# “Project risk management of the construction industry enterprises based on fuzzy set theory”

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# PROJECT RISK MANAGEMENT OF THE CONSTRUCTION INDUSTRY ENTERPRISES BASED ON FUZZY SET THEORY

## Abstract

The construction industry is a crucially important element of the Ukrainian economy, since its development and performance affect other industries. The economic recession consequences and the unforeseen recent events, caused by different types of risks, have adversely affected the construction industry development and necessitated the search for modern methods of risk management. The study is based on a sample of five projects from five construction industry enterprises and covered the period of 2010–2018. A set of project risks, investigated by the group of experts, was analyzed based on fuzzy set theory, and included seven phases of the fuzzy set model construction to assess project risks of construction industry enterprises. Based on the identified elements of a fuzzy set model and a set of significant project risks, a value classifier of significant project risks for construction industry enterprises was developed. This allowed to estimate the current values of project risk indicators and to identify them by levels of their fuzzy subset membership. Besides, a classifier for the quantitative assessment of the total project risks level for investment projects was developed, which allowed estimating the value of the aggregate indicator. In order to improve the existed methodology, the study suggested introducing probabilistic values for the risk of project failure depending on the significance of the overall project risks. Accordingly, the paper identifies the probability of significant project risks simultaneous occurring during the project implementation. However, the higher the likelihood of risk, the higher the probability of investment project failure.

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**JEL Classification** G32, D81, L74

## INTRODUCTION

The construction sector has always played a key role in the structure of the entire Ukrainian industry. In the context of current economic volatility, the riskiness of construction companies increases due to the lack of their readiness to operate in the changing market conditions. This is also complicated by the transformation of the country's economy and the system change in legislative and technical regulation of the Ukrainian construction industry.

The market conditions, where the construction industry operates, set many factors that can simultaneously cause a complex number of diverse and various-directional risks. This makes it difficult to develop a method for aggregate and discrete estimation of project risks based on the theory of classical statistics, since it is not possible to obtain a sample of statistically homogeneous data/events from their general population under constant external observation conditions. In such cases, the experts consider the data totality distribution laws as fuzzy and classify the samples using linguistic means, which allows generating information that is important for decision making. The use of fuzzy set theory allows to obtain more accurate expert judgment data, which are complex and almost inestimable. In addition, as the number of risk factors increases, the inaccuracy degree grows, which is fundamental in using this theory in project risk management.

## 1. LITERATURE REVIEW

Many scholars address a wide range of risk management issues. Among them are Williams et al. (1989), Holton (2003), Barton et al. (2003), Ilyashenko (2006), and Dukhanina (2014). Shenhar et al. (2010), Ward et al. (2003), and Perminova et al. (2008) pointed to the need for project risk management under uncertainty.

Bakker et al. (2012) stress the importance of the risk identification process, followed by a project risk report, registration, distribution, analysis and control of risks. According to Besner and Hobbs (2006), the exchange of project risk information with project stakeholders is an important management practice.

Pinto (2017) pointed to the role and significance of project risks and concluded that project financing is the main tool for project risk management, since it creates value by reducing financing costs, establishing financial flexibility of sponsors, increasing leverage ratios, avoiding environmental risk, reducing corporate taxes, improving risk management, and reducing costs for market deviations. Kolodiziev et al. (2017) investigated the main components of project risk management and came up with a logical justification for an efficient and balanced risk sharing between public and private partners, which is important for effective project risk management. Ostapiuk et al. (2017) proposed a series of actions and methods aimed at developing effective tools to identify risk factors and monitor the effectiveness of investment projects.

Akintoye and Macleod (1997), Kaplinski (2013), Iqbal et al. (2015), Taylan et al. (2014), Serpella et al. (2014), Wang et al. (2004), and Hassanein et al. (2007) stressed the importance of project risk management in the construction industry.

Zadeh (1976), Kovalev (1997), Alekseev (1979), and Nedosekin (2003) reflected the necessity of forming a qualitative methodology for project risk management. Beginning in the late 1970s, methods of fuzzy set theory began to be applied in economics. The following prominent scientists should be mentioned here: Buckley (1992), Bojadziev (1997), Kaufmann et al. (1991), Couturier et al. (2002), and Zimmerman (2001). They developed new descriptions of fuzzy set theory and simultaneously built mathematical models to solve real-world financial problems.

Zadeh (1965, 1971, 1976, 1978) is the founder of fuzzy set theory; his follower Nedosekin (1999, 2003) improved the methodology by using a matrix method of risk assessment. This matrix method classification resulted in a linguistic description of the degree of risk and the degree of confidence of an expert in a particular recognition result.

