Construction of a Mathematical Model for Analyzing the Effectiveness of IT Startups

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Abstract

This article is devoted to the development of a mathematical model for assessing the investment risks of startup projects in the IT industry based on fuzzy set theory. The article examines and analyzes information sources that show that the issue of evaluating the effectiveness of startups is not sufficiently developed. In addition, the future of startups is associated with many parameters that are very conditional and predictable at the initial stages of project consideration. Therefore, it is advisable to use fuzzy modeling methods to accept the project for consideration. By using the fuzzy set method, it is possible to use fuzzy variables that reflect the uncertainty of some parameters of such projects. The proposed research methodology is based on the analysis of the commercial effectiveness of projects and the use of fuzzy set methods. The main financial parameters of the project were taken into account, such as: net present value, internal rate of return. When conducting research, fuzzy parameters were used to evaluate project indicators. For this purpose, membership functions are constructed that establish the degree of belonging of a fuzzy set. The trapezoid model and the specified parameters corresponding to the pessimistic, baseline, and optimistic scenarios are selected as the function type. The novelty of the paper is the determination of the risk indicator of a startup project, which depends on the criterion of project effectiveness. The paper proves the dependence of the project risk indicator on the value of the project effectiveness criterion. The proposed approach has shown its feasibility and can be used to analyze startup projects by scientists, entrepreneurs, and investors.

Keywords

IT projects, startups, model, project efficiency, valuation, fuzzy sets, project risks

1. Introduction

Countries that have managed to establish a continuous process of generating new knowledge and innovative ideas and transforming them into innovative products are now the most efficient and have a leading role in the global economy. The experience of the USA, which brings 85% of innovative products to the market, Japan - 75%, Germany - 55%, Israel - more than 50% is indicative. Unfortunately, the share and innovations in the total volume of manufactured products in Ukraine do not exceed 2%.

Small companies such as startups create favourable conditions for innovation. Start-up is an innovative project for developing new products or services, formed to find a repeatable and scalable business model in conditions of extreme uncertainty. Based on an analysis of the number of startups in 137 countries, Startup Ranking has developed a ranking in which Ukraine took 42nd in 2018 (215 startups). First place went to the USA - 45 004 startups, second place in India - 5203 startups and third place in the UK with 4702 startups [1].

Trends [2] shows that 90% of new start-ups fail (the 20 top reasons for start-up failure shown in the table 1).

2. Analysis of recent research and publications

Many scientists have been involved in the study of innovative development of enterprises: Stephen Blank [4], Brad Feld, Jason Mendelsohn [5]. Among Ukrainian scientists in project management, researches related to the use of a value approach for innovative projects was conducted by such scientists as Vilenskyi P. L. [6], Bushuev S. D., Yaroshenko F. A. [7], Tsypes G. L. [8] et.al. At the same time, the effectiveness of projects was studied in publications of Ukrainian and foreign scientists, such as Kolesnikova K.V. [9], Kononenko I.V. [10], Morozov V. V. [11], Yehorchenkova N. [12], Timinskyi A. G. [13] and foreign scientists – Nonaka I., Takeuchi H. [14], Turner R. [15], Milosevich D. [16], Tom DeMarco [17] et al.

Problems of constructing mathematical models in project management when solving problems of synthesis of management methodologies based on fuzzy input data were considered in the works of Kononenko I.V. [18], Shmatko O. [19], Hrabyna K., Shendryk V. [20]. However, the analysis of risks in such conditions was carried out in works Leonenkov A. [21] and Zhang L., Xu X., Tao L. [22].

Analysis of information sources has shown that currently, the issue of assessing the effectiveness of startups is not sufficiently developed, it is not always possible to use classical analytical methods, especially for problems with uncertainty.

Also, the problems of implementing innovative cooperation in terms of maximizing the profit of all interested parties to increase their value interest are still insufficiently studied and require new developments and improvements.

