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Models of information situations of decision-making under conditions of risk, uncertainty, and fuzzy information

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Abstract. The relevance is conditioned by the need to create mathematical support for a conceptual approach that would allow systematising information situations of decision-making under conditions of risk, uncertainty, fuzzy information, and provide a reasonable choice of methods for solving practical decision-making problems in these situations. The goal was to develop mathematical models of information situations of decision-making under conditions of risk, uncertainty, fuzzy information, and their possible combinations, and to build a model of the decision-making process based on them, which provides for the possibility of applying several methods of choosing alternatives and aggregating their results to improve the efficiency of decision-making. The research methodology was based on a systematic approach using set theory, probability theory, fuzzy set theory, decision theory and methods, and mathematical modelling to formalise information situations of decision-making. Mathematical models of information situations of decision-making under conditions of risk (Risk, R), complete uncertainty (Uncertainty, U), fuzzy information (Fuzzy, F), and possible combinations of situations were developed: R-U, R-F, U-F, R-U-F. The generalised model of information situation of decision-making R-U-F (MISDMRUF) was interpreted as a model of a decision-making problem that formalises the process of choosing an alternative in conditions of simultaneous presence of risk, uncertainty, and fuzzy information. This allowed using existing and creating new decision-making methods depending on the characteristics of the information situation of decision-making. A model of the decision-making process under conditions of risk, uncertainty and fuzzy information (MDMPRUF) was proposed, its tasks, main stages of implementation, and key features, in particular, versatility, flexibility, and integrativity, were defined. The results showed that the proposed MISDMRUF and MDMPRUF models were consistent with a number of studies in decision theory, but simultaneously fill in the existing gaps, providing a systematic, integrated approach to classifying information situations of decision-making and selecting decision methods under complex conditions of risk, uncertainty, and fuzzy information. The proposed mathematical models and an appropriate approach to solving decision-making problems can become the basis for creating information technologies for decision support under complex conditions

Keywords: mathematical models; decision-support models; decision-making methods; decision-support systems; information technologies

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INTRODUCTION

Contemporary decision-making tasks are characterised by a high level of complexity due to the presence of multiple criteria, the impact of various risks, uncertainty in decision-making conditions, and the inclusion of fuzzy input data in real problems. In the decision-making process, management bodies are faced with various information situations that can significantly affect the effectiveness of decision-making. The lack of a single conceptual model that combines these situations and considers their interrelationships makes it difficult to choose and apply decision-making methods. This underscores the relevance of the research aimed at creating a model that will systematise information situations of decision-making under conditions of risk, uncertainty, fuzzy information, and provide a reasonable choice of methods for solving practical decision-making problems in these situations.

In scientific research, decision-making problems are considered through the prism of various information situations that arise in the process of choosing alternatives. Various approaches to the classification and formalisation of decision-making models and methods are widely presented in the scientific literature. The monograph by M.I. Gomes & N.C. Martins (2022) reviewed mathematical models of decision-making, which showed the importance of integrating different opinions and criteria into a single model. Special attention was paid to the integration of multi-criteria decision-making and multi-criteria optimisation as complementary approaches to the analysis of complex information situations. This creates a theoretical basis for reasonable selection and combination of methods depending on the level of information certainty. J. Jaccard & J. Jacoby (2020) focused on the construction of theories and models in the social sciences, which is of direct importance for the development and modification of decision-making methods focused on complex and poorly structured problems. The researchers emphasised the importance of using qualitative, mixed and quantitative approaches to build new models, and the need to adapt and revise models in the event of conflicting empirical data, which is relevant for decision-making tasks in conditions of uncertainty and fuzzy information.

T. Zheldak *et al.* (2020) investigated the use of fuzzy sets in management and decision-making systems. The researchers emphasised the importance of integrating classical mathematical methods with contemporary information technology and data mining. They noted the role of combining quantitative and qualitative criteria and applying fuzzy sets, which helps to more effectively model information situations and make decisions in complex and changing conditions. N. Munier (2021) proposed the SIMUS method for modelling complex decision-making scenarios, which is an example of a modern hybrid approach to solving multi-criteria problems. Special attention was paid to the development of a solution matrix that maximally reflects the real conditions of the problem, considering practical limitations and environmental characteristics. The researcher emphasised that the choice of decision-making method should be carried out in accordance with the structure of this matrix, and the use of the SIMUS method using examples from real scenarios demonstrates its effectiveness for analysing complex, multi-factor situations. N.P. Høj *et al.* (2025) analysed methods for modelling the risk of systems and decision-making, focusing on the typical errors and limitations of existing decision-making approaches, and on the need for careful selection of methods and reasonable consideration of information uncertainty to ensure the rationality of decisions. The researchers stressed that incorrect consideration of uncertainty, interpretation of probabilities and consequences can lead to irrational decisions, sometimes worse than random ones, which is especially critical for events with low probability. This justifies the need for a systematic approach to risk modelling, which involves correct quantitative assessment, uncertainty analysis, and alignment of model assumptions with real-world decision-making conditions. In this context, T. Li *et al.* (2025) proposed an interval fuzzy multi-criteria decision-making model with an improved projection measure that improves the stability and accuracy of results in complex multi-criteria problems, demonstrating greater reliability compared to traditional approaches.

These sources have formed a methodological basis for further development of decision-making theory, but they do not provide a holistic view of the relationship between different types of information decision-making situations. The analysed studies lack a systematic classification of methods that accounts for the simultaneous presence of risk factors, uncertainty, and fuzzy information. Despite a significant amount of research in the field of decision-making, the problem of building models that would integrate complex information situations, in particular decision-making in conditions of risk, uncertainty and fuzzy information, and consider the relationships between them, remains unresolved. According to this problem, the purpose of the study was to develop mathematical models of information situations of decision-making in conditions of risk, uncertainty, fuzzy information, and their possible combinations, and to build a model of the decision-making process that provides integration of various methods of choosing alternatives and aggregation of their results.

