = 0,085$ ;  $\bar{\alpha}_9 = 0,085$ .

**Step 5.** Defuzzification of data, according to Formula (6):  $e_s = 0,425$ .

Then, the assessment is carried out according to the model  $M_H$ .

**Step 1.** Fuzzification of input data.

For fuzzification of the input data  $u(K_H)$ , the membership function according to Formula (10) is used:  $\gamma_1 = 0,839$ ;  $\gamma_2 = 0,973$ ;  $\gamma_3 = 0,623$ ;  $\gamma_4 = 0,895$ ;  $\gamma_5 = 0,94$ ;  $\gamma_6 = 0,895$ ;  $\gamma_7 = 0,623$ ;  $\gamma_8 = 0,993$ .

**Step 2.** Considering the importance of evaluation criteria.

For data comparison, normalized weighting factors are determined according to (11):  $\bar{p}_1 = 0,118$ ;  $\bar{p}_2 = 0,147$ ;  $\bar{p}_3 = 0,132$ ;  $\bar{p}_4 = 0,147$ ;  $\bar{p}_5 = 0,132$ ;  $\bar{p}_6 = 0,103$ ;  $\bar{p}_7 = 0,088$ ;  $\bar{p}_8 = 0,132$ .

**Step 3.** Deriving an aggregated assessment of the competence of the start-up project team.

The aggregated score is calculated using the weighted average convolution according to Formula (12):  $m_3 = 0,859$ .

**Step 4.** Combining the aggregated assessment of the competence of the start-up project team and the expert.

Let the expert express his reasoning in the following form:  $L_2\{\text{composition of a team of strong competence, capable of successfully implementing a start-up project}\}$ . For an adequate interpretation of the dependence, the membership function according to Formula (13) is used:  $e_H = (0,859)^3 = 0,913$ .

Next, we perform an evaluation based on the data fusion model  $M_U$ .

At this stage, normalized estimates of  $e_s = 0,425$ ;  $e_H = 0,913$  were obtained. An aggregate risk assessment of the implementation of this start-up project was also calculated according to the fuzzy risk assessment model developed by the authors and described in the article (Polishchuk et al., 2019). The value of  $e_R = 0,659$  was obtained.

**Table 2** Input data for the model  $M_H$ .

	$K_{H1}$	$K_{H2}$	$K_{H3}$	$K_{H4}$	$K_{H5}$	$K_{H6}$	$K_{H7}$	$K_{H8}$
$u(K_H)$ - point estimate on the questions	15	18	12	16	17	16	12	19
$p$ - weighting factors	8	10	9	10	9	7	6	9

Let the venture funds express themselves regarding the target needs of  $G$  as follows:  $g_{S4}$  — potential customers have evaluated the start-up project and are testing the product;  $g_{R2}$  — the possibility of

bearing an acceptable risk of project implementation;  $g_{H3}$  — high level of competence of the start-up project team regarding the presented innovation. Then, according to the characteristic functions (14)-(16), we obtain  $G = \{0,8; 0,8; 1\}$ .

Next, the values of  $e$  and  $G$  are aggregated according to Formula (17):  $\Delta_S = 0,696$ ;  $\Delta_R = 0,802$ ;  $\Delta_H = 0,957$ .

According to Formula (18), we will obtain a complex estimate:  $/jy = 0,878$ . Based on this assessment, the linguistic  $CA$  level of the security of financing start-up projects by venture capital funds on the crowdfunding platform is derived. Therefore, as  $\mu_y \in (0,8; 0,9]$ , the start-up project has a high level of funding security ( $CA_4$ ).

## 5. Discussion

In this work, a complex model of decision-making support regarding the financing of start-up projects by venture capital funds on the crowdfunding platform has been developed. For this purpose, the following was developed: a vague model for assessing the importance of the innovative idea of start-up projects; a hybrid model for assessing the competence of the start-up project team; and a model for combining data and deriving the level of decision-making regarding the financing of start-up projects.

