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Risk Assessment Model for Innovative Projects Based on Fuzzy Sets and Bayesian Networks

Ludmila Smirnova*

Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
*Corresponding author: dracon260700@gmail.com

Abstract

With the rapidly changing economic environment and inherent market conditions, risk assessment is becoming a major priority for companies involved in innovative projects. Innovative projects are characterized by great uncertainty and their success largely depends on a variety of factors. To improve the quality of risk assessment for such projects, it is essential that you use methods that consider the complex relationships between many variables. This paper suggests a model based on fuzzy sets and Bayesian networks that allows you to effectively analyse and manage the risks of innovative projects. Using fuzzy sets can help you take into account the uncertainty in the data and work with fuzzy information, which is of prime importance, as there are a lot of diverse data that must be considered in innovative projects. With Bayesian networks, you can model probabilistic relationships between risks and project factors, which gives you a more accurate idea of potential risks and helps you predict possible scenarios for the project. Our model represents an innovative approach to assessing the risks of innovative projects and contributes to more effective risk management and informed decision-making in the case of complex projects. It can also facilitate sustainable development of the innovation sector and increase the competitiveness of companies due to the more efficient use of resources and a higher probability of successful innovative initiatives in the long run.

Keywords: innovative project, risk in an innovative project, risk assessment of an innovative project, theory of fuzzy sets, Bayesian networks

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Модель Оценки Рисков Инновационных Проектов на Основе Нечетких Множеств и Байесовских Сетей

Людмила Смирнова*

Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия
*Автор, ответственный за переписку: dracon260700@gmail.com

Аннотация

В условиях быстро меняющейся экономической среды и взаимосвязанных рыночных условий оценка рисков инновационных проектов становится приоритетной задачей для компаний. Инновационные проекты характеризуются высоким уровнем неопределенности и разнообразием факторов, которые могут повлиять на их успешность. Для повышения качества оценки рисков в таких проектах важно использовать методы, способные учитывать сложные взаимосвязи между различными переменными. В статье представлена модель, основанная на нечетких множествах и байесовских сетях, которая позволяет эффективно анализировать и управлять рисками инновационных проектов. Применение нечетких множеств помогает учесть неопределенность в данных и работать с нечеткой информацией, что особенно важно в условиях большого объема и разнообразия данных в инновационных проектах. Байесовские сети позволяют моделировать вероятностные взаимосвязи между рисками и факторами проекта, что дает более точное представление о потенциальных рисках и позволяет прогнозировать возможные сценарии развития проекта. Предложенная модель представляет инновационный подход к оценке рисков инновационных проектов, способствуя более эффективному управлению рисками и принятию обоснованных решений в контексте сложных проектов. Она также может способствовать устойчивому развитию инновационной сферы и повышению уровня конкурентоспособности компаний, обеспечивая более эффективное использование ресурсов и увеличение вероятности успешной реализации инновационных инициатив в долгосрочной перспективе.

Keywords: инновационный проект, риск в инновационном проекте, оценка рисков инновационного проекта, теория нечетких множеств, байесовские сети

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1. Introduction

With the rapid development of technology and constant changes in the market, innovative projects play a key role in the strategic development of organizations. However, when new ideas and technologies are introduced, there is a lot of uncertainty and risk. Thus, it is important to assess the risks of innovative projects to anticipate potential threats and develop effective risk management strategies.

Assessing the risks of innovative projects helps you prevent possible investment losses, identify potential threats to the successful completion of the project, and improve decision-making based on real information. In this way, you can identify opportunities for growth and development, which makes this process an integral part of strategic management in modern business.

One of the main problems in assessing the risks of innovative projects is uncertainty. New ideas and concepts can incur high risk, since statistics are often unavailable and expert assessments can vary. Thus, the possible outcomes and effects are difficult to predict. In addition, the complexity of innovative projects creates more obstacles to risk assessment. These can include various technical, financial, market and strategic aspects, which make the identification and analysis of potential risks and opportunities more complicated. Due to these problems and the difficulties of risk assessment for innovative projects, there is a need for new approaches and methods of risk assessment that could effectively consider the high uncertainty and complexity of such projects.

The sustainable development of innovation is an important aspect of today's economy, so innovative projects call for effective risk management. Having a well-developed methodological and instrumental basis for risk management contributes to a more informed management of innovative projects, which opens the way for achieving sustainable development in the innovation sector. Focusing on risk assessment and using a model based on fuzzy sets and Bayesian networks allow companies to make informed decisions and develop management strategies that increase the sustainability and success of innovative projects.

Fuzzy sets and Bayesian networks are good to use, as they take into account complex and fuzzy relationships and patterns that are often a feature of innovative projects. Thus, you can manage risks more effectively, make informed decisions and increase the chances of success for such projects.

This paper is aimed at developing and studying a risk assessment model for innovative projects based on fuzzy sets and Bayesian networks. The main objective is to build a model that can take into account various types of risks and provide a more accurate and comprehensive assessment of the possible negative effects experienced by innovative projects. To build the model, we applied a methodology for forming fuzzy sets based on expert assessments and data analysis. It includes the definition of probabilities for each risk and its factors in the form of fuzzy terms, given uncertainty and various probabilities.

To model the relationships between risks and factors, we used a Bayesian network-based technique, which considers possible scenarios and the probability of risks under various conditions.

2. Literature review

There are a number of approaches to determining innovation risk, varying from the probability of loss caused by an incorrect strategy to a probabilistic assessment of whether an innovative project can be accomplished successfully.

Researchers such as Valdaytsev (2001), Tapman (2002) and Glukhov, Korobko and Marinina (2003) emphasize the need to cover all stages of the project lifecycle for effective risk assessment, as uncertainty and risks can arise at any stage of the project. Akulov (2012) argues that the individuality of each project requires that uncertainty and risk factors be considered at all stages.

The world literature highlights the difficulty of developing a detailed classification of the risks of innovative projects since this task is subjective. Risk assessment is one of the targets of risk management

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in innovative projects. Various methods can be used for making such an assessment, including statistical, expert and analytical approaches as well as the analogy method.

The statistical method involves analysing the statistics of the losses incurred in the project and determining the frequency of the occurrence of various levels of losses. However, this approach has its constraints, as, in many cases, statistics are unavailable due to the novelty of projects. Expert methods based on the consideration of specialists' opinions can be used, but this requires checking the competence of the experts and the consistency of their assessments (Ashinova, Chinazova, Kadakoeva and Gisheva, 2020).

Among the analytical methods, sensitivity analysis is worth highlighting. It is aimed at determining the impact of changes in individual variables on the efficiency of the project. However, this method has its own limitations, such as the ability to change only one factor in isolation from the rest.