Gavrysh et al. (2017) critically analyzed the regulatory principles of project risk management, which made it possible to build a regulatory and methodological mechanism for project risk management that describes all stages of management, including its assessment. Economic and statistical analysis has confirmed/eliminated hypotheses that there is a correlation between project risks, which were separated according to expert judgment and project performance parameters. Besides, the cluster analysis made it possible to group the confirmed correlations of the most significant risks according to the specified performance parameters (Melnykova, 2019), which enabled, according to the results of qualitative and quantitative analysis of the project risks, to develop models that reflect their impact on the basic project parameters by sequential changes in the magnitudes of the main risk factors. Also, according to the analysis results, a system of indicators has been formed, the limit values of which are indicators of the occurrence of project threats, and thus a prerequisite for responding to project risks.

The expert estimation modeling is to adequately transform qualitative expert statements into judgement-based determinations using assessment boundaries or numerical segments. From this perspective, fuzzy set theory provides a high-


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ly developed formalized apparatus to solve these problems. This study substantiates the need for fuzzy set theory to effectively manage project risks.

## 2. AIMS

The purpose of this study is to manage the project risks of construction industry enterprises based on fuzzy set theory, which results in the creation of classifiers and matrix schemes for project risk aggregation.

## 3. METHODS

The paper offers a quantification method to assess project risks of construction industry enterprises. Quantification assessment of project risks means a system of quantitative and qualitative parameters that allow identification of the degree of project risks and threat to the investment project failure based on an aggregate quantitative parameter.

The methodology of the project risk assessment at construction industry enterprises is proposed to ground on the basics of fuzzy sets theory and matrix method proposed by Nedosekin (2013). The above methodology consists of several specific phases in constructing a fuzzy model of project risk assessment of construction industry enterprises.

Thus, the experts assign a sample of observations from the general population, which is considered insufficient to identify a classical probabilistic law of distribution with well-defined parameters; the certainty degree, however, is determined to be sufficient to substantiate a distribution law, from any given point of view, in probabilistic or any other manner. Moreover, the parameters of this expert law are set by these special rules to satisfy the necessary reliability level in identifying the observation law.

To evaluate the project risks, according to the fuzzy set theory, the expert group of the enterprise identified the linguistic variables of the fuzzy-set model in the first phase $\Omega=\{\omega,T(\omega),U,G,M\}$, where $\omega$ is the variable name; $T$ is a term-set of values, that is, a set of its linguistic meanings; $U$ is a carrier; $G$ is a syntactic rule that generates term-sets of $T$; and $M$ is a semantic rule, according to which, each linguistic meaning of $\omega$ is assigned its meaning $M(\omega)$.

Each value of a linguistic variable is assigned a function of project risk level membership to any given fuzzy subset. Common functions in this case are trapezoidal membership functions (Figure 1).

