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# MODELING DECISION-MAKING UNDER RISK AND UNCERTAINTY

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## ABSTRACT

**Objective:** The purpose of the article was to analyze existing decision-making models under risk, as effective decision-making is critically important for achieving sustainable development in organizations and government structures in today's unstable world.

**Methods:** The authors examine modeling and risk management methods in corporate strategy development. Given the high level of competition in modern business, making well-informed decisions requires a comprehensive assessment of the situation and a reliable forecast of future development.

**Results:** The study analyzed quantitative decision-making methods in the implementation of industrial company strategies. The findings identify the most relevant models and methods used for decision-making under uncertainty and risk.

**Conclusion:** It is concluded that decision-making theories under risk remain relevant, though their applicability depends on the context. While mathematically rigid models provide a strong theoretical foundation, flexible approaches that account for psychological factors offer greater practical value. Future advancements should focus on integrating these theories with technological and interdisciplinary research to enhance their predictive accuracy and real-world applicability.

**Keywords:** Models; Decision-making; Strategy; Risk; Company.

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## INTRODUCTION

The modern world is characterized by a high level of instability and vulnerability to changes, both global and local – especially when these changes occur in leading countries. Under such conditions, forecasting the development of various scenarios based on past experiences, allowing for only minor deviations while considering the growth rate of social indicators and technological progress, is no longer relevant. In today's reality, each developing scenario gives rise to numerous unprecedented situations, complicated by new circumstances and an almost unlimited number of influencing variables (Domashenko, Finogenova, 2010). However, decision-making remains a necessary process in all spheres of life, even under such conditions.

The decision-making process has always been based on the volume and quality of information gathered to verify a particular course of action. When making a choice, a decision-maker (DM) must consider different scenarios, assess their impact on processes, justify and evaluate their usefulness in the context of a modernized process, calculate risks, and anticipate possible consequences. This sequence of actions ultimately forms the rationale for choosing a particular decision.

However, factors such as globalization, the acceleration of technological progress, the instability of global and local markets, political system volatility, and escalating geopolitical tensions – including political pressure between countries, sanctions, and international restrictions – affect the completeness and accuracy of the information necessary for decision-making. Additionally, the consequences of such decisions become far less predictable.

Under these conditions, decision-makers are forced to rely on probabilistic scenarios, risk assessments, and intuition. Unlike times of greater stability, when the primary question guiding decision-making was, "Which decision will bring the most benefit?", today, the more relevant question is, "Which decision will cause the least harm in the event of unforeseen circumstances?" The ability of decision-makers to adequately respond to changing external conditions, predict the likelihood of internal changes, and make well-balanced decisions accordingly is a key factor in the success of individual companies in the market, market ecosystems, and even entire states.

The concept of "risk" is present in almost every area of society's activities. (Algin, 1991; Vlasov, 2013; Ivliev, 2013; Kiseleva & Simonovich, 2014; Kiseleva, 2002; Hohlov, 2003). Risk significantly impacts both tactical decision-making and the

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strategic development of organizations, corporations, and governments. The key areas most affected by risk include:

•Business (operational and production risks, personnel-related risks, strategic and innovative risks)

•Finance (credit risks, market risks, liquidity risks, operational risks)

•Public administration (geopolitical risks, national security risks, risks related to government finance management)

•Healthcare (service quality, patient safety, medical resource management)

•Engineering and construction (compliance with standards, technical risks, logistical risks)

•Information technology (cybersecurity, data protection, system reliability)

•Ecology and natural resources (natural and man-made disasters, environmental pollution, resource depletion)

Risks have a multifaceted impact on society's activities, requiring constant attention to their assessment and management. Effective risk management not only minimizes potential negative consequences but also allows for the identification and utilization of opportunities for development and growth – even in times of crisis (Avdiyskiy, 2012).

Quantitative analysis methods for managerial decision-making have proven to be highly effective when applied in industrial companies, ensuring accuracy and reliability in evaluating the efficiency and degree of risk impact on their marketing strategies.

The purpose of this article is to analyze and compare key decision-making models under risk, exploring their theoretical foundations, practical applications, and limitations.