The purpose of the research. The purpose of the article is to develop a methodology for assessing the investment risks of IT projects in the form of a startup based on fuzzy set theory.

Table 1
Analysis reasons for start-up failure [built on 3]

Reasons for start-up failure	%
No market need	42
Ran out of cash	29
Not the right team	23
Get out competed	19
Pricing/cost issues	18
Poor product	17
Need/lack business model	17
Poor marketing	14
Ignore customers	14
Product mis-timed	13
Lose focus	13
Disharmony on team/investors	13
Pivot gone bad	10
Lack passion	9
Bad location	9
No financing/investor interest Legal challenges	8
Don't use network/advisors	8
Burn out	8
Failure to pivot	7

3. Presentation of the main material

As defined above, scientific research on the development of economic and mathematical models for analyzing the effectiveness of startups requires some improvement. Therefore, it is advisable to use fuzzy modeling. Using the fuzzy set method, fuzzy variables are constructed that reflect uncertainty [6, 23, 24]. The main idea of using this apparatus is that any economic indicator is interpreted as an interval indicator, defined not by a specific number, but by a certain interval, in the form of a fuzzy set. This corresponds to a situation where only the limits of the values of the indicator in which it can change are sufficiently accurately known, but there is no quantitative or qualitative information about the possibilities or probabilities of implementing its various values within a given interval.

Models based on fuzzy logic are characterized by the ability to adapt to changing market conditions [25, 26].

Let's look at the implementation of the mathematical model using a specific example. Let the initial investment for a particular IT-startup be about UAH 7-10 million. The project research will be carried out on the basis of present value and internal profitability [27-32]. Let's define the value of a startup project as $\boldsymbol{P}$ – the difference between monetary income and initial costs:

$$P = -I_0 + \sum_{k=1}^{n} \frac{V_k}{(1+r)^k} \tag{1}$$

where $\boldsymbol{I_0}$– the volume of initial investments for creating a startup; V_k – receipts and payments (profit) in the $\boldsymbol{k}$-th period; $\boldsymbol{n}$– number of periods; $\boldsymbol{r}$ – discount rate in the $\boldsymbol{k}$-th period.

We set project metrics as fuzzy parameters. To do this, we construct belonging functions for them, which set the degree of belonging to a fuzzy set. Based on expression (1), we define variables that we represent in fuzzy form. These are the initial investment $\boldsymbol{I_0}$, profit $\boldsymbol{V}$**,** and discount rate $\boldsymbol{r}$.

Let's choose the limits of changes in the studied indicators. We set the membership functions for them in the form of trapezoidal functions. Let's create **α**-level sets. Constructing **α**-level sets, we obtain an approximate decomposition of the fuzzy set (Figure 1).

Using operations on the **α**- levels, we find $\boldsymbol{P}$ and obtain an approximate decomposition of the fuzzy set over $\boldsymbol{P_\alpha}$ the **α**-levels. In fact, we will build a membership function for $\boldsymbol{P_\alpha}$, which we will investigate.