MATERIALS AND METHODS

The research methodology was based on a systematic approach, which allowed comprehensively analysing information situations in decision-making and considering the relationships between all key elements of the process. For the formalisation and modelling of information situations, the basic concepts of set theory, probability theory, fuzzy set theory, and decision theory, mathematical modelling were used, which provided a strict description of the decision-making process and the ability to quantify the influence of external and internal factors on the results. The models were developed considering the specifics of decision-making tasks in conditions of risk, uncertainty, and fuzzy information, which is typical of real management and information processes.

The study examined the problem of decision-making in an environment where external factors that affect the effectiveness of decisions are not under the control of the decision maker (DM) or the subject of management (SM). It was assumed that these factors and external disturbances were unchanged during the time when the decision is made, that is, the model was static for a certain period of time. In the study, the decision-making situation was defined as a trio of sets (Us & Koriashkina, 2018):

$$DMS = \{A, \Theta, F\}, \tag{1}$$

where A – set of mutually exclusive possible solutions (alternatives) of the management body:

$$A = \{A_1, A_2, \ldots, A_N\} \quad ,(2)$$

where Θ – set of mutually exclusive possible environmental states E where it may be located, but at the time of making the DM decision, it is not known exactly what state it is in (or will be in):

$$\Theta = \{\theta_1, \theta_2, \ldots, \theta_S\}, \tag{3}$$

where F – evaluation functionality that characterises the "utility" or "loss" of the DM when choosing a solution A_i, if the environment will be (or is) in the state θ_j:

$$F = \{f_{ij}\} = \{f(A_i, \theta_j)\}, i = \overline{1, N}, j = \overline{1, S}. \tag{4}$$

The information situation of decision-making in the study was defined as the degree of gradation of uncertainty in the choice of environment E of their states from a given set Θ at the time of decision-making by the management body. In this study, decision-making tasks were analysed in information situation of decision-making under risk conditions (ISDMR), uncertainty (ISDMU), fuzzy information (ISDMF), and their possible combinations. The choice of these three information situations was determined by the desire to cover different levels of availability and accuracy of information, which provided a comprehensive approach to the analysis of decision-making processes within the study.

The study used the conceptual model proposed by A.Y. Maksymov (2025), which reflected the relationship between information situations ISDMR, ISDMU, ISDMF that may arise during decision-making, i.e., the relationship between information situations of decision-making under conditions of risk (Risk, R), complete uncertainty (Uncertainty, U), and fuzzy information (Fuzzy, F). This model is called the "R-U-F" model of possible information decision-making situations. Its representation in the form of a Venn diagram is shown in Figure 1, helped to clearly present possible information situations of decision-making and facilitate identification of the nature of the decision-making problem and substantiation for choosing appropriate methods for solving it.

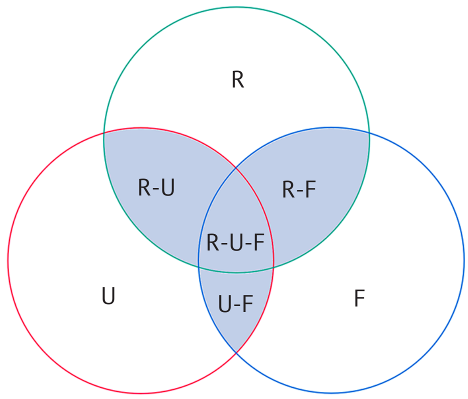

Figure 1. Set-theoretic "R-U-F" model of possible information decision-making situations under conditions of risk, uncertainty, and fuzzy information
Source: created by the authors based on A.Y. Maksymov (2025)

The following is a description of the components of the R-U-F model that intersect (Maksymov, 2025): risk and uncertainty (R-U): any risk is a manifestation of uncertainty, but uncertainty does not always lead to risk. For example, partial availability of statistical data if there is no complete confidence in the parameters. The R-U intersection shows that risk is a quantitative aspect of uncertainty and corresponds to a situation of partial uncertainty; risk and fuzzy information (R-F): fuzzy information can increase risk because it makes it difficult to accurately assess the probabilities and consequences of events. For example, decisions with probabilistic estimates but fuzzy criteria or results; uncertainty and fuzzy information (U-F): fuzzy information increases the level of uncertainty because it makes it harder to make decisions. In this case, this means a complete lack of certainty in the context of fuzzy information; risk, uncertainty, and fuzzy information (R-U-F): the most difficult case is when all three information decision-making situations are present. The common area of the three information situations indicates that the presence of fuzzy information simultaneously increases the level of uncertainty and risk. The intersections of the components of the R-U-F model reflect the relationships between information decision-making situations under conditions of risk, uncertainty, and fuzzy information.

RESULTS AND DISCUSSION

The "R-U-F" model of possible information decision-making situations allows classifying known and creating new decision-making methods according to the type of situation. The above model can also serve as a basis for the development of adaptive information technology, which allows choosing or combining methods depending on the presence of R, U, and F factors in the decision-making problem being solved. In order to implement the capabilities provided by the "R-U-F" model, it is necessary to make a formal description of all information decision-making situations presented in Fig. 1: R, U, F, R-U, R-F, U-F, R-U-F.

1. Model of the information situation of decision-making under risk conditions (*R*):

$$MISDMR = \{A, \Theta, P, F\}, \tag{5}$$

where A, Θ, F – sets of the form (2), (3), (4) accordingly, P – set of risk levels, which depend on the probability of possible occurring states Θ of environment E:

$$P = \{p_1, p_2, \dots, p_S\}, \tag{6}$$

$p_j = p(\theta_j)$ – probability of occurrence of the condition θ_j environment E, $j = \overline{1, S}$ that satisfy the condition:

$$p_j \in [0; 1], \sum_{j=1}^{S} p_j = 1, \tag{7}$$

F – evaluation functional of the form (4).