Risk assessment can be carried out for innovation and investment projects in various ways, which are selected depending on the time frame, information available, software and the current stage of the project. For example, Delphi and expert assessment methods best suit projects at the research development stage (Babordina, Garanina, Garanin and Chirkunova, 2021; Jin, Liu, Long, 2021). Modelling, scenario and decision tree methods can be used, for example, for projects aimed at having a competitive advantage on the market (Lytvynenko and Naumov, 2021; Pupentsova and Livintsova, 2018). By classifying and distributing risks into groups, it is possible to identify possible risk scenarios and develop risk management strategies.

Choosing the risk analysis method depends on the objectives and aims of the enterprise. Various factors, such as the importance of the project, the information available, the expertise of the participants, the depth of the analysis and access to necessary tools, have a bearing on which approach to choose for the analysis. There is no universal method, and it cannot be argued that qualitative or quantitative methods are preferable to others. It is often advisable to combine different methods and apply an integrated approach so that the best results can be achieved in risk analysis (Vyatkin, Gamza and Maevsky, 2018).

At the moment, there are disadvantages in the attempts to create effective models describing the risk of innovative projects since expert methods for assessing these risks are far from being perfect. Another issue is that there is no single universal method, while a variety of methods can often be applied only at the initial stage to choose the project. At the same time, when some parameters are being determined, such as manageability and attainability, the initial data are mostly approximate and can be obtained either by estimating plans without taking into account the dynamics of the transition process or by using an expert opinion.

Analytical assessment methods allow you to estimate the value of the unknown parameters using the available data and system characteristics based on theorems, models and algorithms. The common problem in this case is caused by the fact that the task must clearly coincide with the model (a certain set of known functions and parameters). Only then do the methods become applicable and give you an accurate answer. Given that in the case of innovative projects, you work in a situation of uncertainty, such methods are mostly unsuitable for assessments. If the task is about examining random variables, a probabilistic approach should be used because now deterministic models are not applicable (since they cannot be built for this kind of task).

The probabilistic approach is characterized by distributions of random variables, their averages, values of variance and standard deviation, which can be found using statistical methods. However, in most cases, these methods are elaborated only for one-dimensional quantities. If you want to consider the relationship between several factors, you need to build a multidimensional statistical model, which may require either too much time or computational resources. Moreover, such models frequently assume a Gaussian distribution or are not justified by theory. Anyway, with the probabilistic approach, some probabilistic model of the task must be known initially. Quite often, multidimensional statistics, lacking a theoretical basis, entail the use of poorly substantiated heuristic methods.

This problem can be resolved by applying complex expert analytical assessment methods using mathematical methods of fuzzy sets and Bayesian networks.

3. Materials and methods

Assessing risks of innovative projects is a difficult task due to the lack of statistical information about a new idea, technology or product that is being developed. Drawing analogies with similar projects is also complicated. Therefore, the risks of innovative projects can be determined using a combination of expert and quantitative methods, since participants in the innovation process are forced to rely on their subjective assessments and feelings rather than on solid data and calculations based on past experience (Samokhvalov, 2021).

An important step in assessing the risk of an innovative project is to conduct a qualitative risk analysis. The purpose of this analysis is to identify the main risk factors of a particular project and assess their probability and potential damage. According to Gracheva and Sekerin, a qualitative risk analysis is most commonly presented as a table that includes the name of the risk, risk factors, effects, possible damage, prevention measures and their estimated cost (Gracheva, 2009). However, when assessing the risk of a project, calculating prevention measures is important but not mandatory for risk assessment. In this regard, only the first three columns must be filled in to assess the risk.

An expert performing a modified qualitative analysis of an innovative project must first identify the main types of risks specific to the project. This procedure requires a thorough analysis of all information materials, including the business plan, financial model and marketing research. Only after experts have fully understood the essence of the project will they be able to identify all the risk factors specific to this innovation (Boris, Parakhina, 2020).

Determining the risks specifically for an innovative project, as opposed to applying a general risk classification, is usually a more appropriate approach. Innovative projects often have unique features that can entail specific risks that differ from general risk categories. These unique features may include new technologies, unexplored markets and new market positions. In this regard, there is a need for a thorough analysis aimed at identifying all the main risks associated with a particular innovative project. The comprehensive risk of an innovative project is an integral assessment of the riskiness of the project and depends on the totality of all the risks that may arise in the process of its implementation.

To speed up the analysis process, the expert can, if necessary, use a generally accepted risk classification. The following risk categories can be considered:

1. Political risk is the risk of the restriction or termination of the project activities due to the actions of the authorities caused by a change in the political situation in the country. This may include factors such as changes in legislation, tax policy and other regulatory measures, which may lead to higher project costs and reduced project effectiveness. Political risk may also cause obstacles to the project, such as delays in obtaining construction permits or other restrictions imposed by the authorities.

2. Environmental risk is associated with the impact of the project on the environment and human health. It may be caused if environmental requirements are ignored, there are violations of ethics or there is insufficient control over the use and disposal of waste.

3. Market risk is caused by changes in consumer demand and the competitive environment, the entry of new players into the market, changes in government regulations or possible fluctuations in interest rates of national and foreign currencies (Mamiy, 2018). They may arise if the project does not comply with market requirements or if the competitive environment has not been analysed correctly.

4. Social risk is associated with the negative impact of a project on the social sphere, including changes in the living conditions of the population, deterioration of health and relationship problems in society. As a result, the project may have the effect of change rejection (Dalevska, Khobta, Kwilinski, Kravchenko, 2019).

5. Investment and financial risk is the risk of possible depreciation, as well as loss of the investment portfolio of securities (owned and attracted ones) (Kireeva and Pupentsova, 2012).

6. Institutional and legal risk is caused by changes in legislation, non-compliance with rules and regulations, violations of intellectual property and patent rights, and risks of legal litigation.

7. Production risk is caused by the possibility of failures in the production process arising from unsuccessful production planning or other factors, which can lead to a complete shutdown of the production, a higher level of defects, greater current costs of the enterprise and other negative consequences (Boev, 2020).

8. Financial risk arises from financial transactions (servicing debt or other loans), including those related to investing in projects or financial instruments, as a result of which the financial stability of the enterprise or its profitability is declining (Samis and Steen, 2020). It may be caused by varying exchange rates, reduced financing or higher costs.

9. Project management risk is the possibility of errors at various stages of the project (varying from the pre-investment stage to dissolution). This is caused by an insufficiently high level of management in the enterprise or the low qualifications of management personnel. These errors can result in the failed production or marketing of products, problems with the purchase, installation and start-up of equipment, and other similar problems (Pchelintseva, Gordashnikova, Goryacheva and Vasina, 2020).