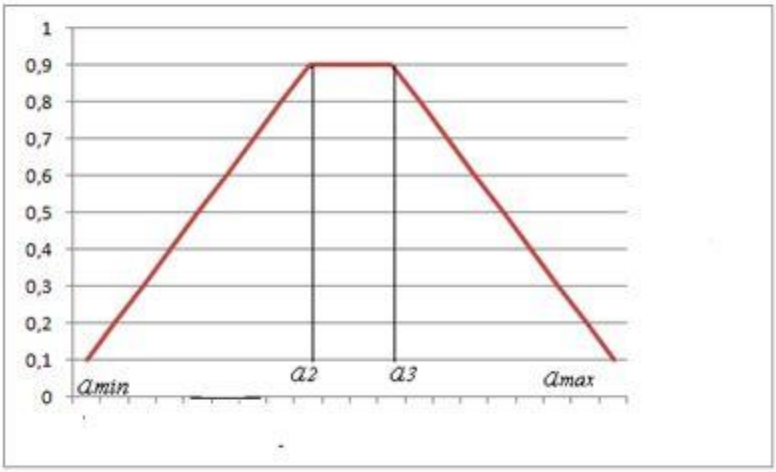

Figure 1. Graph of trapezoidal membership functions

A trapezoidal fuzzy number is written as $A=(a_{min},a_2,a_3,a_{max})$. The Elements of set **A** are uniquely in the range $[a_{min},a_{max}]$, and the range $[a_2,a_3]$ – is the tolerance interval (stability interval), i.e. the elements of set a are approximately equal to any number from this segment. Arguments a_{min},a_2,a_3,a_{max} are called significant points of a fuzzy number $\boldsymbol{A}$. When describing a mathematical model using trapezoidal fuzzy numbers, significant points can be interpreted as pessimistic, most likely on the segment, and optimistic scenarios for the development of the situation.

It is assumed that the initial investment is UAH 7-10 million, we assume $\boldsymbol{I_0}$ the set with numerical parameters I_0= (7; 8; 9; 10).

We assume the profit set using numerical parameters V = (4; 4.5; 5.5; 6). For discount rates r<21,5% the implementation of a startup project is profitable since its profitable value is $\boldsymbol{P}$>0 For the discount rate r = 21,5%, the income from the implementation of a startup project is equal to investment costs. This is the maximum possible discount rate at which you can invest funds without losses. Choose a discount rate r ranging from 12% to 21% with a probability value of 17%. We assume the set using numeric parameters r = (0.12; 0.14; 0.18; 0.21). The trapezoidal membership function can generally be given analytically by the following expression (2).

Similarly, the membership functions are constructed for I_0, R. Next, we construct an approximate decomposition of fuzzy sets I_0, V, r by **α**-levels. We calculate the limits of sets I_0, V, r for a given value **α** – confidence intervals. Choose 10 levels **α** on the segment [0,1]: $\alpha \in \{0;0{,}1;\ 0{,}2;\ 0{,}3;\ 0{,}4;\ 0{,}5;\ 0{,}6;\ 0{,}7;\ 0{,}8;\ 0{,}9;\ 1\}$.

$$f_T(x;a_{\min};a_2;a_3;a_{\max}) = \begin{cases} 0, & x < a_{\min} \\ \dfrac{x-a_{\min}}{a_2-a_{\min}}, & a_{\min} \le x \le a_2 \\ 1 & a_2 \ge x \ge a_3 \\ \dfrac{a_{\max}-x}{a_{\max}-a_3}, & a_3 \le x \le a_{\max} \\ 0, & a_{\max} \le x \end{cases}, \tag{2}$$

where $a_{\min};a_2;a_3;a_{\max}$ – are some numerical parameters that take arbitrary real values and ordered relationships.

To calculate confidence intervals for a given value of α_i i, equations of the following form are solved:

$$I(x)_i = \alpha_i, V(x)_i = \alpha_i\ r(x)_i = \alpha_i$$

Confidence intervals are represented as matrices with elements $I\alpha_{ij}$, $V_{\alpha ij}$, $R_{\alpha ij}$, *(i=1,…,10; j=1,2).*

Using the confidence interval matrices $I\alpha$, $V\alpha$, $r\alpha$ we find the function $P\alpha(I\alpha, V\alpha, r\alpha)$ by the formula (3):

$$P\alpha(I\alpha,V\alpha,r\alpha) = -I\alpha + \sum_{k=1}^{n} \frac{V\alpha}{(1+r\alpha)^k} \tag{3}$$