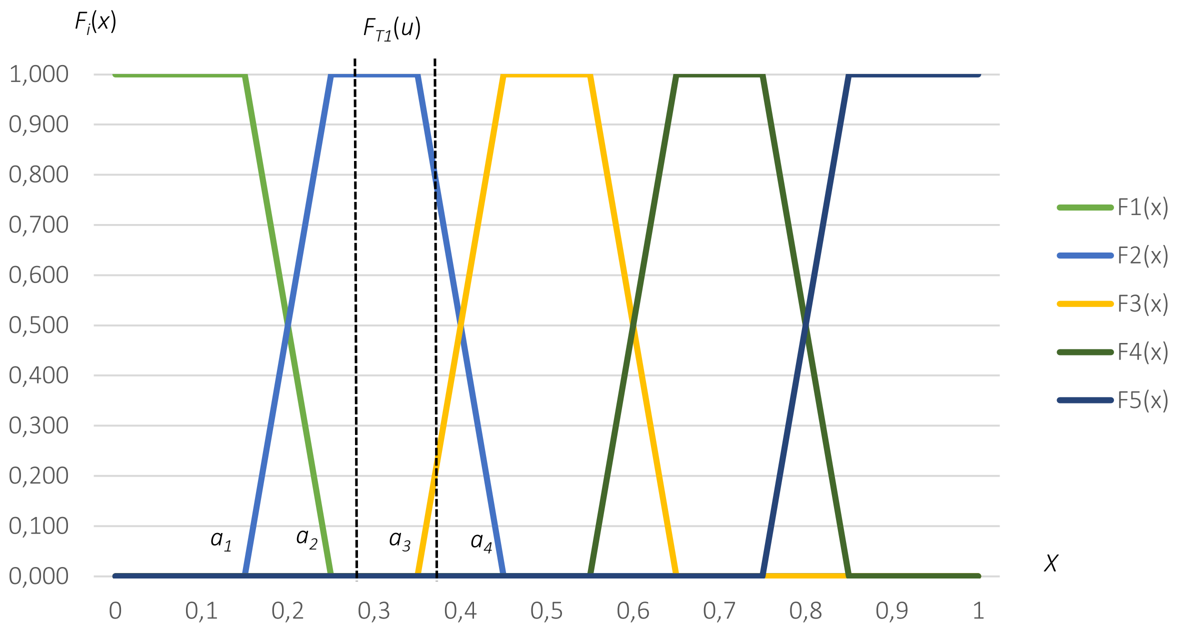


**Figure 1.** The system of trapezoidal membership functions $F_i(x)$ on the 01 carrier

The upper base of the trapezoid corresponds to the expert's complete confidence in the correctness of his classification, and the lower one relates to the belief that no other values of the interval (0,1) fall into the selected fuzzy subset (Nedosekin, 2003).

The trapezoidal membership functions $F_i(x)$ are described by the trapezoidal numbers of the form of $\beta$ ($a_1$, $a_2$, $a_3$, $a_4$), where $a_1$ and $a_4$ are the abscissas of the lower base of the trapezoid, and $a_2$ and $a_3$ are the abscissas of the upper base.

In the second phase, a set of individual project risk indicators $X$={$X_i$} was introduced with a total number of $N$, which, according to an analyst, affect the project risk assessment on the one hand, and, on the other hand, assess the different conditions for fulfilling the investment project by a construction industry enterprise. In the next phase, the importance of the significant risk factor of $X_i$ was determined, for which each indicator of $X_i$ project risk was compared with $r_i$ – its significance level. To assess this level, all indicators were ranked in descending order so that rule (1) was satisfied:

$$r_1 \geq r_2 \geq \ldots \geq r_N. \tag{1}$$

If the indicator system is ranked in descending order, then the significance of the $i$-th indicator of $r_i$ is determined using the Fishburn rule (Fishburn, 1978), namely:

$$r = \frac{2\cdot(N-i+1)}{(N+1)\cdot N}. \tag{2}$$

In the fourth phase, a classifier of indicator values of construction industry enterprises' significant project risks was developed to normalize the quantitative and qualitative values of these indicators to a single quantification metric. As a result, the indices of the significant project risks of the construction industry enterprises were evaluated according to a single quantification metric.

A matrix of membership levels for the carriers of significant project risk indicators of construction enterprises was also developed by fuzzy subsets of the linguistic variables of the project risk term set.

The classifier for the quantitative assessment of the total project risks for investment projects is not specified enough in terms of sufficient informativeness of its quantitative expression metric. Therefore, this paper proposes to improve the methodology outlined in Nedosekin (2003), on the basis of which, the quantitative assessment of project risks of construction industry enterprises is based. The improvement is proposed by introducing probabilistic values for the threat of failure to fulfill the investment project depending on the value of the investment project risks $AP$.

For which number of simultaneous significant project risks $k$ realization the likelihood would be highest, was determined according to the Bernoulli scheme, namely by formulas (3) and (4):

$$P_n(k) = C_n^k \cdot p^k \cdot (1-p)^{n-k}, \tag{3}$$

where $P_n(k)$ is the likelihood of simultaneous realization of $k$ significant project risks, $C_n^k$ is the number of combinations from the $n$-total number of possible events (study objects) by $k$-arbitrary number of events in the total set, $p$ is the given probability of occurrence of each individual event under equal conditions for all, $n = 22$ is the number of significant project risks for the economic-mathematical decision of this study objective:

$$C_n^k = \frac{n!}{(n-k)!\cdot k!}. \tag{4}$$

According to the calculation data, a quantitative system is built for parameter estimation to interpret the level of threat of the investment project failure; it is based on the classifier's membership functions of the total level of project risks for investment projects of the construction industry enterprises.