## METHODOLOGY

During this research, the authors employed scientific literature analysis methods. The literature search was conducted using academic databases such as Scopus, Web of Science, and Google Scholar. The following keywords were used for the search: decision-making, strategy, company.

The selection of sources was based on the following criteria:

•Sources had to be in English or Russian.

•Sources had to contain theoretical data reflecting various approaches to the

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research problem.

•Sources had to include an analysis of approaches and strategies relevant to the study's topic.

This article examines key aspects, starting with the definition of risk and its classification, which helps to better understand the nature of uncertainty, the reasons for its emergence in decision-making situations, and possible ways to manage it. The risk classifications presented provide a structured framework for studying decision-making approaches under risk conditions and enable an analysis from different perspectives of social life.

A central focus of this study is the examination of theories and corresponding models that describe the decision-making process under risk and justify the behavior of an agent/individual within a particular approach.

## RESULTS

### *Concept and Types of Risks*

The term "risk" is often associated with a predominantly negative meaning – commonly understood as an event that may result in adverse consequences such as damage or loss. However, such an event is a risk factor – a condition or characteristic of the environment that increases the likelihood of a negative situation occurring.

Currently, there are numerous definitions of risk that reveal its essence from the perspective of various sciences. In economic sciences, risk is interpreted differently as well. For instance, in economic theory, risk is often regarded as a form of "negative" product that can be freely bought and sold (Kiseleva, 2002; Chernova & Kudryavtsev, 2003; Weatherford & Kimes, 2003)

In a general sense, risk is understood as the possibility of an unfavorable event occurring in the future. An event is considered unfavorable if it leads to failure to achieve a set goal and/or loss of resources. Risk can be defined as a characteristic of the possibility and degree of attainability of a potential result, depending on a particular action or managerial decision – that is, a possible combination of the event's probability and its consequences (Rostova, 2013; Dubrov et al., 2003; Chagina, 2011).

To work effectively with different categories of risks, they are classified according to various criteria, which may include source, nature of occurrence, type of impact, and

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field of application. The main types of risks are classified as follows:

- Financial risks (credit, market, liquidity, interest rate risks)
- Operational risks
- Strategic risks
- Legal and regulatory risks
- Environmental risks
- Reputational risks
- Technological risks
- Political risks

In modern decision-making, a decision-maker (DM) evaluates not only risks directly related to their field but also risks from other categories due to their potential indirect influence on the situation. In today's unstable environment, risk assessment has become more complex and multidimensional – requiring an examination of as many influencing factors and domains as possible to identify even the most non-obvious risks, whose impact can be highly unpredictable.

**Table 1.** Methods for Assessing Risk Levels

| Method | Description |
|---|---|
| «Decision Tree» | A graphical method of quantitative analysis. By mapping decision points and connecting them, it becomes easier to visualize multiple strategic options and their consequences, considering external environmental conditions. This method is used in situations requiring sequential structuring of possible decisions. |
| Statistical Decision Method | A quantitative analysis method utilizing tools such as standard deviation, coefficient of variation, and variance. It involves the collection, processing, and use of statistical observations. Data are considered quantitative characteristics of certain objects – if economic in nature, they relate to economic entities. These data emerge under various influencing factors, some of which are uncontrollable, leading to randomly determined values. Therefore, special mathematical statistical methods are required to analyze and process this data. |
| Stochastic Programming | This method studies mathematical programming problems where data is randomly determined. There are three main approaches to solving such problems:<br>Expected Value Approximation – Replacing randomly assigned parameters with their mean values to obtain mathematical expectation-based solutions.<br>Two-Stage Linear Programming – The first stage involves solving for demand uncertainty using mathematical expectation. The second stage determines the most suitable control vector for production based on fixed product demand.<br>Chance-Constrained Programming – A method where probability constraints are used to formulate and solve optimization problems. |