For further risk analysis, experts need to assess the probability of each risk factor. They can assess the probability of each risk factor based on their professional experience, statistics collected and expert assessments. They can use statistical analysis and modelling techniques, conduct interviews with stakeholders and analyse research studies in the field related to the project.

Bayesian networks are a graphical model in which nodes represent random variables, while edges between nodes indicate probabilistic relationships between these variables. Each node in the network corresponds to a specific random variable, which can take different values, depending on the conditions of the model. The major principle of Bayesian networks is the use of Bayes' theorem to update probabilistic information about the variables in the network based on new data. By combining the probability distributions and conditional probabilities of the nodes and edges of the network, it is possible to draw conclusions about the probabilities of the possible states of the variables.

The structure of the Bayesian trust network is a directed acyclic graph with n nodes, where the nodes correspond to random $X_1, X_2, \ldots, X_n$ elements. Each of these random elements is described by a probability distribution function, and each node of the network stores a tensor of conditional probabilities. For example, these random elements can symbolize different types of risks that can affect the system. These risks are often interrelated; for example, the human factor can influence the probability of certain risks. To analyse and assess the overall risk of the system, it is critically important to consider all risks and their interrelationships (Musina, 2013).

"One of the key aspects of Bayesian confidence networks as probabilistic graphical models is the application of the decomposition rule based on the d-separability property. Formally, this rule can be described as follows:

$$f_0\left(x_1, x_2, \ldots, x_n\right) = \prod_{i=1}^{n} f_i\left(x_i | pa\left(X_i\right)\right), \tag{1}$$

where $f_0\left(x_1, x_2, \ldots, x_n\right)$ is the joint probability distribution of all random elements, $f_i\left(x_i | pa\left(X_i\right)\right)$ is the probability distribution of the random element X_i subject to the designation of random elements—the parents of the node corresponding to the random element X_i" (Musina, 2013).

Thus, to assess the risks of an innovative project, a Bayesian network must be built using the following rules:

1. Identify key variables that can influence the success of an innovative project and represent the potential inherent risks of the project. The project's own risks can be formulated using generally recognized classifications or by the expert.

2. For each of your own risks, identify a variety of factors that may affect this type of risk. It is possible that some of the risk factors can affect several of the project's own risks. In the Bayesian network, such risk factors must be specified only in the singular.

3. Place the "Comprehensive Risk of the Innovative Project" at the centre of the network. All of the project's own risks must be located right around it.

4. Describe the cause-and-effect relationship in the form of arcs oriented between the network nodes. If a risk factor affects several of the project's own risks, an arc must be drawn from it to each of the risks that it affects. At the centre is the integrated risk of the project, which arcs can only enter. Figure 1 shows an example of such a graphical structure.

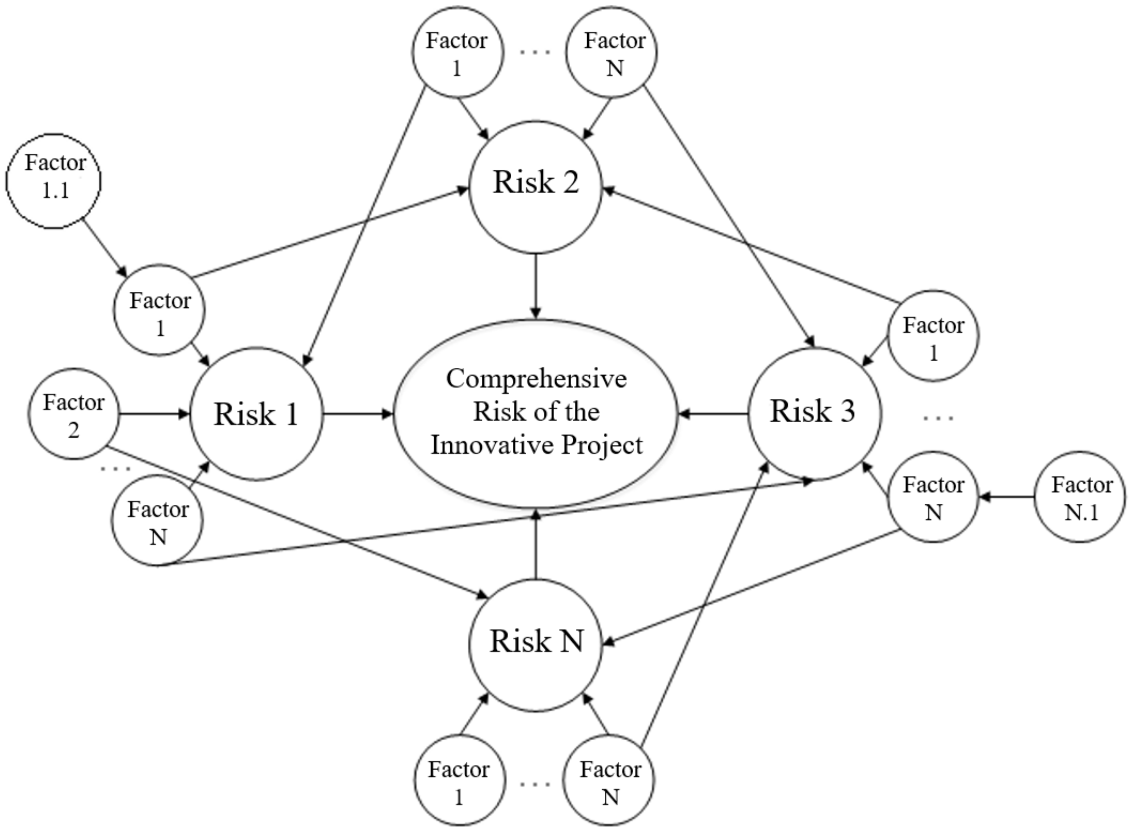

Figure 1. An example of the Bayesian network of an innovative project

To estimate the comprehensive risk of an innovative project, unconditional probabilities must be set for all the nodes of the network that do not have input arcs, and conditional probabilities must be set for all the nodes that have a "parent", that is, a node from which the connection goes to them. To do this, let us turn to the theory of fuzzy sets.

Using the theory of fuzzy sets to formalize the probabilities of risk factors is reasonable because it allows one to describe the uncertainty and blurriness in the data. When assessing risk probabilities, you often encounter situations in which accurate numerical values of probabilities are not sufficiently informative or adequate for an accurate assessment. In this case, the theory of fuzzy sets allows one to consider different levels of uncertainty and express probabilities in the form of linguistic variables, which makes them more flexible and adaptive to real conditions and uncertainty, especially in the case of innovative projects where the data on past and expert assessments may be incomplete or blurred.