In the sixth phase, the current values of significant project risk indicators $X_i$ and the recognition of indicators by their membership to fuzzy subsets {Bi} were estimated, based on a set of indicators of the construction industry enterprises' significant project risks according to the {B$i$} set of an integrated quantification metric. According to the fuzzy set theory, indicators, by the levels of their belonging to fuzzy subsets {Bi}, are calculated by formulas



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(5)-(9). The results of calculations are presented in Table 5.

$$F_1(x)=\begin{cases}1.0 \le x < 0.15;\\ 10(0.25-x), 0.15 \le x < 0.25;\\ 0, 0.25 \le x \le 1.\end{cases} \tag{5}$$

$$F_2(x)=\begin{cases}0, 0 \le x < 0.15;\\ 10(x-0.15), 0.15 \le x < 0.25;\\ 1, 0.25 \le x < 0.35;\\ 10(0.45-x), 0.35 \le x < 0.45;\\ 0, 0.45 \le x \le 1.\end{cases} \tag{6}$$

$$F_3(x)=\begin{cases}0, 0 \le x < 0.35;\\ 10(x-0.35), 0.35 \le x < 0.45;\\ 1, 0.45 \le x < 0.55;\\ 10(0.65-x), 0.55 \le x < 0.65;\\ 0, 0.65 \le x \le 1.\end{cases} \tag{7}$$

$$F_4(x)=\begin{cases}0, 0 \le x < 0.55;\\ 10(x-0.55), 0.55 \le x < 0.65;\\ 1, 0.65 \le x < 0.75;\\ 10(0.85-x), 0.75 \le x < 0.85;\\ 0, 0.85 \le x \le 1.\end{cases} \tag{8}$$

$$F_5(x)=\begin{cases}0, 0 \le x < 0.75;\\ 10(x-0.75), 0.75 \le x < 0.85;\\ 1, 0.85 < x < 1.\end{cases} \tag{9}$$

In the seventh phase, an aggregate indicator of the quantitative assessment of aggregate project risks threat of $AP$ was calculated, according to the matrix of baseline data and significance levels of project risks, which is as follows:

$$AP=\sum_{j=1}^{5} g_j \sum_{i=1}^{22} r_i f_{ij}, \tag{10}$$

where $AP$ is the aggregate indicator of the quantitative assessment of the level of aggregate project risks of construction industry enterprises, $g_j$ are the nodal points calculated by the following formula:

$$g_j = 0.9 - 0.2(j-1), \tag{11}$$

$f_{ij}$ means that the carriers of significant project risk indicators of construction industry enterprises belonging to fuzzy subsets of the linguistic term-set variables of the project risks level $\{RPR_i\}$ are determined in accordance with the Table 5 data, $r$ are levels of the project risk significance that are calculated by formula (2).

The essence of formulas (10) and (11) is that the internal summation in (10) is carried out by the indicator's value, and the external – by the nodal points of the standard location {0.1, 0.3, 0.5, 0.7, 0.9} in the fuzzy set theory of the project risk degree 5-level classifier. Thus, the resultant quantification assessment of the level of aggregate project risks of construction industry AP is defined as the weighted average of all significant project risk indicators and of all qualitative levels of these indicators.

## 4. RESULTS

In the analysis, the results of study on the seven-phase quantification assessment of construction enterprises' project risks are presented. In the first phase, the following elements of the fuzzy set model were identified:

A) The linguistic variable *SIP*, Investment Project Status, with five meanings:

- $SIP_1$ is a fuzzy subset of boundary non-performance states;
- $SIP_2$ is a fuzzy subset of non-performance states;
- $SIP_3$ is a fuzzy subset of medium performance states;
- $SIP_4$ is a fuzzy subset of sufficient performance states; and
- $SIP_5$ is a fuzzy subset of boundary performance states.

B) The linguistic variable $PR_i$ $\left(i \in [1,5]\right)$ – Aggregate Project Risk of the Investment Project, which corresponds to the SIP variable:

- $PR_1$ is a fuzzy subset of boundary project risk;
- $PR_2$ is a fuzzy subset of high risk;
- $PR_3$ is a fuzzy subset of average project risk;
- $PR_4$ is a fuzzy subset of low project risk; and
- $PR_5$ is a fuzzy subset of insignificant project risk.

The *PR* set carrier is an indicator of the project risk degree *g* that takes the value from 0 to 1 (standard 01 carrier) as defined by the fuzzy set theory above.

C) The indicator of significant project risk $X_i$, which may threaten the investment project of the construction company, is set as the linguistic variable $RPR_i$, Project Risk Level $X_i$, on the following term-set of values:

- $RPR_1$ is a subset of very low $X_i$;
- $RPR_2$ is a subset of low $X_i$;
- $RPR_3$ is a subset of the medium $X_i$;
- $RPR_4$ is a subset of high $X_i$;
- $RPR_5$ is a subset of very high $X_i$.

In the second and third phases, a set of individual project risk indicators were introduced (Table 1), which allowed, according to the Fishburn's rule, establishing a term for the lack of information regarding the indicators' significance level, except those that are in Table 1. Then, the estimate (see Table 2) corresponds to the maximum entropy of the available information uncertainty about the study object, that is, it allows the experts to make the best evaluation decisions in the worst information situation (Trukhaev, 1978).