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| | |
|---|---|
| Monte Carlo Method | In many cases, the methods mentioned above do not fully meet the reliability and accuracy requirements necessary for risk and efficiency assessment in marketing environments. Monte Carlo simulation provides more accurate and effective risk assessment by predefining and distributing random numbers based on probabilistic parameters of external and internal factors (Konstantinov, 2013).<br>Data distribution is based on historical statistical trends. However, not all organizations have access to sufficient historical data. In such cases, the Monte Carlo method is used to estimate risks. This method involves recalculating all data upon the introduction of new random numbers, selecting values of random variables through stochastic generation (Ivliev, 2013).<br>The results are then grouped and analyzed using statistical methods to calculate risk indicators in various research fields (e.g., marketing research) (Kiseleva, 2002).<br>The Monte Carlo method evaluates multiple risk parameters, including standard deviation and mathematical expectation (Vlasov, 2013). It is one of the most effective techniques for marketing research, helping to identify the most optimal strategy within predefined limits. Additionally, it is successfully applied in marketing risk management. |

The next step is to examine existing risk management models. To minimize risks, it is necessary to implement measures to reduce them, which in turn leads to additional costs – both financial and resource-based (Cross et al., 2009). However, such costs can have a negative impact on marketing strategies, reducing their effectiveness.

Thus, when setting goals, models are applied that aim to minimize costs and optimize risk-reduction measures (Redhead & Hughes, 2005).

For this reason, optimization methods have gained widespread use in practice. These methods focus on:

- Minimizing costs while maintaining a given level of risk
- Minimizing risk while staying within a predefined maximum allowable cost

The main approaches to risk management and minimization include:

1. Reducing uncertainty
2. Calculating the probability of risk events
3. Limiting exposure to risk through diversification or risk-sharing

By strategically implementing these methods, companies can achieve a balance between cost efficiency and risk mitigation, ensuring long-term sustainability and competitiveness.

### *Key Theories and Models of Decision-Making Under Risk*

Economic decisions under uncertainty are made within the framework of

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decision-making theory – an analytical approach to selecting the best action (alternative) or sequence of actions.

Even though in modern conditions, the decision-making process can be significantly complicated due to high-speed global changes, existing decision-making theories fundamentally remain relevant. They form the basis for both theoretical exploration of new aspects of the process and its practical application.

There are three key theoretical approaches to decision-making under risk, each involving unique methods and principles for evaluating and selecting optimal options:

- Expected Utility Theory
- Prospect Theory by D. Kahneman and A. Tversky
- Rational Choice Concept

***Expected Utility Theory (Utility Model)***

Expected Utility Theory (EUT) was first published in the second edition of the book Theory of Games and Economic Behavior (von Neumann & Morgenstern, 1944) and was initially presented as a supplement to game theory. In its original form, the authors enhanced game theory with the axiomatic foundation of expected utility.

EUT provides a mathematical basis for analyzing and predicting the behavior of rational agents under risk and uncertainty.

Within this theory, rational agents seek to maximize their utility when making decisions. "Utility" refers to the measure of satisfaction or value (a certain benefit) that an agent gains from a specific outcome.

Within EUT, each possible outcome of a given situation is assigned a utility value (coefficient) that reflects the subjective value of the outcome for the agent. The utility formula U(x) expresses the dependence of utility on the level of wealth x.

Expected utility is the key calculated unit in EUT. When a decision involves risk, each outcome has a specific probability of occurring. Expected utility is calculated as the sum of the products of each possible outcome and its respective probability.

The formula for expected utility is as follows:

$$EU = \sum p_i U(x_i) \quad (1)$$

Where:

- EU = Expected utility
- $p_i$ = Probability of outcome iii

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•$U(x_i)$ = Utility of outcome iii

Within Expected Utility Theory (EUT), the principle of expected utility maximization is also considered. It assumes that a rational agent selects the alternative for which the expected utility value is maximal. This implies the agent's ability to objectively assess the probabilities and utilities of different outcomes.

The mathematical formalization of EUT is based on four key axioms, which ensure the rationality of choice – allowing the agent's preferences to be represented by an expected utility function:

•Axiom of Completeness (Given two alternatives A or B, the agent will either prefer A over B, B over A, or perceive them as equal (indifference, when A = B)).

•Axiom of Transitivity (Given three alternatives A, B, and C, if the agent prefers A > B and B > C, then they will necessarily choose A over C).

•Axiom of Continuity (If the agent prefers A > B and B > C, then with some probability p, they will be indifferent between B and a mix of A and C).

•Axiom of Independence (If the agent prefers A over B, then with probability p, they will also prefer a mix of A and C over a mix of B and C).