The theory of fuzzy sets, developed by Zadeh in 1965, is a mathematical theory for modelling fuzzy and incomplete data, which allows one to consider uncertainty in data and describe fuzzy concepts. This method allows you to develop expert systems and knowledge bases for storing fuzzy information. The main advantage of this approach is that both quantitative and qualitative factors are taken into account in decision-making, and they cannot be calculated as an exact number. The result is an approximate but effective method for describing the behaviour of complex and poorly structured systems. The feature distinguishing this approach is its flexibility in determining the accuracy of the decision, depending on the requirements and information available (Kuchta, Zabor, 2021).

The theory of generalized fuzzy numbers (GFN), first proposed in 1985, is an alternative to the widely used conventional fuzzy numbers in the analysis of economic problems. According to the GFN, experts have the right to change their level of confidence in various statements if they are unsure of their decisions (Kuchta, Zabor, 2021). Thus, the GFN theory expands and generalizes the concept of ordinary fuzzy numbers, and the conclusions obtained with it are applicable to standard fuzzy numbers. Formally speaking, a generalized fuzzy number can be a fuzzy number with any type of membership function. However, the variants of GFN that are most widely studied today are those based on the trapezoidal membership function. This is because this function consists of linear sections, making accurate and simple calculations easier. Moreover, the trapezoidal function describes various types of uncertainty in a good way and can be easily transformed into a triangular function. Given the above, it is trapezoidal fuzzy numbers that we will investigate further (Chen, 1985).

A trapezoidal number is designated as $\grave{A} = \left(a_1, a_2, a_3, a_4\right)$. In case $a_2 = a_3$, you obtain a triangular number (Figure 2). Correspondingly, for triangular numbers, you use the designation $\grave{A} = \left(a_1, a_2, a_4\right)$ (Gavrilenko, 2013).

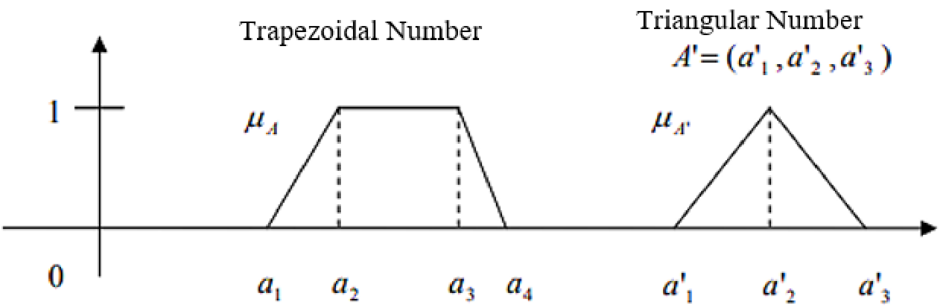

Figure 2. The representation of trapezoidal and triangular fuzzy numbers

To formalize the risk assessment model, you have to define a set of states for each risk factor, the linguistic variable, a set of values and the compliance of all variables included in the model with the numerical characteristics.

We suggest describing the degree of risk—high, low and medium—as possible states of the nodes in the Bayesian network.

For this model, we suggest setting the probability of the risk value for each of the factors as a linguistic variable. The set of terms of the linguistic variable is defined as follows:

Probability = {High, Low, Medium}.

Table 1 shows the reference value of the linguistic variable represented. The choice of coordinates for linguistic terms of risk probability was first proposed in the work of Chen S.J. and Chen S.M. (2008). Many subsequent studies related to the GFN theory also use this type of risk variable setting. This is primarily due to the need to compare the simulation results with the results of previous studies after the development or modification of a new model. The results of these studies can be compared if they use the same formulation of the risk variable.

An alternative way of specifying the coordinates of the linguistic variable can be useful to experts, allowing them to express their individual expert opinions and preferences in a more accurate way when building membership functions. In this case, you can use the method of statistical processing of the opinions of a group of experts and the method of paired comparisons. In the first method, each expert fills out a questionnaire to express his or her opinion about the presence of fuzzy set properties in the elements. The experts provide their estimates or descriptions for various types of variables, which allows you to collectively assess the degree of belonging to each term of the variable. In the second case, the initial information for building membership functions consists of expert paired comparisons. In this method, for each pair of elements of a universal set, the expert evaluates the advantage of one element over another with respect to their fuzzy set properties (Grigorieva, Gareeva and Basyrov, 2018; Skorokhod, 2010).

Table 1. Reference value of the presented linguistic variable

No.	Term name	Coordinates
1	Extremely low	(0.0; 0.0; 0.02; 0.07; 1.0)
2	Very low	(0.04; 0.1; 0.18; 0.23; 1.0)
3	Low	(0.00; 0.1; 0.18; 0.23; 1.0)
4	Quite low	(0.17; 0.22; 0.36; 0.42; 1.0)
5	Medium	(0.32; 0.41; 0.58; 0.65; 1.0)
6	Quite high	(0.58; 0.63; 0.80; 0.86; 1.0)
7	High	(0.72; 0.78; 0.92; 1.00; 1.0)
8	Very high	(0.93; 0.98; 1.0; 1.0; 1.0)
9	Extremely high	(1.0; 1.0; 1.0; 1.0; 1.0)

Linguistic variables are advantageous since they can be standardized and then compared to other models. You can also change their accuracy, which depends on the number of linguistic values included in a set of linguistic variables.

Thus, there are nodes in the Bayesian network with three possible levels: high, low and medium. In Figure 3, which presents a part of the Bayesian network, for node F1, these three states are designated as F11, F12 and F13.

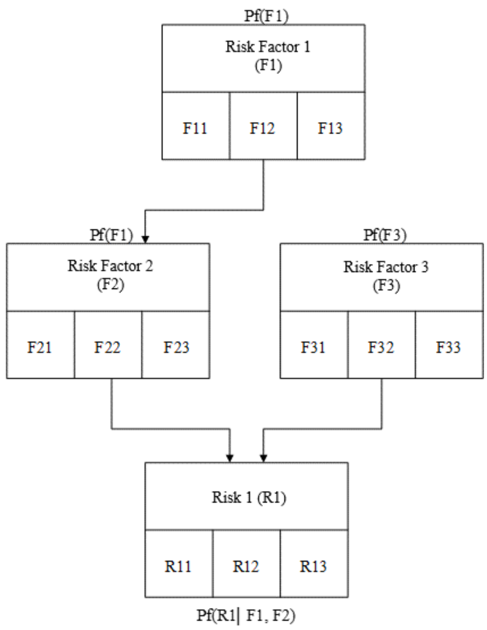

Figure 3. Part of the Bayesian network for assessing the risk of an innovative project

The expert needs to set unconditional probabilities using linguistic terms for all nodes that do not include any arcs, as Table 2 shows.