2. Model of the information situation of decision-making under conditions of complete uncertainty (*U*):

$$MISDMR = \{A, \Theta, U, F\}, \tag{8}$$

where U – set of levels of uncertainty of the environment E:

$$U = \{u_1, u_2, \dots, u_S\}, \tag{9}$$

which corresponds to a situation of complete lack of information about the risk levels $P = \{p_1, p_2, \dots, p_S\}$, in this case, as a rule:

$$u_j = p_j = 1/S. \tag{10}$$

3. Model of the information situation of decision-making under conditions of fuzzy information (*F*):

$$MISDMR = \{A, \Theta, L, F\mu\}, \tag{11}$$

where in the evaluation functionality values $F\mu$:

$$f\mu_{ij} = \mu_{ij} = \mu(A_i, \theta_j),\ i = \overline{1, N}, j = \overline{1, S}, \tag{12}$$

are fuzzy estimates that characterise the "gain" or "loss" of the decision-maker when choosing a decision A_i, if the environment will be (or is) in the state of θ_j, presented in the form of linguistic assessments from the set:

$$L = \{L_1, L_2, \dots, L_r\}, \tag{13}$$

that is $\mu_{ij} \in L, i = \overline{1, N}, j = \overline{1, S}$, with fuzzy estimates from a set of linguistic assessments L in calculations, they can be represented, in particular, in the form of triangular, or trapezoidal fuzzy numbers.

4. Model of the information situation of decision-making under conditions of partial uncertainty (R-U):

$$MISDMR = \{A, \Theta, P, U, F\}, \tag{14}$$

where P – multiple risk levels:

$$P = \{p_1, p_2, \dots, p_k\}, 1 \le k < S, \tag{15}$$

$p_j = p(\theta_j)$ – probability of occurrence of the condition θ_j of environment E that satisfy the condition $p_j \in [0; 1]$, $j = \overline{1, k}$, U – set of levels of partial uncertainty of the form:

$$U = \{u_{k+1}, u_{k+2}, \dots, u_S\}, \tag{16}$$

where:

$$u_j = \frac{1 - \sum_{r=1}^{k} p_r}{S - k}, u_j \in [0,1],\ j = \overline{k+1, S}, \tag{17}$$

with this:

$$\sum_{j=1}^{k} p_j + \sum_{j=k+1}^{S} u_j = 1. \tag{18}$$

5. Model of the information situation of decision-making under risk and fuzzy information (R-F):

$$MISDMR = \{A, \Theta, P, L, F\mu\}, \tag{19}$$

where the set P is defined by the relations (6), (7), L – set of fuzzy estimates of the form (13), and in the evaluation functional $F\mu$ the quantities $f\mu_{ij} = \mu_{ij}$ – fuzzy estimates corresponding to condition (12).

It should be noted that there may be situations when the evaluation functionality $F\mu$ of part of the values $f\mu_{ij} = f\mu(A_i, \theta_j)$ may be clear estimates $f_{ij} = f(A_i, \theta_j)$, and some of the fuzzy estimates:

$$f\mu_{kl} = \mu_{kl} = \mu(A_k, \theta_l), \text{where } i \ne k, j \ne l. \tag{20}$$

In such situations, it is necessary to perform the procedure for phasing values $f_{ij} = f(A_i, \theta_j)$ for the purpose of further use in calculations of fuzzy numbers.

6. Model of the information situation of decision-making under conditions of uncertainty and fuzzy information (U-F):

$$MISDMR = \{A, \Theta, U, L, F\mu\}, \tag{21}$$

where the set U meets the conditions (9), (10), L – set of fuzzy estimates of the form (13), and in the evaluation functional $F\mu$ he quantities $f\mu_{ij} = \mu_{ij}$ – fuzzy estimates that meet condition (12), or meet the conditions of the MISDMRF model, when part of the estimates $f\mu_{ij}$ may be clear estimates, and some of them may be fuzzy estimates.

7. Model of the information situation of decision-making under conditions of risk, uncertainty and fuzzy information (R-U-F):

$$MISDMR = \{A, \Theta, P, U, L, F\mu\}, \quad (22)$$

where P – set of risk levels of the form (15), U – set of uncertainty levels, either complete uncertainty of the form (9), (10) or partial uncertainty of the form (16), (17), with elements of sets P and U satisfying condition (18), L – set of fuzzy estimates of the form (13), and in the evaluation functional $F\mu$ values $f\mu_{ij} = \mu_{ij}$ – fuzzy estimates that either satisfy condition (12), or correspond to the case when part of the values $f\mu_{ij}$ may be crisp estimates, and the remaining values are fuzzy estimates, i.e., condition (20) is satisfied. The *MISDMRUF* model (22) is a generalisation of models (5)-(7), (8)-(10), (11)-(13), (14)-(18), (19)-(20), (21) and it can be adapted to various information decision-making situations that correspond to the information situations of the R-U-F conceptual model.

For the case when the set in (22) P contains S elements, i.e., satisfies conditions (6), (7), and sets U and L empty ($U = \emptyset$, $L = \emptyset$), and $F\mu = F$ type (4), there is an informational situation of decision-making under risk conditions. For the case when (22) $P = \emptyset$, $L = \emptyset$ and $F\mu = F$ of the form (4), that is, conditions (8)-(10) are met, and an information situation in decision-making occurs under conditions of complete uncertainty. For the case where in (22) $P = \emptyset$, $U = \emptyset$, $L = \emptyset$ and $F\mu$ all $f\mu_{ij} = \mu_{ij}$ – fuzzy estimates, i.e., conditions (12)-(13) are met, respectively, there is an information situation of decision-making under conditions of fuzzy information.

For the case when in (22) $P = \emptyset$ $(1 \le k < S)$, $U = \emptyset$, $L = \emptyset$ and $F\mu = F$ of the form (4), i.e., conditions (14)-(18) are met, then an information situation of decision-making occurs under conditions of partial uncertainty. For the case where in (22) the set P has S elements, i.e., satisfies conditions (6), (7), set $U = \emptyset$, and in the evaluation functionality $F\mu$ values $f\mu_{ij} = \mu_{ij}$ – fuzzy estimates meeting condition (12), or when part of the estimates $f\mu_{ij}$ there may be clear estimates, and some of them are fuzzy estimates, i.e., condition (20) is met, then there is an information situation of decision-making under conditions of risk and fuzzy information. For the case where in (22) $P = \emptyset$, U meets the conditions (9), (10), L – a set of fuzzy estimates of the form (13), and in the estimated functionality $F\mu$ values $f\mu_{ij} = \mu_{ij}$ – fuzzy estimates that meet condition (12), an information situation of decision-making occurs under conditions of uncertainty and fuzzy information.