Despite being developed a long time ago, Expected Utility Theory is still actively applied in various areas of decision-making. In finance, for instance, investors use the theory to assess investment portfolio choices, particularly when balancing risk and return. In economic planning, organizations and governments apply the theory to evaluate policy and investment projects, considering standard planning risks.

However, EUT faces significant criticism and limitations, even under stable conditions. For example:

•The theory does not account for behavioral deviations of agents (i.e., real-world agents do not always act rationally when making choices and decisions).

•It excludes the possibility of changing preferences, even though agent preferences can depend on context and how choices are framed—which EUT does not incorporate.

•The theory assumes that agents have complete information about the probabilities and utilities of outcomes. In reality, this assumption is rarely met.

Although Expected Utility Theory remains fundamental in the study of decision-making under risk, its pure application in modern risk assessment is impractical. The growing number of influencing factors makes it difficult to directly apply the theory in real-world decision-making. Since EUT is not flexible enough to account for these

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complexities, it is now more useful as a research framework rather than a strict decision-making manual.

***Prospect Theory (Probabilistic Choice Models)***

Prospect Theory by Kahneman and Tversky (1979) is another fundamental decision-making theory under risk conditions. It is often proposed as a more advanced alternative to Expected Utility Theory, which was originally developed to improve upon in 1979.

Unlike Expected Utility Theory (EUT), which is based on the ideal, rational behavior of an agent, Prospect Theory considers psychological aspects and behavioral deviations of decision-makers. This demonstrates that people do not always make rational choices, as assumed by classical economic theory.

A key difference between the two theories is their focus: while EUT considers a utility function, Prospect Theory introduces a value function. The value function differs from the utility function in that it is steeper for losses than for gains. This means that losses and negative outcomes evoke stronger emotional reactions than equivalent gains and positive outcomes.

In this framework, agents evaluate outcomes relative to a specific reference point (typically their current state) rather than in absolute terms. This makes Prospect Theory more flexible in accounting for behavioral factors. The value function also reflects the fact that people tend to be more risk-seeking when facing potential losses, but more risk-averse when dealing with potential gains. This is a key departure from EUT, which assumes that agents' preferences remain stable when making choices.

Unlike classical economic theories, Prospect Theory is built on the framing effect, meaning that the way choices and outcomes are presented significantly influences decision-making. This suggests that identical options can be perceived differently depending on how they are framed – for example, whether a choice is presented in terms of the probability of winning or the probability of losing.

Additionally, Prospect Theory incorporates cognitive biases, such as overconfidence in one's abilities or a tendency to seek confirmation of existing beliefs rather than exploring new alternatives or outcomes. In Prospect Theory, the value function is formulated as follows:

$$v(x) = \{\, x \propto, \text{ if } x \geq 0 \; -\lambda(-x) \propto, \text{ if } x < 0 \qquad (2)$$

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where α represents the degree of risk aversion, typically within the range of 0 < α ≤ 1, and λ is the loss aversion coefficient, which is usually strictly greater than 1.

This highlights a fundamental aspect of Prospect Theory: losses are perceived more intensely than equivalent gains. A crucial component of Prospect Theory is the probability weighting function, which accounts for the way people subjectively interpret probabilities when making decisions under risk. This function incorporates cognitive distortions and biases, which influence how individuals assess the likelihood of different outcomes. The probability weighting function is expressed as:

$$\pi(p) = p\ \gamma\ (p\ \gamma + (1 - p)\ \gamma)\ 1/\gamma \qquad (3)$$

where γ represents an individual's tendency to overestimate small probabilities and underestimate moderate to high probabilities.

The overall evaluation of a prospect for generating an outcome sample is calculated as the sum of the products of value and probability for each respective outcome. Like Expected Utility Theory, Prospect Theory continues to have a broad range of applications today. It is widely used in finance and investment, not just to predict standard investor behavior but also to explain it—for example, the tendency to overreact to market events, the inclination to sell winning assets too soon, or conversely, to hold on to losing assets for too long. Understanding the framing principles described in the theory enables marketing professionals to present products in the most advantageous way, directly influencing consumer perception. In the political sphere, Prospect Theory provides a deeper understanding of citizen and voter behavior, as well as a more accurate means of predicting how political changes might affect public sentiment.