Table 2

Matrices $I\alpha$, $V\alpha$, $r\alpha$

	IL	IR	VL	VR	rL	rR
1	4	10	4	6	0,12	0,21
2	4,15	9,85	4,1	5,9	0,125	0,206
3	7,3	9,7	4,2	5,8	0,13	0,202
4	7,45	9,55	4,3	5,7	0,135	0,198
5	7,6	9,4	4,4	5,6	0,14	0,194
6	7,75	9,25	4,5	5,5	0,145	0,19
7	7,9	9,1	4,6	5,4	0,15	0,186
8	8,05	8,95	4,7	5,3	0,155	0,182
9	8,2	8,8	4,8	5,2	0,16	0,178
10	8,35	8,65	4,9	5,1	0,165	0,174

The function P has a trapezoidal appearance, while $P_{\min}$ = 0,571, $P_{\max}$ = 0,958, $P_{2,3}$ = 0,9. $P_3 = P_{\min}$ – a pessimistic scenario, $P_{\max}$ – is an optimistic scenario. P_2, P_3 – base value. Get calculations of the values P, shown in (Figure 2).

Fuzzy numbers are a fairly convenient way to model startup projects with ambiguous, probabilistic characteristics. When using fuzzy sets the calculation formula is P transformed as follows:

$$[P_{\min}, P_2, P_3, P_{\max}] = -[I_{\min}, I_2, I_3, I_{\max}] + \sum_{k=1}^{n} \left(\frac{[V_{\min}, V_2, V_3, V_{\max}]}{(1+[R_{\min}, R_2 R_3, R_{\max}])^k} \right) \tag{4}$$

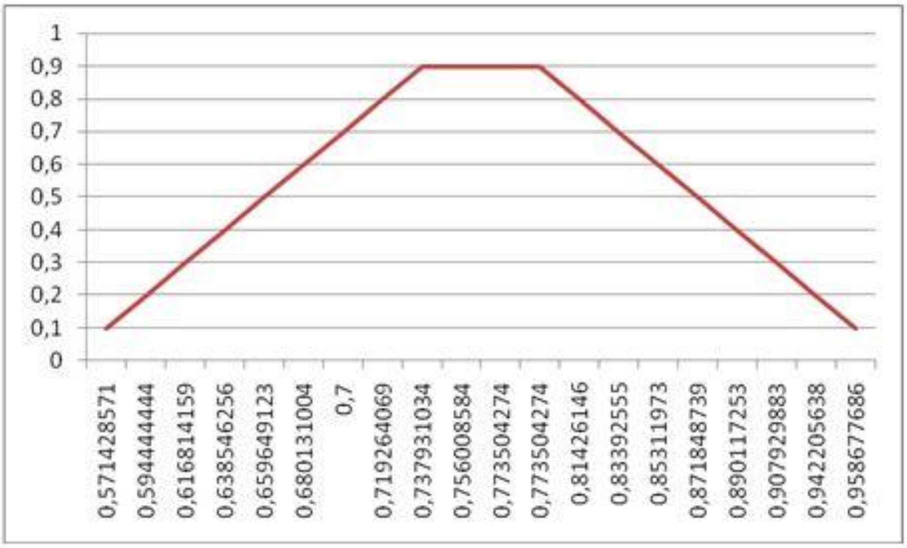

Figure 2. Function graph P

As a result of calculations, we get a trapezoidal fuzzy value of the indicator $P=(P_{\min}, P_2, P_3, P_{\max})$.

The project has a positive value if P there is more than the criterion set by investors W. Where W – an investment risk assessment – determination of criteria under which the resulting value of the investment process P will be lower than the established limit level.

Let W– be the selected limit value. In this task with fuzzy variables, we will evaluate the possibility of an event $P < W$, that determines the risk that the project will be ineffective.

Since the result of the calculation P, is a fuzzy number, the following variants of its correlation with the efficiency criterion W (Figure 3) are possible.

The specified areas of shapes can be found in different ways. In the most general form, the area of the shape on the interval $[a_{\min}, W]$ is a certain integral of the function that restricts the shape from above:

$$S_{(a_2, a_{\min})} = \int_{a_{\min}}^{W} \mu_{lef}\, dx \ , \tag{5}$$

where μ_{lef} – is a function describing *the left side* of the trapezoidal fuzzy number membership function P.