If the situations of the set Θ of environment E, so that the situations are initially located θ_j for which the probability of their occurrence is known $p_j = p(\theta_j), j = \overline{1, k}$, where $k < S$, and then located situations θ_j $j = \overline{k+1, S}$), for which the probabilities of their occurrence are unknown, i.e., a set of levels of partial uncertainty U of the form (16)-(18) is nonempty, while, for certainty, it is assumed that in the estimated functional $F\mu$ values $f\mu_{ij} = \mu_{ij}$ $(i = \overline{1, N}, j = \overline{1, k})$ – clear estimates, and values $f\mu_{ij} = \mu_{ij}$ $(i = \overline{1, N}, j = \overline{k+1, S})$ – fuzzy estimates, then a detailed model of the information situation of decision-making *MISDMRUF* under conditions of risk, uncertainty, and fuzzy information, form (22) is characterised by a matrix of:

Θ	θ_1	θ_2	…	θ_k	θ_{k+1}	θ_{k+2}	…	θ_S
P	p_1	p_2	…	p_k	u_{k+1}	u_{k+2}	…	u_S
A_1	f_{11}	f_{12}	…	f_{1k}	μ_{1k+1}	μ_{1k+2}	…	μ_{1S}
A_2	f_{21}	f_{22}	…	f_{2k}	μ_{2k+1}	μ_{2k+2}	…	μ_{2S}
…	…	…	…	…	…	…	…	…
A_i	f_{i1}	f_{i2}	…	f_{ik}	μ_{ik+1}	μ_{ik+2}	…	μ_{iS}
…	…	…	…	…	…	…	…	…
A_N	f_{N1}	f_{N2}	…	f_{Nk}	μ_{Nk+1}	μ_{Nk+2}	…	μ_{NS}

(23)

Figure 2 shows a model of the decision-making process under risk, uncertainty, and fuzzy information (MDMPRUF) that integrates the set-theoretic R-U-F model (Fig. 1) and the generalised model of the information situation of decision-making MISDMRUF (22).

The key features of the decision-making model under conditions of risk, uncertainty, and fuzzy information are versatility, flexibility, and integrativity. Versatility is shown when considering various combinations of information situations (R, U, F and their combinations), which allows covering a wide range of practical tasks. Flexibility is provided by the presence of several categories of methods, which allows adapting the approach to the specifics of a particular task. Integrativity consists in aggregating results using multiple methods, which increases the reliability of the final solution. This model fully reflects the logic of building information technology for decision-making in complex environments and can be used as a basis for implementing decision support systems (DSS) in various industries. The main stages of implementing a model of the decision-making process in conditions of risk, uncertainty, and fuzzy information, which corresponds to the proposed conceptual model R-U-F of possible information situations of decision-making, are given below.