The research is based on the apparatus: fuzzy sets and membership functions, intellectual analysis of knowledge, and system analysis. This makes it possible to increase the degree of validity of decisions, reveal the ambiguities of incoming expert opinions, and obtain a quantitative assessment of linguistic conclusions regarding the target needs of venture capital funds. Thus, biased conclusions on the part of experts of the crowdfunding platform regarding the evaluation of start-up projects will be impossible. Venture funds have the opportunity to manage the decision-making support process at all stages of project evaluation.

Hence, the results of our study eliminate the problems pointed out by several authors including **Ademi et al. (2022)**, **Gedda et al. (2016)**, **Courtney et al. (2017)**, **Minola & Giorgino (2008)** and others.

For the expert on the crowdfunding platform, the evaluation procedure is natural, as he works with the project application and provides answers to questions. Next, the input data are processed by decision support models that can be configured by the project analyst.

The models are designed in such a way that they do not depend on the number of evaluation criteria, and project analysts can always improve many criteria or introduce new indicators for start-ups in a certain industry. The model takes into account the target needs of venture funds, which is important in the process of managing their financial resources and risks. The model determines the level of security of startup project financing based on the obtained comprehensive quantitative assessment. In the case of multiple start-up projects, it is possible to build a ranking series to select the best ones for investment on the crowdfunding platform. The models are based on the modern type of hybrid data, reveal their vagueness, and enable unbiased assessment, both by experts and venture funds, which in turn increases the security of financing start-up projects.

A limitation of our study was the use of different types of unidimensional and multidimensional membership functions, as well as convolutions for data aggregation. The choice of the membership function can lead to ambiguous final results, but this does not affect the content of the evaluation

since the project analyst can always adjust the decision-making levels regarding the security of funding of start-up projects.

The rationality of the received assessment of the level of security of funding start-up projects by venture capital funds on the crowdfunding platform proves the advantages of the developed model. The reliability of the obtained results is ensured by the reasoned use of the modern apparatus of intellectual analysis of knowledge and functions belonging to one and many variables, system analysis, which is also confirmed by the results of research. Thus, the hypothesis of this study was proven.

The results of our study created a clear appeal for the need for continuous research in the field of crowdfunding platforms with the aim of gradually gaining an integrated view of investor decision-making in crowdfunding, drawing attention to the systematic differences between the individual decisions within crowdfunding and comparing them with traditional decisions. The importance of these comparative analyses for the improvement of decision-making processes is also pointed out by the studies of the authors **Butticè & Vismara, 2022; Lam & Law, 2016; Gao et al. 2021**). It will be important in subsequent studies to focus on the identification of less researched decision-making aspects, as well as the causes of the different results achieved (**Gedda et al. 2016; Motylska-Kuźma, 2020; Butticè & Vismara, 2022**). A high-quality database will still be one of the priorities to achieve the goals of improving decisionmaking processes. As shown by several research studies, the absence of a quality database can cause the alternation of missing data, which can have a negative impact on decision-making processes (**Blaseg et al. 2021; Kleinert et al. 2022; Wasiuzzaman, 2021; Meoli & Vismara, 2021; Vismara, 2018; Mamonov and Malaga, 2019**). It is also necessary to examine the decision-making processes in a vertical as well as a horizontal process line and thus to create the comparative dimensions for the various groups of entrepreneurs (for instance B2B, B2C, B2G).

The results of the study have strong practical implications for founders, involved actors, and different platforms. Founders can better understand the decision-making processes of investors and thus adapt campaigns and communications. Founders can also adapt campaigns to the different types of investors, taking into account individual differences. This can increase the likelihood of funding success and improve relationships with your investors. These findings fully correspond with the outcomes of the studies by **Hoegen et al. (2018), Siering et al. (2016), Hornuf & Schwienbacher, (2018), Liu et al. (2021)** and others.