Then, a classifier of indicators of the construction enterprises' project risks was developed. According to the basic provisions of the fuzzy set theory, in the cells of Table 2, based on expert analysis, trapezoidal numbers are selected, which characterize the corresponding membership functions of $F_i(x)$ and the corresponding nodal points $g_i$ (see Figure 1). For example, when classifying the level of indicator $X_1$, an expert, hesitating to differentiate the level to "medium" and "high", can determine the range of their uncertainty within the interval of 0.5, 0.65, etc.

**Table 1.** Indicators of the construction companies' significant project risks according to the reduced impact degree on investment projects

Source: Developed by the authors.

| Index symbol | Sub-category code, project risk index name |
|---|---|
| $X_1$ | 1. Obtaining permits and licenses |
| $X_2$ | 2.1. Availability and conditions for land use |
| $X_3$ | 2.2. Technology disadvantages |
| $X_4$ | 7.6. Current debt on long-term liabilities in the construction industry |
| $X_5$ | 7.7. Credit debts |
| $X_6$ | 2.3. Cost overruns |
| $X_7$ | 2.4. Delay in completion |
| $X_8$ | 7.8. Private partner financial capacity (business solvency) |
| $X_9$ | 2.5. Contractor inability |
| $X_{10}$ | 4.1. Supplies and inputs |
| $X_{11}$ | 3.4. Price indices for construction and installation works |
| $X_{12}$ | 3.5. Household cash expenditure |
| $X_{13}$ | 6.2. Inflation rate |
| $X_{14}$ | 7.3. Capital investment indices for construction |
| $X_{15}$ | 7.4. Mortgage loan rate |
| $X_{16}$ | 7.5. Volumes of mortgage lending to individuals |
| $X_{17}$ | 8.3. Average monthly income |
| $X_{18}$ | 4.4. The solvency of suppliers of building materials |
| $X_{19}$ | 8.1. Staff turnover in the construction sector |
| $X_{20}$ | 8.2. Labor productivity |
| $X_{21}$ | 3.2. GDP per capita |
| $X_{22}$ | 2.6. Risks of environmental impact |

In the next phase, a classifier for the quantitative assessment of the level of the overall project risks was constructed (Table 3). According to the fuzzy set theory outlined above, this classifier is a standard five-level classifier on a 01 carrier, where the *AR* values are in the range of $g_j$ – nodal points belonging to the set {0.9, 0.7, 0.5, 0.3, 0.1} and are inverted from the standard location {0.1, 0.3, 0.5, 0.7, 0.9} in the quantification estimate classifier.



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**Table 2.** The classifier of indicator values for significant project risks $X_{ij}$ of construction industry enterprises according to a single quantification metric

Source: Developed by the authors based on expert estimates.