Table 2. An example of assigning linguistic terms to unconditional probabilities in the Bayesian network

Node name	Probability		
	High	Medium	Low
Risk Factor F1	Low	Medium	Quite high
Risk Factor F3	Medium	Low	Low
…	High	Low	Very low
Risk Factor N	Very low	Low	High

You need to set unconditional probabilities for all nodes that have "parents", nodes that are the cause. In the example shown in Figure x, for Node F2, the conditional probabilities will be set using the answers to the following questions:

1. What is the probability of Factor F2 if the value of Factor F1 is "High" (F11)?

2. What is the probability of Factor F2 if the value of Factor F1 is "Medium" (F12)?

3. What is the probability of Factor F2 if the value of Factor F1 is "Low" (F13)?

The unconditional probabilities for child nodes can be estimated using the formula of the full possibility of events:

$$\tilde{P}_f(Y = y_i) = \sum_i \tilde{P}_f(X = x_i)\tilde{P}(Y = y_i \mid X = x_i), \tag{2}$$

where Y is the child node, y_i – is the status of the child node, X – is the parent node and x_i – is the state of the parent node.

Thus, for Risk Factor F2:

1) $\tilde{P}_f(F2 = F21) \tilde{=} \tilde{\oplus} \tilde{P}_f(f1, F2 = F21) = \tilde{P}_f(F1 = F11), F2 = F21) \tilde{\oplus} \tilde{P}_f(F1 = F12, F2 = F21) \tilde{\oplus} \tilde{P}_f(F1 = F13, F2 = F21) = \tilde{P}_f(F1 = F11) \tilde{\oplus} \tilde{P}_f(F2 = F21 | F1 = F11) \tilde{\oplus} \tilde{P}_f(F1 = F12) \tilde{\oplus} \tilde{P}_f(F2 = F21 | F1 = F12) \tilde{\oplus} \tilde{P}_f(F1 = F13) \tilde{\oplus} \tilde{P}_f(F2 = F21 | F1 = F13)$;

2) $\tilde{P}_f(F2 = F22) \tilde{=} \tilde{\oplus} \tilde{P}_f(F1, F2 = F22) = \tilde{P}_f(F1 = F11, F2 = F22) \tilde{\oplus} \tilde{P}_f(F1 = F12, F2 = F22) \tilde{\oplus} \tilde{P}_f(F1 = F13, F2 = F22) = \tilde{P}_f(F1 = F11) \tilde{\oplus} \tilde{P}_f(F2 = F22 | F1 = F11) \tilde{\oplus} \tilde{P}_f(F1 = F12) \tilde{\oplus} \tilde{P}_f(F2 = F22 | F1 = F12) \tilde{\oplus} \tilde{P}_f(F1 = F13) \tilde{\oplus} \tilde{P}_f(F2 = F22 | F1 = F13)$;

3) $\tilde{P}_f(F2 = F23) \tilde{=} \tilde{\oplus} \tilde{P}_f(F1, F2 = F23) = \tilde{P}_f(F1 = F11, F2 = F23) \tilde{\oplus} \tilde{P}_f(F1 = F12, F2 = F23) \tilde{\oplus} \tilde{P}_f(F1 = F13, F2 = F23) = \tilde{P}_f(F1 = F11) \tilde{\oplus} \tilde{P}_f(F2 = F23 | F1 = F11) \tilde{\oplus} \tilde{P}_f(F1 = F12) \tilde{\oplus} \tilde{P}_f(F2 = F23 | F1 = F12) \tilde{\oplus} \tilde{P}_f(F1 = F13) \tilde{\oplus} \tilde{P}_f(F2 = F23 | F1 = F13)$.

For the node, risk 1 is R1:

1) $\tilde{P}_f(R1 = R11) = \tilde{\oplus} \tilde{P}_f(\tilde{F}2, \tilde{F}3, R1 = R11);$

2) $\tilde{P}_f(R1 = R12) = \tilde{\oplus} \tilde{P}_f(\tilde{F}2, \tilde{F}3, R1 = R12);$

3) $\tilde{P}_f(R1 = R13) = \tilde{\oplus} \tilde{P}_f(\tilde{F}2, \tilde{F}3, R1 = R13);$

Using similar calculations, you need to estimate the probabilities of all the network's own risks. In the same way, the total risk of the project has to be calculated; that is, at the output, you get three states of the total risk of the project and three fuzzy probabilities of these states.

The exact value of the probability of each integrated risk state can be calculated using the formula below:

$$P_f(R) = \frac{\int_{min}^{max} \tilde{P}_f(R) * \varphi(\tilde{P}_f(R)) d\tilde{P}_f(R)}{\int_{min}^{max} \varphi(\tilde{P}_f(R)) d\tilde{P}_f(R)} = \frac{a_3^2 + a_4^2 + a_3 a_4 - a_1^2 - a_2^2 - a_1 a_2}{3(a_4 + a_3 - a_1 - a_2)}, \tag{3}$$

where $\tilde{P}_f(R) = (a_1, a_2, a_3, a_4)$ is the calculated value of the probability of one of the states of the overall risk of the project: "high", "medium" and "Low" (Ashinova, Chinazova, Kadakoeva, Gisheva, 2020).

Thus, there is an algorithm for assessing the risk of an innovative project using fuzzy sets and Bayesian networks. It includes the following stages:

Stage 1. Experts conduct a qualitative risk analysis of the project.

At this stage, experts carry out a qualitative risk analysis of an innovative project, using their experience and knowledge in project management to identify risks.

Stage 2. Identify the set of the project's own risks.

At this stage, many of the innovation project's own risks are identified. The experts highlight the unique features of the project, which may be a source of specific risks that differ from the general categories of risk. It is advisable to identify your own risks, given the unique features of innovative projects.

Stage 3. Identify factors for each individual risk.

The experts identify the factors that can influence the incurrence of each individual risk. This allows you to assess the probability and impact of each risk on the project more accurately, considering the unique features of the project.

Stage 4. Create a Bayesian network.

At this stage, you form a Bayesian network, which is a graphical model reflecting the relationship between the risks and the factors in the project, according to the rules described above.

Stage 5. Define linguistic terms.

At this stage, the expert defines the linguistic terms that will be used to describe the probabilities and magnitude of risks.

Stage 6. Set fuzzy probabilities.

At this stage, each linguistic term is assigned a fuzzy number based on previously set reference values or alternative methods.

Stage 7. Assess the unconditional probabilities of "parent" nodes.

This stage includes the assessment of the probability of risks that do not depend on other factors. The expert analyses the main risks and assesses their probabilities, regardless of other factors.

Stage 8. Assess the conditional probabilities of child nodes.

You assess conditional probabilities for child nodes, reflecting the dependencies between the risks and project factors.

Stage 9. Calculate the Bayesian network.

Calculations are carried out based on the specified probabilities and the Bayesian network to assess the probability of risks.