The operators of the various platforms can use the results of the study for a better understanding of investment behavior and to provide founders with the various tools and recommendations that would help to implement better campaigns and thus to attract more investors. Investors can better understand what influences their decisions and reveal other decision-making factors. An investigation of the motivational factors of investors will have an increasingly strong overlap in multidisciplinary areas that will create pressure for the further development of decision-making methods (**Bagheri et al. 2019; Kang et al. 2016; St John et al. 2021**). The studies by **Ogunlusi & Obademi (2021), Montford & Goldsmith (2016), Kappal & Rastogi (2020), and Mala & Chand (2015)** draw attention to the importance of investigating and revealing new factors in decision-making processes. This will also influence the demand for the development of new decision-making methods and the construction of data platforms for comparative analyses.

The results of the study may also be beneficial for regulatory authorities - for instance, in investor protection processes, setting financial mechanisms within the economic policy of countries, and so forth. These aspects appear in the results of the studies only occasionally, and they represent a secondary output in the studies. The study can also be beneficial for traditional investors, such as business angels and venture capital. According to the knowledge of the systematic differences

between crowdfunding and their core business, traditional investors can expand their investment activities and develop their optimal strategies purposefully.

## **6. Conclusion**

The development of the crowdfunding mechanism also stimulates the increased interest of experts as well as researchers in the investigation of the increasingly complex decision-making processes within the triadic relationship of the involved actors. There is a strong appeal for a systematic examination of the components of the decision-making processes within crowdfunding. The available studies on this issue are quite heterogeneous, both from the point of view of the process and the results. Many research studies often applied limited data that generated mixed results and thus made it difficult to design a comparative base. This also had an impact on the aggregation of the results and insufficient support for the implementation of subsequent research and analysis. Without subsequent empirical studies, it is very problematic to improve decision-making processes and to support the further development of crowdfunding platforms. These consistent facts created the motivation to carry out our research.

Research was conducted on the actual task of developing a decisionmaking support model for financing start-up projects by venture funds, and the following results were obtained.

First, a fuzzy model for assessing the importance of an innovative idea for start-up projects was developed. The model reduces the subjectivity of expert evaluations and takes into account the wishes of venture funds regarding evaluations by criteria. At the output of the model, we will receive an estimate that characterizes the level of importance of the innovative idea of a start-up project with the wishes of venture capital funds.

Second, a hybrid model for assessing the competence of the start-up project team was developed, which can derive an aggregated assessment of the competence of the composition of the start-up project team. The advantage of the model is the ability to take into account the experts' empirical considerations regarding the start-up team and, if necessary, take into account other additional indicators.

Third, a model for combining data and deriving the level of decisionmaking regarding the financing of start-up projects on the crowdfunding platform was developed for a comprehensive model of decision-making support. The model is based on linguistic considerations of the target needs of venture funds and uses intelligent knowledge analysis and multidimensional membership functions. As a result, a linguistic level of security in financing a start-up project on a crowdfunding platform is obtained.

Fourth, the research results were verified and tested on the example of the evaluation of a real start-up project, demonstrating the applied value of the decision support model in conditions of risk and uncertainty. Further research of the problem can be seen in the design of software for crowdfunding platforms, which will be a means of supporting informed decision-making by venture funds regarding the selection and financing of start-up projects on the crowdfunding platform. The developed model and its software will be a useful tool for B2B cooperation in the context of e-commerce in the framework of the security of financing start-up projects.

## **Ethical approval**

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

#### **CRedit authorship contribution statement**

**Marinko Skare:** Conceptualization, Data curation, Formal analysis, Supervision, Visualization, Validation, Writing – original draft, Writing – review & editing. **Beata Gavurova:** Conceptualization, Methodology, Validation, Writing – original draft, Writing – review & editing. **Voloodymyr Polishchuk:** Data curation, Formal analysis, Methodology, Software, Visualization, Writing – review & editing.

#### **Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### **Data availability**

Data will be made available on request.

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