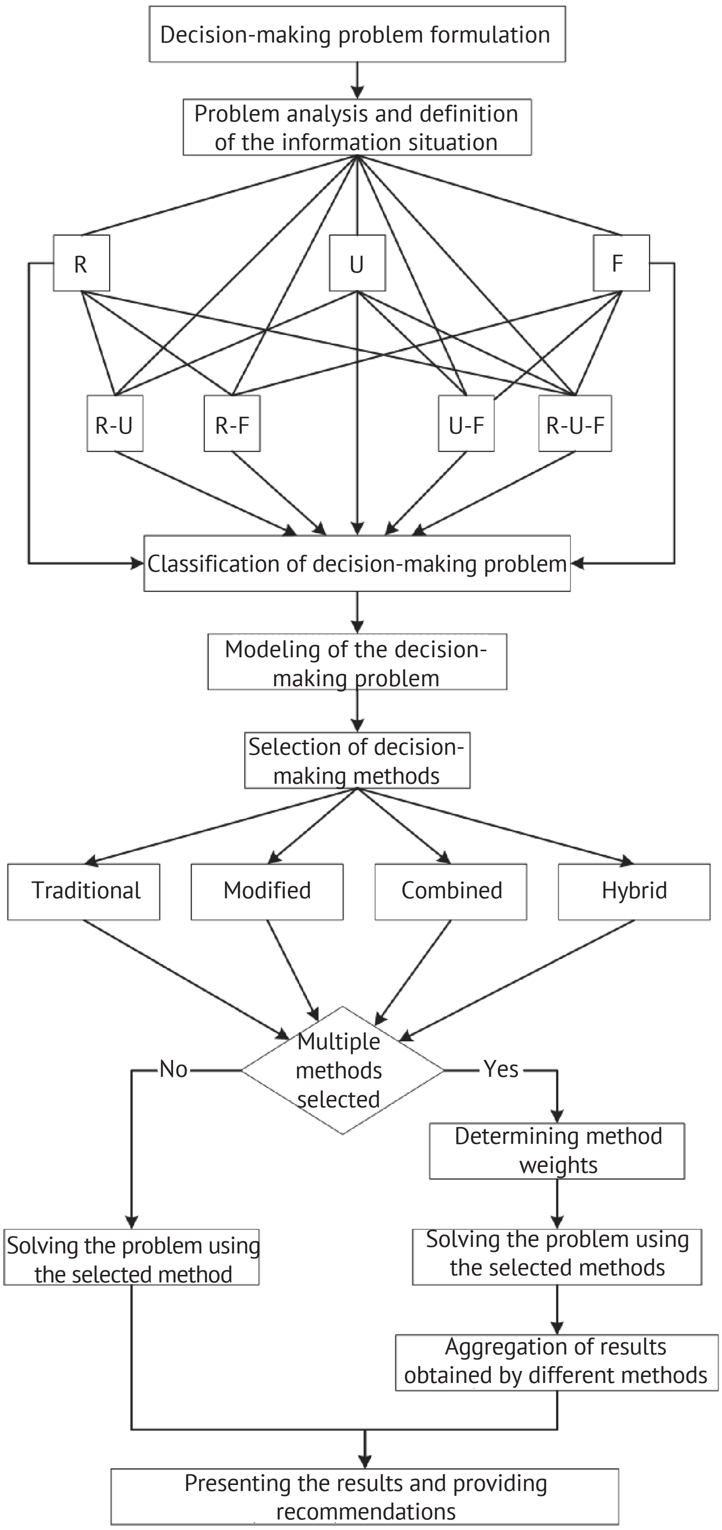

Figure 2. Model of the decision-making process under conditions of risk, uncertainty, and fuzzy information (MDMPRUF)

Source: created by the authors based on A.Y. Maksymov (2025)

Stage 1. Decision-making problem formulation. This stage defines the context and conditions in which the decision is made. A correctly formulated problem is the key to the effectiveness of subsequent analytical and computational procedures. The main steps of problem formulation are given below.

Step 1.1. Defining the purpose of decision-making. The very first task is to clearly define the main goal (or set of goals), the achievement of which is necessary within the framework of a problem situation, that is, the goal can be either single-goal or multi-goal.

Step 1.2. Defining a set of alternatives. This step describes a set of possible alternative solutions that are considered during the selection process. Alternatives can be discrete (for example, specific solutions) or continuous (when the solution belongs to a specific range of values).

Step 1.3. Defining restrictions and acceptable decision-making areas. At this step, the constraints corresponding to the problem condition are formulated. These can be: strict constraints (for example, budget constraints, technical requirements); fuzzy constraints (for example, acceptable risk limits described in fuzzy sets). At this stage, it is important to define a valid area that defines the space of possible solutions.

Step 1.4. Defining the goal of the decision-making task. The decision-making task implies the existence of a clearly formulated goal, according to which alternatives are evaluated. As a rule, this goal is to choose the best alternative according to the specified criteria.

Stage 2. Problem analysis and definition of the information situation. This stage combines two important tasks: deep analysis of the task and determination of the information situation of decision-making. The purpose of this stage was to investigate in detail the initial data, requirements, and conditions of the problem to create a complete picture of the problem and its context. This allows laying the foundation for the next stages and ensuring its relevance and compliance with real conditions.

Task 2.1. Task analysis. This task was aimed at a comprehensive investigation of the problem being solved, in order to clearly understand it and determine key parameters, and involves performing several steps:

Step 2.1.1. Analysis of goals and objectives. At this stage, the industry or sphere within which the task arose is defined, a specific problem that needs to be solved is outlined, and the main goals of the task are analysed, which will determine the area of decision-making, for example: improving efficiency, minimising costs, reducing risks, etc.

Step 2.1.2. Identification of stakeholders. The subjects that are affected by the task (the company's management, government agencies, the public, etc.) and whose interests can influence the criteria and choice of solutions are identified.

Step 2.1.3. Assessment of the complexity and structure of the task. The nature of the alternatives (discrete or continuous), the number of criteria, the presence of a multi-level task structure, and possible conflicts between criteria are analysed.

Step 2.1.4. Defining restrictions. Restrictions that affect the task are highlighted.

Task 2.2. Determination of the information situation of decision-making. This task is to determine the nature of available information about alternatives, criteria, and decision-making environments. When solving this problem, the type and type of information situation of decision-making is identified. Both individual types of these situations (R, U, F) and their combinations (R-U, R-F, U-F, R-U-F) are taken into consideration. Analysis of the information situation of decision-making allows: avoiding erroneous application of methods that do not correspond to the real conditions of the task; ensuring the adequacy of the task model to the real situation; responding to changes in the information environment through the possibility of repeated analysis.

Solving this problem allows clearly structuring the main components of the task, consider the existing limitations and conditions of risk, uncertainty, and fuzzy information that affect decision-making. This task is aimed at determining the available information about the situation, which makes it possible to form a reasonable strategy for further actions based on it. Defining a situation usually involves identifying and evaluating the main factors that influence decision-making, and the degree of confidence or risk associated with each of them. After the analysis, a certain information situation is recorded, which makes it possible to perform further actions. This task involves performing the following steps.

Step 2.2.1. Evaluation of available information. At this stage, it is important to evaluate exactly what data is available for analysis. These can be statistics, expert assessments, previous experience, or actual observations. If the information is incomplete or fuzzy, it is necessary to specify the exact nature of its uncertainty or imprecision. This assessment facilitates informed decision-making and ensures that associated risks are properly considered.

Step 2.2.2. Classification of the type of input information. At this stage, the types of information that the model will work with are determined: clear information – when the values of all parameters of the situation are known accurately; fuzzy information – when there is ambiguity or indistinctness in determining the values of parameters, which requires the use of fuzzy logic; information with elements of uncertainty – when it comes to the lack of sufficient data or uncertainty about the possible consequences of specific alternatives; information with elements of risk – when the probability of occurrence of various states of external conditions is known, to which statistical or other type of analysis can be applied to assess the probabilities of risk.

Step 2.2.3. Identification of critical parameters and factors. After determining the type of input information, it is important to identify key factors that may influence the decision-making process. These can be both internal and external factors. Each of the factors should be analysed for their impact on the choice of alternative solutions.

Step 2.2.4. Determining the level of confidence in data. An important step is to determine the degree of data reliability, which allows distinguishing between important and less significant aspects of the situation. This is especially important when using fuzzy or incomplete information.

Step 2.2.5. Creating a context for problem formulation. The final step of task 2.2 is to create an information context for the next steps. This means a clear understanding of the information situation of decision-making with all its parameters and factors, which allows accurately formulating the problem and determining which actions will be most effective. The context includes both informational and situational aspects that form the basis for decision-making.