Since the graph of the membership function of a trapezoidal fuzzy number is a trapezoid μ_{lef} we use the formula of a straight line passing through two points to obtain the equation of the function:

$$\frac{\mu_{lef} - \mu_2}{\mu_2 - \mu_{\min}} = \frac{x - a_2}{a_2 - a_{\min}}$$

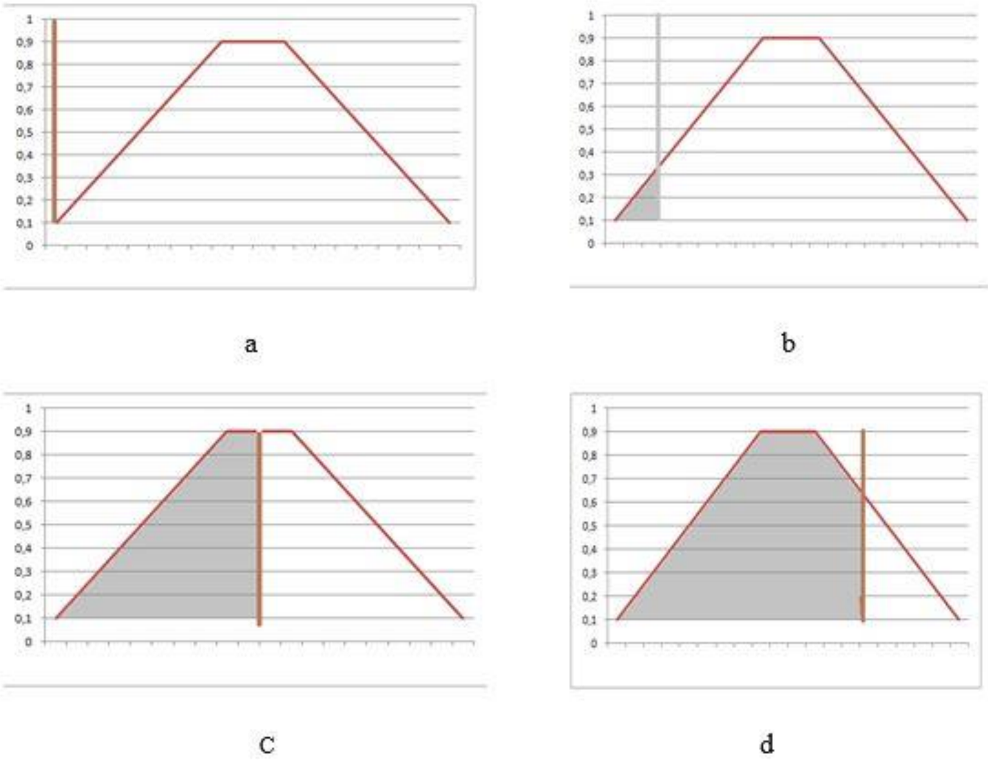

Figure 3. Determining the degree of project risk: a. amin<W; b. amin<W<a2; c. a2<W<a3;
d. a3<W<amax

Knowing that $\mu_{lef} = 0$ at point $x = a_{\min}$ and $\mu_{lef} = 1$ at $x = a_2$, we can obtain the following equation of the graph of the function μ_{lef} :

$$\mu_{lef} = \frac{x - a_2}{a_2 - a_{\min}} \tag{6}$$

Now, knowing the function, we can calculate the area of the shape:

$$S_{(a_{\min},W)} = \int_{a_{\min}}^{W} \mu_{lef}\,dx = \frac{(W - a_{\min})}{2(a_2 - a_{\min})} \tag{7}$$