| Index symbol | T-figures for the {Bi} set for the linguistic variable values of the term-set of project risks {*RPRi*} | | | | |
|---|---|---|---|---|---|
| | $RPR_1$ = Very low | $RPR_2$ = Low | $RPR_3$ = Medium | $RPR_4$ = High | $RPR_5$ = Very high |
| $X_1$ | (0,0,0.1,0.2) | (0.1,0.2,0.25,0.3) | (0.25,0.3,0.5,0.65) | (0.5,0.65,0.7,0.8) | (0.7,0.8,1,1) |
| $X_2$ | (0,0,0.1,0.2) | (0.1,0.2,0.25,0.3) | (0.25,0.3,0.5,0.65) | (0.5,0.65,0.7,0.8) | (0.7,0.8,1,1) |
| $X_3$ | (0,0,0.15,0.25) | (0.15,0.25,0.35,0.45) | (0.35,0.45,0.55,0.65) | (0.55,0.65,0.75,0.85) | (0.75,0.85,1,1) |
| $X_4$ | (0,0,0.1,0.15) | (0.1,0.15,0.25,0.35) | (0.25,0.35,0.45,0.55) | (0.45,0.55,0.65,0.75) | (0.65,0.75,1,1) |
| $X_5$ | (0,0,0.1,0.15) | (0.1,0.15,0.25,0.35) | (0.25,0.35,0.45,0.55) | (0.45,0.55,0.65,0.75) | (0.65,0.75,1,1) |
| $X_6$ | (0,0,0.15,0.25) | (0.15,0.25,0.35,0.45) | (0.35,0.45,0.55,0.65) | (0.55,0.65,0.75,0.85) | (0.75,0.85,1,1) |
| $X_7$ | (0,0,0.15,0.25) | (0.15,0.25,0.35,0.45) | (0.35,0.45,0.55,0.65) | (0.55,0.65,0.75,0.85) | (0.75,0.85,1,1) |
| $X_8$ | (0,0,0.1,0.25) | (0.1,0.25,0.3,0.4) | (0.3,0.4,0.55,0.65) | (0.55,0.65,0.7,0.85) | (0.7,0.85,1,1) |
| $X_9$ | (0,0,0.1,0.25) | (0.1,0.25,0.3,0.4) | (0.3,0.4,0.55,0.65) | (0.55,0.65,0.7,0.85) | (0.7,0.85,1,1) |
| $X_{10}$ | (0,0,0.15,0.25) | (0.15,0.25,0.35,0.45) | (0.35,0.45,0.55,0.65) | (0.55,0.65,0.75,0.85) | (0.75,0.85,1,1) |
| $X_{11}$ | (0,0,0.15,0.3) | (0.15,0.3,0.35,0.4) | (0.35,0.4,0.5,0.6) | (0.5,0.6,0.7,0.8) | (0.7,0.8,1,1) |
| $X_{12}$ | (0,0,0.15,0.3) | (0.15,0.3,0.4,0.5) | (0.4,0.5,0.6,0.65) | (0.6,0.65,0.7,0.8) | (0.7,0.8,1,1) |
| $X_{13}$ | (0,0,0.3,0.4) | (0.3,0.4,0.5,0.6) | (0.5,0.6,0.65,0.7) | (0.65,0.7,0.75,0.85) | (0.75,0.85,1,1) |
| $X_{14}$ | (0,0,0.3,0.4) | (0.3,0.4,0.5,0.6) | (0.5,0.6,0.65,0.7) | (0.65,0.7,0.75,0.85) | (0.75,0.85,1,1) |
| $X_{15}$ | (0,0,0.15,0.25) | (0.15,0.25,0.35,0.45) | (0.35,0.45,0.55,0.65) | (0.55,0.65,0.75,0.85) | (0.75,0.85,1,1) |
| $X_{16}$ | (0,0,0.15,0.25) | (0.15,0.25,0.35,0.45) | (0.35,0.45,0.55,0.65) | (0.55,0.65,0.75,0.85) | (0.75,0.85,1,1) |
| $X_{17}$ | (0,0,0.15,0.25) | (0.15,0.25,0.35,0.45) | (0.35,0.45,0.55,0.65) | (0.55,0.65,0.75,0.85) | (0.75,0.85,1,1) |
| $X_{18}$ | (0,0,0.1,0.25) | (0.1,0.25,0.3,0.4) | (0.3,0.4,0.55,0.65) | (0.55,0.65,0.7,0.85) | (0.7,0.85,1,1) |
| $X_{19}$ | (0,0,0.15,0.25) | (0.15,0.25,0.35,0.45) | (0.35,0.45,0.55,0.65) | (0.55,0.65,0.75,0.85) | (0.75,0.85,1,1) |
| $X_{20}$ | (0,0,0.15,0.25) | (0.15,0.25,0.35,0.45) | (0.35,0.45,0.55,0.65) | (0.55,0.65,0.75,0.85) | (0.75,0.85,1,1) |
| $X_{21}$ | (0,0,0.3,0.4) | (0.3,0.4,0.5,0.6) | (0.5,0.6,0.55,0.65) | (0.55,0.65,0.75,0.85) | (0.75,0.85,1,1) |
| $X_{22}$ | (0,0,0.3,0.4) | (0.3,0.4,0.5,0.6) | (0.5,0.6,0.55,0.65) | (0.55,0.65,0.75,0.85) | (0.75,0.85,1,1) |

**Table 3.** The classifier of the aggregate project risk quantification assessment for investment projects at the construction industry enterprises

Source: Developed by the authors.

| The range of aggregate parameter (AP) values of the aggregate project risks | Classes of the aggregate project risk of an investment project | The value of trapezoidal membership functions in the degree of expert confidence |
|---|---|---|
| 0 ≤ **AP** ≤ 0.15 | $PR_5$ | 1 |
| 0.15 < **AP** < 0.25 | $PR_5$ | $\mu_5 = 10 \times (0.25 - AP)$ |
| | $PR_4$ | $1 - \mu_5 = \mu_4$ |
| 0.25 ≤ **AP** ≤ 0.35 | $PR_4$ | 1 |
| 0.35 < **AP** < 0.45 | $PR_4$ | $\mu_4 = 10 \times (0.45 - AP)$ |
| | $PR_3$ | $1 - \mu_4 = \mu_3$ |
| 0.45 ≤ **AP** ≤ 0.55 | $PR_3$ | 1 |
| 0.55< **AP** < 0.65 | $PR_3$ | $\mu_3 = 10 \times (0.65 - AP)$ |
| | $PR_2$ | $1 - \mu_3 = \mu_2$ |
| 0.65 ≤ **AP** ≤ 0.75 | $PR_2$ | 1 |
| 0.75 < **AP** < 0.85 | $PR_2$ | $\mu_2 = 10 \times (0.85 - AP)$ |
| | $PR_1$ | $1 - \mu_2 = \mu_1$ |
| 0.85≤ **AP** ≤ 1.0 | $PR_1$ | 1 |