Stage 3. Classification of decision-making problem. As a result of completing the previous stages, the task belongs to a certain type of information situations in decision-making.

Stage 4. Modeling of the decision-making problem. At this stage, a mathematical model of the decision-making problem is created that coincides with one of the developed models: MISDMR (5)-(7), MISDMR (8)-(10), MISDMR (11)-(13), MISDMR (14)-(18), MISDMR (19)-(20), MISDMR (21), MISDMR (22).

Stage 5. Selection of decision-making methods. At this stage, one or more methods are selected that most adequately consider the specifics of the problem model (22), (23), the type of input information, risk and uncertainty conditions, and requirements for accuracy, reliability and speed of obtaining results.

Stage 6. Analysis of the number of selected methods. If one method is selected to solve the problem, then step 6.1 is performed. If more than one method is selected, step 6.2 is performed.

Step 6.1. If one method is selected to solve the problem, then the user applies the DSS to solve the problem using the selected method and proceeds to stage 7.

Step 6.2. If more than one method is selected, the following sub-steps are performed.

Sub-step 6.2.1. Determining method weights. Determining the weights of methods allows quantifying their relative significance and coordinating their contribution to the overall solution. For example, the weights of methods can be calculated by comparing them in pairs using the hierarchy analysis method.

Sub-step 6.2.2. Solving the problem using the selected methods. The user applies the DSS to consistently solve the problem for each of the selected methods. At this stage, information technology should load input information and, if necessary, adapt it to the requirements of specific method classes. Specifically, for methods operating under conditions of fuzzy information, it is necessary to fuzzify the data, i.e., convert precise values into a fuzzy format using the framework of fuzzy sets. In cases where the input data is already provided in a fuzzy form, but methods that do not incorporate fuzzy set mechanisms are applied, it is necessary to defuzzify the data, i.e., convert fuzzy estimates into precise values.

Sub-step 6.2.3. Aggregation of results obtained by different methods. At this step, the results obtained by different decision-making methods are integrated into a single consistent solution that considers the impact of each method according to certain weights. The results of each method can be presented at different scales (ratings, utility function values, fuzzy estimates, etc.). To ensure correct aggregation, they are brought to a common unified scale (for example, normalized within the range [0;1]). The results of each method are then multiplied by the corresponding weighting factor, which reflects its significance in the overall decision-making model. This ensures a balance between methods with different influence on decision-making.

Stage 7. Presenting the results and providing recommendations. DSS generates recommendations for choosing the best alternative based on the results of calculations performed in previous stages. The development of recommendations is based on the results of applying decision-making methods selected by the user, which can be presented as a vector of priorities, ranks, etc. Providing recommendations completes the decision-making cycle by translating formalised calculations into practical steps.

The generalised model of the information situation of decision-making MISDMRUF (22) integrates models of other information decision situations that correspond to the information situations of the R-U-F conceptual model, since it includes all their key components. In particular, in the absence of fuzzy estimates, the model is reduced to a model of a decision-making problem under risk or uncertainty conditions, and in the absence of stochastic factors, to models of decision-making problems in a fuzzy environment. Consequently, the MISDMRUF (22) model provides a single formal basis for describing a wide range of information situations of decision-making. In turn, the MISDMRUF model can be interpreted as a model of a decision-making problem that formalises the process of choosing an alternative in conditions of simultaneous presence of risk, uncertainty, and fuzzy information.

The practical value of the proposed MISDMRUF model lies in the fact that it allows systematising the process of analysing the information environment of the problem and provides a methodological basis for choosing effective decision-making methods. Simultaneously, the limits of application of the model are determined by the class of decision-making problems in complex information conditions. The model is primarily focused on tasks that combine statistical data, expert assessments, and fuzzy information, which is typical for managerial, economic, engineering, and socio-economic systems.

The results of the study are consistent with the analysed literature, which also emphasises the need to systematise and formalise information situations in order to increase the validity of decision-making. S.A. Us & L.S. Koriashkina (2018) investigated typical information situations that arise in the process of choosing alternatives, in particular, in conditions of risk, uncertainty, and fuzzy information. The researchers emphasised the need to formalise input information, which allows for a more systematic approach to the decision-making process and increases the accuracy of evaluating alternatives. O.F. Voloshyn & S.O. Mashchenko (2018) reviewed the fundamentals of decision theory, including basic principles, utility theory, expert procedures, and approaches to decision-making in terms of certainty, conflict, and fuzzy information. Their study demonstrated the relevance of systematising information and using structured approaches to improve the effectiveness of the decision-making process.

S.K. Kaya *et al*. (2022) proposed a hybrid model of fuzzy multi-criteria decision-making based on the Fuzzy Best-Worst Method (F-BWM) and RAFSI, focused on considering the uncertainty of expert assessments and improving the stability of ranking alternatives. The results showed the effectiveness of integrating fuzzy approaches to accurately evaluate alternatives. The MISDMRUF model developed in this study extended this approach by integrating risk, uncertainty, and fuzzy information, and their combinations, allowing for systematic classification of information situations and the choice of appropriate decision-making methods. M. Aregbesola *et al*. (2025) applied fuzzy logic to risk management in project tasks, demonstrating the effectiveness of quality information processing and risk assessment in various scenarios. In comparison, the MDMPRUF model focuses on formalising the decision-making process, providing the ability to use multiple methods to select alternatives and aggregate results. This approach increases flexibility and practical applicability in complex environments of risk, uncertainty and fuzzy information.

A. Puška *et al*. (2022) proposed a hybrid Z-numbers – Fuzzy LMAW – Fuzzy CRADIS model that considers both the fuzziness and reliability of expert assessments. The conducted experiments showed the stability of the model and the ability to reduce the level of uncertainty. MISDMRUF in this study combines these factors together with risk and uncertainty, which allows comprehensively classifying information situations and choose methods based on their characteristics. MDMPRUF, in turn, formalises the decision-making process and provides multiple methods with the ability to aggregate results, increasing efficiency and practical applicability. The study by A. Ali *et al*. (2024) proposed a three-step method of multi-criteria decision-making using fuzzy soft relations and additive consistency, which allows simultaneous ranking, classification and selection of alternatives in complex information situations. MISDMRUF extends this approach by integrating risk, uncertainty, and fuzzy information into a wider range of situations, while MDMPRUF focuses on formalising the decision-making process and aggregating results to improve the accuracy of evaluating alternatives.