The area value of the entire area of possible values *P* can be calculated much easier if you remember that the graph of the property function is a trapezoid:

$$S_{(a_{\min},a_{\max})} = \frac{(a_{\max} - a_2) + (a_3 - a_2)}{2} \tag{8}$$

So, now we can get a calculated formula for the risk indicator at $a_{\min} < W \le a_2$:

$$R = \frac{(W - a_{\min})}{(a_2 - a_{\min})(a_{\max} - a_{\min})(a_2 - a_2)} \tag{9}$$

At $a_2 < W \le a_3$, the degree of risk *R* will be determined by analogy with the previous case (fig. 3.c):

$$R = \frac{S_{(a_{min},a_2)} + S_{(a_2,W)}}{S_{(a_{min},a_{max})}},$$

where R – is the project risk indicator,
$S_{(a_{min},a_2)} + S_{(a_2,W)}$ – area of inefficient investment region,
$S_{(a_{min},a_{max})}$ – area of possible values region P.

$$S_{(a_{min},a_2)} = \frac{a_2 - a_{min}}{2} \qquad (10)$$

Formula for the risk indicator at $a_2 < W \le a_3$:

$$R = \frac{(2W) - a_2 - a_{min}}{(a_{max} - a_{min}) + (a_3 - a_2)} \qquad (11)$$

When $a_3 < W \le a_{max}$, the degree of risk R will be determined by analogy with the previous case (fig. 3.d):

$$R = \frac{S_{(a_{min},a_2)} + S_{(a_2,a_3)} + S_{(a_2,W)}}{S_{(a_{min},a_{max})};} \ , \qquad (12)$$

where R – is the project risk indicator,
$S_{(a_{min},a_2)} + S_{(a_2,a_3)} + S_{(a_2,W)}$ – area of inefficient investment region,
$S_{(a_{min},a_{max})}$ – area of possible values region P.

In the case of $a_{max} \le W$, the entire range of values obtained P is unambiguously less than the estimated criterion W , this indicates that the risk of such a project is 100%, i.e. R=1.

As a result, for all the described cases, we can write down the following system of solutions, which greatly simplifies the mechanism for calculating the risks of investment startup projects:

$$R = \begin{cases} 0, & W \le a_{min}, \\ \dfrac{(W - a_{min})^2}{(a_2 - a_{min})((a_{max} - a_{min}) + (a_3 - a_2))}, & a_{min} < W \le a_3, \\ \dfrac{(2W) - a_2 - a_{min}}{(a_{max} - a_{min}) + (a_3 - a_2)}, & a_2 < W \le a_3 \\ 1 - \dfrac{(a_{max} - W)^2}{(a_{max} - a_3)((a_{max} - a_{min}) + (a_3 - a_2))}, & a_3 < W \le a_{max}, \\ 1, & a_{max} \le W, \end{cases} \qquad (13)$$

where a_{min} – is the lower limit of the value interval P,
a_2 – the leftmost limit of the stability (tolerance) interval of values P,
a_3 – the rightmost limit of the stability (tolerance) interval of values P,
a_{max} – upper limit of the value interval P,
W – criterion for the effectiveness of implementing a startup project.
The dependence of the project performance criterion on the net present value is shown in Figure 4.