This classifier (see Table 3) is not adequately specified in terms of sufficient informativeness of the metric of its quantitative expression. Therefore, the paper proposes to improve the methodology by means of introducing probabilistic values for the threat that investment project may not be completed, depending on the value of the aggregate project risks *AP*.

Thus, the economic and mathematical setting is limited to the following: during the investment project implementation of construction enterprises, there is a threat of 22 types of significant project risks (see Table 2). It is essential to determine the $P(X_i)$ probability that *k* types of significant project risks will be realized simultaneously during the project implementation. However, the higher the likelihood of manifesting *k* risks, the higher the probability of investment project failure.

The above task in this work was solved using the MSExcel spreadsheet.

According to Table 4, if the value of the linguistic variable "Aggregate Project Risk" falls into the class of boundary project risk and the limit values have eleven significant project risks from the total list of 22 risks (see Table 2), then the probability of investment project failure is 16.8%. If six of the first 11 of the most significant project risks are included in this class, then the probability of the investment project failure is 22.6%.

If the value of the linguistic variable of "Aggregate Project Risk" (see Table 3) falls into the "high risk" class, and the high values have 12 or 10 significant project risks of the total list of 22 risks in Table 2, then the probability of the investment project failure is 15.4%. If seven of the first 11 rated most significant project risks fall into this class, then the probability of the investment project failure is 16.1%.

If the value of the linguistic variable "Aggregate Project Risk" (see Table 3) falls into the "middle level of project risk" class, and 13 or nine significant project risks of the total list of 22 risks in Table 2 are relevant, then the probability of the investment project failure is 11.8%. If four of the first 11 of the most significant project risks are included in this class, then the probability of failure of the investment project also equals 16.1%.

In the sixth phase, the current values of the significant project risks of $X_i$ were evaluated and the indicators were identified by their membership levels as to fuzzy subsets $\{B_i\}$. The result of classification by subsets $B_{ij}$ of values $x_{ij}$ is made for one of the enterprises under study, the Kyivmiskbud

**Table 4.** A quantification system for assessing the level of threat of the investment project failure of construction industry enterprises

Source: Developed by the authors.

| Interpretation of risk quantification parameters | | Probability of the investment project failure, provided that the validity of *k* risks from the general list of significant project risks (Table 2) is confirmed | | Probability of the investment project failure, provided that the validity of *k* risks from the total of the first 11 significant project risks (Table 2) is confirmed | |
|---|---|---|---|---|---|
| The value of the linguistic variable *SIPi*, The Status of the Investment Project | The value of the linguistic variable, Aggregate Project Risk, *PRi* | The number of likely significant project risks (*k*) acting simultaneously | The probability of the investment project failure, $P(X_{ij})$ | The number of likely significant project risks (*k*) acting simultaneously | The probability of the investment project failure, $P'(X_{ij})$ |
| $SIP_1$ = boundary non-performance | $PR_1$ = boundary project risk | 11 | 0.168 | 6; 5 | 0.226 |
| $SIP_2$ = non-performance | $PR_2$ = high risk | 12; 10 | 0.154 | 7 | 0.161 |
| $SIP_3$ = middle performance | $PR_3$ = middle project risk | 13; 9 | 0.118 | 4 | 0.161 |
| $SIP_4$ = sufficient performance | $PR_4$ = low project risk | – | – | – | – |
| $SIP_5$ = boundary performance | $PR_5$ = insignificant project risk | – | – | – | – |


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**Table 5.** The membership level matrix of indicator carriers of construction enterprises' significant project risks in fuzzy subsets of linguistic variable values of the project risk $\{RPR_i\}$ term-set

| Indicator symbol | Identification results according to subsets of $B_{ij}$ of the current values | | | | |
|---|---|---|---|---|---|
| | $Bi_1$ | $Bi_2$ | $Bi_3$ | $Bi_4$ | $Bi_5$ |
| $x_1$ | f11 | f12 | f13 | f14 | f15 |
| $x_2$ | f21 | f22 | f23 | f24 | f25 |
| … | … | .. | … | … | … |
| $x_N$ | fn1 | fn2 | fn3 | fn4 | fn5 |

Holding Company. The values of significant project risks $x_{ij}$ construction industry enterprises were classified for two periods within the term of the enterprise investment project (2017–2018).