Stage 10. Transit from fuzzy sets to the exact value.

This stage involves the transition from fuzzy probabilities to exact values of the probabilities of a particular risk value, using the formula above.

Figure 4 shows the algorithm for assessing the risk of an innovative project using fuzzy sets and Bayesian networks.

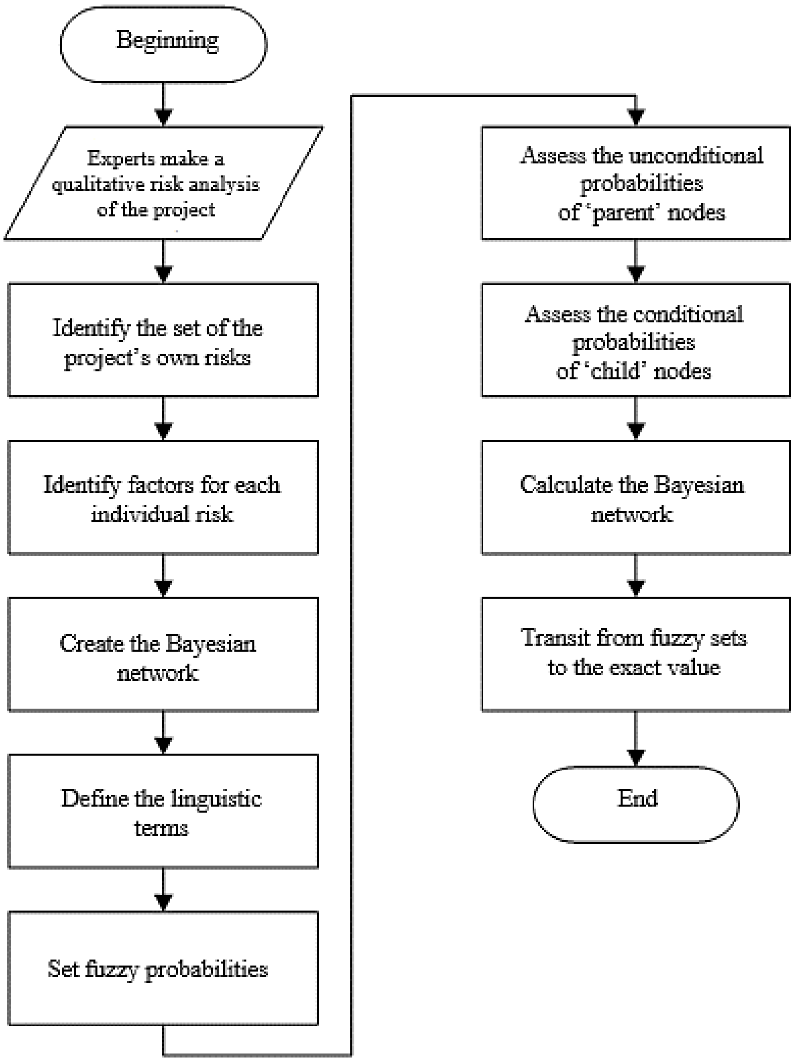

Figure 4. Algorithm for assessing the risk of an innovative project using fuzzy sets and Bayesian networks

4. Results

An example of algorithm implementation.

Step 1. Imagine that the expert faces the task of assessing the risk of a specific innovation project. The expert is familiar with all the necessary information about the project and has a sufficient level of knowledge to determine the types of risks specific to this innovative project.

Stage 2. The expert identifies four risks for the innovative project: project participant risk, sales risk, marketing risk and financial risk.

Stages 3 and 4. The expert determines a set of factors for each of the project's own risks and builds a Bayesian network based on the interrelationships between the factors and risks, as Figure 5 shows.

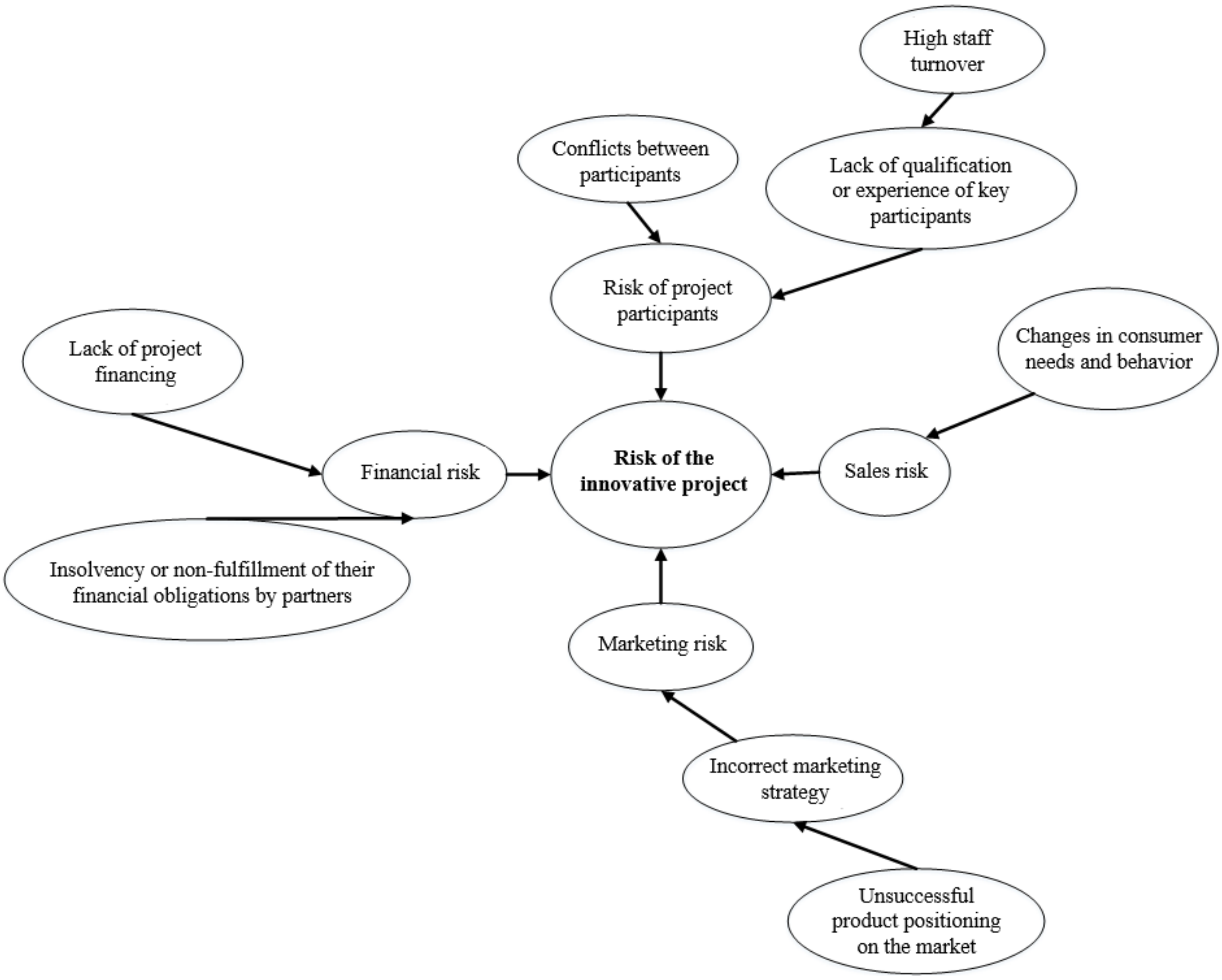

Figure 5. Bayesian network of the innovation project

Stages 5, 6. The risk value described by three states was chosen as the states for the nodes of the Bayesian network: high, low and medium.