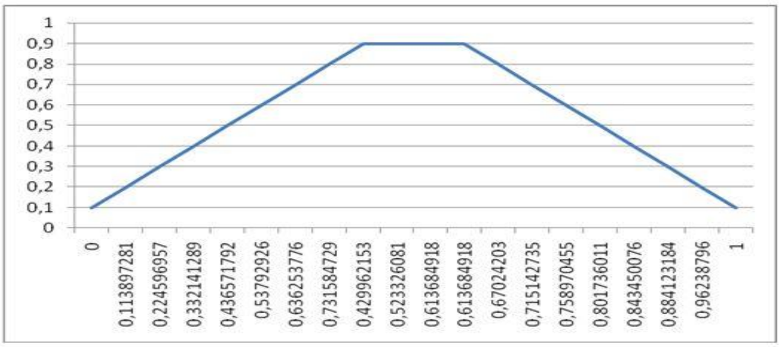

Figure 4. Calculating the effectiveness of a startup project for investors

Thus, we have obtained a model that can be used to calculate the risks of investors when investing in startup projects. It is worth noting that this model calculates risk estimates for investing in a startup project for an investor, depending on the startup's effectiveness criterion. An indicator is calculated, below the value of which the project will be considered unprofitable for the investor. The use of fuzzy set theory in the work is considered on a real example of investing in a startup project. Much attention is paid to the development of a system of indicators that characterize the financial condition of the project. Analysis of scientific papers has shown that the authors have different approaches to determining the list of indicators necessary for evaluating and grouping them. Most often, the efficiency of production, investment and financial activities is evaluated through indicators of net cash flow, liquidity, financial stability, business activity and profitability. The study is conducted on the basis of maximizing net present value and internal profitability. Variables that are presented in a fuzzy form are defined as follows: initial investment I, profit V , and discount rate r. As a result, a model is obtained that can be used to calculate the risks of investors when investing in startup projects. Simultaneously with the vagueness of estimates of criteria indicators, there is a vagueness of their standards, that is, the maximum permissible levels, undesirable deviations from which upon the implementation of the planned event mean its failure or inefficiency in the relevant aspects or in general. Unclear standards, along with unclear criteria, complicate the task of assessing the degree of risk.

4. Results consideration.

In cases where there is not enough information to make a decision, fuzzy set theory is used, which allows describing concepts that cannot be written clearly. Thus, fuzzy mathematical modeling problems are generalizations of mathematical modeling problems. The main advantages of this theory are the ability to model situations in which information is expressed indistinctly. In many cases, this allows building a more adequate mathematical model and simplify the solution. The use of fuzzy set methods complements traditional financial analysis. It is possible to quantify the sustainability of different project performance characteristics to compare the sustainability of different indicators. This is necessary when identifying project bottlenecks. It becomes possible to quantify the reliability of the calculated project performance indicators obtained. Such estimates cannot be made on the basis of traditional analysis methods. Fuzzy set theory has its drawbacks. Namely, subjectivity in the formation of membership functions of fuzzy sets. Indeed, decisions about the type of membership functions of fuzzy sets are made on the basis of knowledge and subjective opinions of experts and are generally subjective in nature. Today, the capabilities of researchers are significantly expanded due to the introduction of non-traditional, as well as hybrid fuzzy sets, which to varying degrees can reduce the negative impact of the subjectivity of fuzzy sets. The existing disadvantages of fuzzy sets, which significantly limit the feasibility of using them, especially in dynamic problems, should also be attributed to their static nature, that is, not taking into account the possibility of changing the type of the fuzzy set membership function within the constructed model. The paper deduces the dependence of the project risk indicator on the value of the project performance criterion. Using fuzzy set methods will allow estimating the level of sustainable forecasting of financial flows generated by the project, depending on the variants of important input parameters of the project.

5. Conclusions

The paper develops an economic and mathematical model for calculating investment risks of a startup project based on fuzzy set theory. It is proved that fuzzy set theory is one of the most effective mathematical theories aimed at processing indefinite information, which integrates well-known approaches and methods. The application of fuzzy set theory opens up new methods and opportunities for solving project evaluation problems and forming an optimal project portfolio. First, fuzzy sets allow taking into account the qualitative characteristics of projects, turning them into a numerical form. Second, in relation to quantitative characteristics of a project, such as ***P***, the theory provides a means to work with uncertainty even in cases where the available information is insufficient to draw statistical conclusions with a certain level of probability. On the other hand, fuzzy set theory has developed an apparatus for switching from fuzzy estimates to ordinary numbers, which makes it possible to form a portfolio of projects based on their fuzzy estimates by ranking projects or solving the corresponding mathematical programming issue. The flexibility and power of fuzzy set theory methods allow considering them as a promising and effective tool for solving various project management issues.

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