According to the fuzzy sets theory, indicators are identified by the membership levels as to fuzzy subsets $\{B_i\}$ by formulas (5)-(9), and the results of the calculations are proposed to be presented in matrix form (Table 5).

The calculations for the recognition of significant project risks by the fuzzy subset membership $\{B_i\}$ levels are made for Kyivmiskbud-1 (Housing Complex Urlivskyi-1), one of the enterprises of the Kyivmiskbud Holding Company under study. The calculations according to formulas (5)-(9) were also performed over two periods within the term of the enterprise's investment project (2016–2017–2018).

In the seventh phase, an integrated indicator of the quantitative assessment of the aggregate project risks *AR* of construction industry enterprises was calculated by formula (10). The initial data for the calculation were formed by way of a matrix (see Table 5).

The aggregate *AR* index for Kyivmiskbud-1 was calculated using the MSExcel spreadsheet.

The obtained value of the aggregate *AR* indicator is identified based on the quantitative assessment classifier of aggregate project risks for investment projects of the construction industry enterprises (see Table 3). Therefore, the classification results in the linguistic description of the aggregate indicator of the quantitative assessment of the construction industry enterprises' aggregate project risks, the degree of expert confidence in the result of recognition, an indicator of the probability level of the investment project failure influenced by the cumulative effect of *k*-significant project risks.

Table 6 presents the obtained values of the calculation results for Kyivmiskbud-1.

Table 6 allows concluding that aggregate project risks in the second period of the invest-

**Table 6.** Quantification estimate results for the level of integrated project risks for Kyivmiskbud-1's investment projects

Source: Developed by the authors.

| Period of the investment project implementation | Aggregate indicator of the level of total project risks, *AR* | Linguistic description of the aggregate indicator of the quantitative assessment of total project risks | The linguistic variable "Investment Project Status", *SIP* | The degree of expert confidence resulting from the recognition | The probability of the investment project failure influenced by the cumulative effect of *k*-significant project risks |
|---|---|---|---|---|---|
| I | 0.34 | PR4 = low project risk | SIP4 = sufficient performance | 1 | – |
| II | 0.374 | PR3 = medium project risk | SIP3 = medium performance | 0.24 | 0.161 (*k=4*) |
| | | PR4 = low project risk | SIP4 = sufficient performance | 0.76 | – |

ment project implementation at Kyivmiskbud-1 increased, because the aggregate AR indicator increased from 0.34 in the first period to 0.374. Thus, if in the first period experts with 100% certainty rated the aggregate risk level as low and the status of the investment project was expected to be sufficient to reach the planned NPV value, then in the second period the aggregate project risks already had boundary values of the linguistic description between low and medium project risks. This also corresponds to boundary investment project performance as medium and sufficient. Despite the fact that the degree of expert confidence in recognition results in only 24 percent of the average aggregate risk (as opposed to 76% of confidence in assessing project risk as low), but the four most significant risks are among the 11 most influential, which translates the investment project implementation status to medium with a 16.1% probability.

Thus, the degree of project risk can be assessed as a complex indicator that characterizes the financial, macroeconomic and microeconomic positions of the construction company, as well as the quality of management of the enterprise and the investment project, which leads to the combination of qualitative and quantitative estimates of project risks within the same model. This method is possible to implement based on so-called matrix methods.

## CONCLUSION

The analysis of the Kyivmiskbud-1's investment project makes it possible to conclude that the aggregate project risks in the second period increased by 3.4% compared to the first period. In the first period, the experts assessed the risk as low with 100% certainty, and the investment project`s status was expected to be sufficient to reach the planned NPV. In the second period, the investment project execution boundary was between medium and sufficient levels. Overall, despite the fact that experts' confidence in the second period was 24% relative to the average level of aggregate risk exposure, four significant risks were among the most influential. In turn, the probability of the investment failure project was negligible, which indicates the feasibility of implementing the planned project.

In general, the use of fuzzy set theory in project risk management has numerous advantages. In particular, it allows: analyzing many of linguistic parameters and building a holistic view of project risk management; developing classifiers and matrix schemes of aggregation of enterprises' project risks; assessing the level of aggregate risk exposure; and identifying the probability of risks that may arise at the same time as the project is implemented. Thus, the use of fuzzy set theory is appropriate and promising for further studies of project risk management.

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