For this model, it is proposed that the probability of realizing the risk value for each of the factors be set as a linguistic variable. The set of terms of a linguistic variable is assigned as follows: Probability = {High, Low, Medium}.

In addition, each linguistic term is assigned a fuzzy number of reference values, as proposed above by Chen S.J. and Chen S.M. (Babordina, Garanina, Garanin, Chirkunova, 2021). Table 3 shows the values.

Table 3. Reference values of the presented linguistic variable

№	Term name	Coordinates
1	Extremely low	(0.0; 0.0; 0.02; 0.07; 1.0)
2	Very low	(0.04; 0.1; 0.18; 0.23; 1.0)
3	Low	(0.00; 0.1; 0.18; 0.23; 1.0)
4	Quite low	(0.17; 0.22; 0.36; 0.42; 1.0)
5	Medium	(0.32; 0.41; 0.58; 0.65; 1.0)
6	Quite high	(0.58; 0.63; 0.80; 0.86; 1.0)
7	High	(0.72; 0.78; 0.92; 1.00; 1.0)
8	Very high	(0.93; 0.98; 1.0; 1.0; 1.0)
9	Extremely high	(1.0; 1.0; 1.0; 1.0; 1.0)

Step 7. You need to set unconditional probabilities using linguistic terms for all nodes that do not have arcs. For this example, the unconditional probabilities are presented in Table 4.

Table 4. Table of unconditional probabilities of the parent nodes of the Bayesian network

Node name	Probability		
	High	Medium	Low
High staff turnover	High	Medium	Low
Conflicts between participants	Medium	Quite low	Quite high
Lack of project financing	Quite high	Low	Very low
Insolvency or non-fulfilment of their financial obligations by partners	Medium	Low	Very low
Unsuccessful product positioning on the market	High	Very high	Very low
Changes in consumer needs and behaviour	Quite low	Low	Very high

Step 8. At this stage, you need to set unconditional probabilities for all child nodes. Table 5 shows an example for the node “Lack of qualification or experience of key participants”, with the parent node “High staff turnover”.

Table 5. Table of conditional probabilities of the child node “Lack of qualification or experience of key participants” of the Bayesian network

High (F11)		High staff turnover (F1)		
		Medium (F12)	Low (F13)	
Lack of qualification or experience of key participants (F2)	High (F22)	High	High	Low
	Medium (F22)	High	High	Medium
	Low (F23)	Low	Low	Medium

Step 9. Below is an example of the estimation of unconditional probabilities for the node “lack of qualifications or experience of key participants” based on the specified conditional probabilities:

1) $\tilde{P}_f(F2=F21)=\tilde{\oplus}\tilde{P}_f(F1,F2=F21)=\tilde{P}_f(F1=F11,F2=F21)\tilde{\oplus}\tilde{P}_f(F1=F12,F2=$

$$F21)\tilde{\oplus}\tilde{P}_f(F1=F13,F2=F21)=\tilde{P}_f(F1=F11)\tilde{\oplus}\tilde{P}_f(F2=F21\,|\,F1=F11)\tilde{\oplus}\tilde{P}_f(F1=$$

$$F12)\tilde{\oplus}\tilde{P}_f(F2=F21\,|\,F1=F12)\tilde{\oplus}\tilde{P}_f(F1=F13)\tilde{\oplus}\tilde{P}_f(F2=F21\,|\,F1=F13);$$

$$\tilde{P}_f(F2=F21)=(0,00;0,1;0,18;0,23)\tilde{\oplus}(0,00;0,1;0,18;0,23)\tilde{\oplus}(0,32;0,41;0,58;0,65)\tilde{\oplus}$$

$$\tilde{\oplus}(0,72;0,78;0,92;1,00)\tilde{\oplus}(0,72;0,78;0,92;1,00)\tilde{\oplus}(0,72;0,78;0,92;1,00)=$$

$$=(0,7488;0,9382;1,00;1,00);$$

2) $\tilde{P}_f(F2=F22)=\tilde{\oplus}\tilde{P}_f(F1,F2=F22)=\tilde{P}_f(F1=F11,F2=F22)\tilde{\oplus}\tilde{P}_f(F1=F12,F2=$

$$F22)\tilde{\oplus}(F1=F13,F2=F22)=\tilde{P}_f(F1=F11)\tilde{\oplus}\tilde{P}_f(F2=F22\,|\,F1=F11)\tilde{\oplus}\tilde{P}_f(F1=$$

$$F12)\tilde{\oplus}\tilde{P}_f(F2=F22\,|\,F1=F12)\tilde{\oplus}\tilde{P}_f(F1=F13)\tilde{\oplus}\tilde{P}_f(F2=F22\,|\,F1=F13);$$

$$\tilde{P}_f(F2=F22)=(0,00;0,1;0,18;0,23)\tilde{\oplus}(0,32;0,41;0,58;0,65)\tilde{\oplus}(0,32;0,41;0,58;0,65)\tilde{\oplus}$$

$$\tilde{\oplus}(0,72;0,78;0,92;1,00)\tilde{\oplus}(0,72;0,78;0,92;1,00)\tilde{\oplus}(0,72;0,78;0,92;1,00)=$$

$$=(0,00;0,41;0,1044;0,1495)\tilde{\oplus}(0,23;0,32;0,53;0,65)\tilde{\oplus}(0,52;0,61;0,85;1,00)=$$

$$=(0,7488;0,962;1,00;1,00);$$

3) $\tilde{P}_f(F2=F23)=\tilde{\oplus}\tilde{P}_f(F1,F2=F23)=\tilde{P}_f(F1=F11,F2=F23)\tilde{\oplus}\tilde{P}_f(F1=F12,F2=$

$$F23)\tilde{\oplus}\tilde{P}_f(F1=F13,F2=F23)=\tilde{P}_f(F1=F11)\tilde{\oplus}\tilde{P}_f(F2=F23\,|\,F1=F11)\tilde{\oplus}\tilde{P}_f(F1=$$