M. Kozielski *et al*. (2026) considered aggregation functions for working with fuzzy data, improving the consistency and interpretability of solutions. The MISDMRUF model integrates aggregation into the broader context of information situations, combining risk, uncertainty, and fuzzy information to ensure a systematic and consistent decision-making process. I. Hasiuk & O. Ivanii (2024) analysed the combination of qualitative and quantitative criteria and the integration of various logic systems in multi-criteria control problems. The results showed that the effectiveness of decision-making depends on the standardisation of procedures and a clear distribution of roles. MISDMRUF complies with these principles by integrating various methods and criteria into a single system, which increases the structure and efficiency of alternative selection.

The study by O. Syniuk (2025) analysed the relationship between cognitive factors and analytical methods, demonstrating how peer review and cognitive biases affect the choice of alternatives. The MISDMRUF model takes these aspects into account by combining information situations of decision-making in conditions of risk, uncertainty and fuzzy information, which increases the reliability of results and practical effectiveness of decision-making. The study by M. Aslantas *et al*. (2025) proposed an integrated fuzzy multi-criteria approach for assessing the potential risks of autonomous vehicles, which considers expert assessments and optimistic and pessimistic scenarios, demonstrating the effectiveness and rationality of the choice of methods in the analysis of complex and uncertain information situations. R. Rajesh (2024) analysed decision-making methods in conditions of uncertainty during pandemics using Grey models, which demonstrated the effectiveness of these approaches for decision-making in complex and incompletely defined information situations.

J. Więckowski *et al*. (2025) proposed the Fuzzy RANCOM method for modelling uncertainty in decision-making processes, which provides effective determination of the weights of criteria and reduces the impact of inaccuracies in expert assessments, demonstrating the applicability of fuzzy multi-criteria approaches in complex and incompletely defined information situations. Thus, research by R. Rajesh (2024), V.J. Montero *et al*. (2025), M. Aslantas *et al*. (2025) and J. Więckowski *et al*. (2025) demonstrated the practical effectiveness of risk and uncertainty modelling, with MISDMRUF consistent with these approaches, providing an integrated assessment of risk, uncertainty, and fuzzy information, and MDMPRUF formalising the decision-making process and enabling multiple methods with aggregated results to improve efficiency.

The results of the study showed that the MISDMRUF and MDMPRUF models, on the one hand, are consistent with a number of classical and contemporary studies in the field of decision-making, and, on the other hand, fill in existing gaps, providing a systematic and integrated approach to the classification of information situations of decision-making and the choice of decision-making methods under complex conditions of risk, uncertainty, and fuzzy information.

CONCLUSIONS

As a result of the research conducted based on the conceptual model R-U-F, mathematical models of all possible information decision-making situations were constructed: R, U, F, R-U, R-F, U-F, R-U-F. A generalised model of the information situation of decision-making MISDMRUF of the form (22), (23) was also presented, which can be interpreted as a problem of single-criteria decision-making under conditions of risk, uncertainty, and fuzzy information. A model of the MDMPRUF decision-making process was developed, focused on the conditions of risk, uncertainty, and fuzzy information, which used the proposed mathematical model of possible information situations of decision-making of the MISDMRUF type. The MDMPRUF model provided for the possibility of using one or more methods for selecting alternatives, in particular, traditional, modified, combined, and hybrid decision-making methods, the results of which can be aggregated. The proposed model of the MDMPRUF decision-making process defines its main tasks, and structures the sequence of key stages and steps necessary for solving the choice problem in complex information conditions. It can be the basis for the development of adaptive information technology, which will allow choosing or combining methods depending on the presence of R, U, and F factors in the decision-making problem.

Prospects for further research are: development of modified, combined and hybrid methods that solve decision-making problems in information situations R-U, R-F, U-F, R-U-F, and can be used at Stage 5 of the proposed MDMPRUF decision-making model; expansion of the proposed model MISDMRUF information situations of decision-making on the problem of multi-criteria choice in conditions of risk, uncertainty, and fuzzy information, and in the development of appropriate methods for their solution; the development of DSS based on the proposed models and methods for solving decision-making problems in conditions of risk, uncertainty, and fuzzy information.

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CONFLICT OF INTEREST

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REFERENCES

[1] Ali, A., Rehman, N., Ali, M., & Hila, K. (2024). A novel approach to three-way decision model under fuzzy soft dominance degree relations and emergency situation. *Expert Systems with Applications*, 239, article number 122369. doi: 10.1016/j.eswa.2023.122369.

[2] Aregbesola, G.D., Asghar, I., Akbar, S., & Ullah, R. (2025). Fuzzy logic model for informed decision-making in risk assessment during software design. *Systems*, 13(9), article number 825. doi: 10.3390/systems13090825.

[3] Aslantas, M., Gündoğdu, F.K., & Moslem, S. (2025). Evaluating the potential risks posed by autonomous vehicles by using a decomposed fuzzy multi-criteria decision-making model. *Transportation Engineering*, 21, article number 100372. doi: 10.1016/j.treng.2025.100372.

[4] Gomes, M.I., & Martins, N.C. (2022). *Mathematical models for decision making with multiple perspectives: An introduction*. Boca Raton: CRC Press. doi: 10.1201/9781003015154.

[5] Hasiuk, I., & Ivanii, O. (2024). Logical-formal and criteria methods of management decision-making in public administration. *Scientific Perspectives*, 8(50), 112-129. doi: 10.52058/2708-7530-2024-8(50)-112-129.

[6] Høj, N.P., Kroon, I.B., Nielsen, J.S., & Schubert, M. (2025). System risk modelling and decision-making – reflections and common pitfalls. *Structural Safety*, 113, article number 102469. doi: 10.1016/j.strusafe.2024.102469.

[7] Jaccard, J., & Jacoby, J. (2020). *Theory construction and model-building skills: A practical guide for social scientists (2nd ed.)*. New York: The Guilford Press.

[8] Kaya, S.K., Pamucar, D., & Aycin, E. (2022). A new hybrid fuzzy multi-criteria decision methodology for prioritizing the antivirus mask over COVID-19 pandemic. *Informatica*, 33(3), 545-572. doi: 10.15388/22-INFOR475.

[9] Kozielski, M., Prokopowicz, P., & Mikolajewski, D. (2026). New fuzzy aggregators for ordered fuzzy numbers for trend and uncertainty analysis. *Electronics*, 15(2), article number 309. doi: 10.3390/electronics15020309.

[10] Li, T., Ali, M.K.M., & Zhou, X. (2025). Interval-valued hesitant fuzzy decision model based on improved projection measure. *International Journal of Fuzzy Systems*. doi: 10.1007/s40815-025-02113-x.

[11] Maksymov, A.Y. (2025). *Information technology for solving multi-criteria decision-making problems under conditions of risk, uncertainty and fuzzy information*. (Doctoral dissertation, Cherkasy State Technological University, Cherkasy, Ukraine).

[12] Montero, V.J., Logrosa, G., Calorio, J.L., Lato, J.I., Hassall, M., & Mata, M.A. (2025). Risk modeling with Bowtie method for decision-making towards public health and safety. *Safety Science*, 185, article number 106777. doi: 10.1016/j.ssci.2025.106777.

[13] Munier, N. (2021). *Mathematical modelling of decision problems: Using the SIMUS method for complex scenarios*. Cham: Springer International Publishing. doi: 10.1007/978-3-030-82347-4.

[14] Puška, A., Božanić, D., Nedeljković, M., & Janošević, M. (2022). Green supplier selection in an uncertain environment in agriculture using a hybrid MCDM model: Z-numbers-Fuzzy LMAW-Fuzzy CRADIS model. *Axioms*, 11(9), article number 427. doi: 10.3390/axioms11090427.
[15] Rajesh, R. (2024). Grey models for data analysis and decision-making in uncertainty during pandemics. *International Journal of Disaster Risk Reduction*, 113, article number 104881. doi: 10.1016/j.ijdrr.2024.104881.
[16] Syniuk, O. (2025). Behavioral and analytical aspects of managerial decision-making in a changing environment. *Economy and Society*, 80. doi: 10.32782/2524-0072/2025-80-53.
[17] Us, S.A., & Koriashkina, L.S. (2018). *Models and methods of decision making*. Dnipro: Dnipro University of Technology.
[18] Voloshyn, O.F., & Mashchenko, S.O. (2018). *Models and methods of decision making* (3rd ed.). Kyiv: Liudmyla Publishing House.
[19] Więckowski, J., Kizielewicz, B., & Sałabun, W. (2025). Fuzzy RANCOM: A novel approach for modeling uncertainty in decision-making processes. *Information Sciences*, 694, article number 121716. doi: 10.1016/j.ins.2024.121716.
[20] Zheldak, T., Koryashkina, L., & Us, S. (2020). *Fuzzy sets in management and decision-making*. Dnipro: Dnipro University of Technology.

Моделі інформаційних ситуацій прийняття рішень в умовах ризику, невизначеності та нечіткої інформації

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Анотація. Актуальність зумовлена потребою у створенні математичного забезпечення концептуального підходу, який би дозволив систематизувати інформаційні ситуації прийняття рішень в умовах ризику, невизначеності, нечіткої інформації та забезпечив обґрунтований вибір методів для розв’язання практичних задач прийняття рішень у цих ситуаціях. Мета полягала в розробці математичних моделей інформаційних ситуацій прийняття рішень в умовах ризику, невизначеності, нечіткої інформації та їх можливих комбінацій, а також у побудові на їх основі моделі процесу прийняття рішень, що передбачає можливість застосування кількох методів вибору альтернатив і агрегування їх результатів для підвищення ефективності прийняття рішень. Методологія дослідження ґрунтувалася на системному підході із застосуванням теорії множин, теорії ймовірностей, теорії нечітких множин, теорії і методів прийняття рішень, математичного моделювання для формалізації інформаційних ситуацій прийняття рішень. Розроблено математичні моделі інформаційних ситуацій прийняття рішень в умовах ризику (Risk, R), повної невизначеності (Uncertainty, U), нечіткої інформації (Fuzzy, F), а також можливих комбінацій ситуацій: R-U, R-F, U-F, R-U-F. Узагальнену модель інформаційних ситуацій прийняття рішень R-U-F (MISDMRUF) інтерпретовано як модель задачі прийняття рішень, що формалізує процес вибору альтернативи в умовах одночасної наявності ризику, невизначеності та нечіткої інформації. Це дозволило використовувати наявні та створювати нові методи прийняття рішень залежно від характеристик інформаційної ситуації прийняття рішень. Запропоновано модель процесу прийняття рішень в умовах ризику, невизначеності та нечіткої інформації (MDMPRUF), визначено її завдання, основні етапи реалізації та ключові особливості, зокрема універсальність, гнучкість та інтегративність. Результати засвідчили, що запропоновані моделі MISDMRUF та MDMPRUF узгоджуються з рядом досліджень у теорії прийняття рішень, але водночас заповнюють наявні прогалини, забезпечуючи системний, інтегрований підхід до класифікації інформаційних ситуацій прийняття рішень та вибору методів прийняття рішень у складних умовах ризику, невизначеності й нечіткої інформації. Запропоновані математичні моделі та відповідний підхід до розв’язання задач прийняття рішень можуть стати основою для створення інформаційних технологій підтримки прийняття рішень у складних умовах

Ключові слова: математичні моделі; моделі підтримки прийняття рішень; методи прийняття рішень; системи підтримки прийняття рішень; інформаційні технології