$$F12)\tilde{\oplus}\tilde{P}_f(F2=F23\,|\,F1=F12)\tilde{\oplus}\tilde{P}_f(F1=F13)\tilde{\oplus}\tilde{P}_f(F2=F23\,|\,F1=F13);$$

$$\tilde{\oplus}(F2=F23)=(0,00;0,1;0,18;0,23)\tilde{\oplus}(0,32;0,41;0,58;0,65)\tilde{\oplus}(0,32;0,41;0,58;0,65)\tilde{\oplus}$$

$$\tilde{\oplus}(0,00;0,1;0,18;0,23)\tilde{\oplus}(0,72;0,78;0,92;1,00)\tilde{\oplus}(0,00;0,1;0,18;0,23)=$$

$$=(0,00;0,041;0,1044;0,1495)\tilde{\oplus}(0,00;0,41;0,1044;0,1495)\tilde{\oplus}$$

$$\tilde{\oplus}(0,00;0,078;0,1656;0,23)=(0,00;0,16;0,3744;0,529).$$

In the same way, you need to calculate the entire Bayesian network. In this case, the values presented in Table 6 were calculated for the comprehensive risk of the innovative project.

Table 6. Fuzzy values of the probabilities of comprehensive risk

No.	Name of comprehensive risk value	Fuzzy value
1	Low	(0.00; 0.0019; 0.45; 0.6589)
2	Medium	(0.00; 0.0172; 0.3826; 0.5684)
3	High	(0.0088; 0.0977; 0.9954; 1)

Stage 10. Transit from fuzzy values to exact ones. This can be done using the following formula:

$$P_f\left(R\right)=\frac{\int_{min}^{max}\tilde{P}_f\left(R\right)*\varphi\left(\tilde{P}_f\left(R\right)\right)d\tilde{P}_f\left(R\right)}{\int_{min}^{max}\varphi\left(\tilde{P}_f\left(R\right)\right)d\tilde{P}_f\left(R\right)}=\frac{a_3^2+a_4^2+a_3a_4-a_1^2-a_2^2-a_1a_2}{3\left(a_4+a_3-a_1-a_2\right)}. \quad (4)$$

The probability that the risk value of the project is high:

$$P_f(B)=\frac{0,9954^2+1+0,9954*1-0,0088^2-0,0977^2-0,0088*0,0977}{3\left(1+0,9954-0,0088-0,0977\right)}=0,525. \quad (5)$$

In the same way, you need to make calculations for medium- and low-risk cases:

$$P_f(C)=0,245 \quad (6)$$

$$P_f(H)=0,28 \quad (7)$$

Thus, it can be concluded that with a probability of 52.5 percent, the comprehensive risk of the innovative project is high; with a probability of 24.5 percent, the risk is medium, and with a probability of 28 percent, it is low.

Based on this risk assessment, combined with other assessments, such as the feasibility of the project and its financial attractiveness, it is recommended to conduct further analysis and make an informed decision regarding the launch of the innovative project. Given that the probability of high risk is 52.5%, it is recommended to carefully study the risk management strategies in the project, develop an action plan to reduce the identified risks and assess their impact on the project.

5. Discussion

This paper presents a model for assessing the risk of an innovative project using fuzzy sets and Bayesian networks.

Methods such as Monte Carlo analysis, decision tree analysis or PERT network analysis usually operate with precise values and probabilities, which can result in simplified risk modelling based on fixed assumptions. For example, in the PERT analysis, three assessment points are used for each activity, which can lead to subjective estimates and averaged results. The model with fuzzy sets allows one to consider fuzziness and uncertainty in risk assessment, which is a more realistic approach to estimating probabilities (Ashinova, Chinazova, Kadakoeva and Gisheva, 2020).

Another significant advantage of the proposed methods is that one can operate directly with an integrated risk indicator, avoiding complex calculations for individual risk factors and analysing their interaction, which seems better for a decision maker. This allows you to make more informed and balanced decisions (Lashmanova, Maltsev and Klimchuk, 2014). Compared with other methods, such as decision tree analysis or statistical modelling, this approach has an integrated risk indicator in the assessment model of innovative projects with fuzzy sets and Bayesian networks, which reduces the need for complex calculations and simplifies the decision-making process. Instead of having to consider many individual factors and their interrelationships, with this method, you can focus on an aggregated risk assessment as a whole, which makes decision-making more practical and efficient.

Thus, our risk assessment model based on fuzzy sets and Bayesian networks has tangible advantages over traditional methods, allowing for a deeper and more realistic consideration of uncertainty, variability and interactions in the risk management process of innovative projects.

However, it should be noted that to apply this model, you need sufficient amounts of data and expertise to identify risks and their factors correctly. Moreover, developing and updating the Bayesian network can be time- and resource-consuming.

Thus, further research and development of the risk assessment model for innovative projects using fuzzy sets and Bayesian networks opens up wide opportunities for better risk management, higher quality of decision-making and success of the project. Continuous improvement of the model, its testing in practice and adaptation to changing conditions will make it a tool that can help you to effectively cope with challenges in today's business world and ensure the sustainable development of your organization.

6. Conclusion

This paper researches a model for assessing the risk of an innovative project using fuzzy sets and Bayesian networks. The results of the study show that this model is a powerful tool for a more accurate and reliable assessment of project risks. Fuzzy sets allow for uncertainty and semantic ambiguity, and Bayesian networks help you model the relationship between risks and factors.

Effective risk management is one of the key aspects of the success of innovative projects. With proper risk assessment, you can anticipate negative consequences and make informed management decisions. The model, based on fuzzy sets and Bayesian networks, considers different levels of probability and complex relationships between risks, which contributes to a deeper analysis and risk management of the project.

Further research and experiments are necessary for the development of this model and its application in practice. The model must be tested in more detail on various innovative projects to evaluate its effectiveness and identify its possible constraints.

An important area of research is the adaptation of the risk assessment model of innovative projects based on fuzzy sets and Bayesian networks to modern technologies, such as machine learning and artificial intelligence. This approach will automate the process of risk assessment and management, which will make the model more efficient and reduce the human factor in decision-making.

By and large, the risk assessment model of an innovative project based on fuzzy sets and Bayesian networks is a promising area of research in the field of risk management. Its application can help you improve the decision-making process and increase the effectiveness of risk management and the success of innovative projects.

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About the author:

Ludmila Smirnova, Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia. https://orcid.org/0009-0005-1599-150X, dracon260700@gmail.com

Информация об авторе:

Людмила Смирнова, Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия. https://orcid.org/0009-0005-1599-150X, dracon260700@gmail.com