Despite offering greater flexibility compared to Expected Utility Theory, Prospect Theory is not without its criticisms. One of its main limitations is the difficulty of parameter measurement—determining precise values for the theory's variables across different individuals can be challenging due to behavioral variations. Furthermore, despite its adaptability, the theory is difficult to apply in cross-cultural contexts, as it does not account for cultural and individual differences in risk perception among people from different backgrounds. Another critique concerns its lack of dynamic consistency—it does not consider how an agent's preferences and risk attitudes may change over time as circumstances evolve.

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Nevertheless, despite these criticisms, Prospect Theory remains one of the most widely used decision-making models today. Given its flexibility and ability to account for different agent states, it continues to be relevant and applicable in contemporary research. One of the most promising directions for its future development is its integration with neuroeconomics, which would allow for a deeper exploration of the biological foundations of decision-making, ensuring the theory's continued relevance for many years to come.

### *The rational choice concept*

The rational choice concept represents the third fundamental approach in decision-making theory under risk. It serves as a framework not only in economic theory but also in sociology, political science, and other social sciences. Similar to Expected Utility Theory (EUT), the rational choice approach describes how an agent makes decisions aimed at maximizing utility. It assumes that agents act systematically, relying on available information and their preferences to achieve the best possible outcomes. Rational behavior, according to this concept, is determined by an individual's desires and is directed toward their optimal fulfillment in the most efficient way.

The concept of rational choice is built on several key principles. Firstly, it defines specific characteristics of an agent that constitute rationality. A core assumption is goal orientation—meaning that an agent's actions are primarily aimed at achieving objectives that they deem most important. Furthermore, the concept assumes that an agent is capable of establishing a preference order among different options. For example, if an agent prefers option A over option B and option B over option C, they must also prefer A over C when making a choice between them.

Additionally, as in EUT, the rational choice model assumes that the agent possesses complete and accurate information about all available alternatives and their consequences. However, this is also a major limitation of the concept, as real-world decision-makers rarely have access to perfect information due to technological and practical constraints.

Another fundamental principle is utility maximization—just as in EUT, it is assumed that an agent selects the alternative that provides the highest benefit or utility. The core calculation in this framework is based on the utility function, where each possible outcome is assigned a numerical value reflecting the degree of satisfaction or

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benefit the agent derives from it. According to this model, an agent's preferences remain fixed during the decision-making process and do not change, which is another notable limitation.

Decision-making under this concept involves evaluating multiple available alternatives and selecting the one that maximizes expected utility. Mathematically, the model relies on the utility function (U(x)) and expected utility (EU(A)), both of which are also central to EUT.

$$U(x) = \text{utility of outcome } x \tag{4}$$

A key addition to the rational choice concept is the principle of utility maximization, which states that an agent will always select the alternative A for which the expected utility EU(A) is the highest among all available options.

Although the rational choice concept closely resembles EUT, it is a broader theoretical framework that includes multiple perspectives on agent behavior. In contrast, EUT is a more formalized model specifically designed for analyzing decision-making under risk. While both models share mathematical similarities, rational choice theory allows for greater cognitive flexibility and considers the influence of social norms, cultural differences, and constraints, whereas EUT relies strictly on computational utility values.

Today, the rational choice concept remains widely used in economics, particularly in analyzing consumer behavior when selecting goods or services. Businesses use these insights to refine products and increase their perceived value to consumers. The concept is also applied in political science, where it helps model the decision-making processes of voters and policymakers, ultimately aiding in strategy development for maximizing favorable public responses. In sociology, rational choice is used to study social norms and behaviors, analyzing how individuals make decisions within established societal frameworks and expectations.

The limitations of rational choice theory largely mirror those of EUT. These include cognitive constraints, as real-world agents have limited computational abilities; emotional influences, where stress or external pressures may lead to less optimal decisions; and cultural variability, which the model does not account for. Additionally, like EUT, the rational choice concept does not incorporate preference changes over time or in different contexts, which is a significant drawback when applied to dynamic decision-making environments.

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In conclusion, despite its initial similarities to EUT and its inherent limitations, the rational choice concept remains a highly flexible framework that continues to be relevant in decision-making analysis. With necessary adaptations, it remains applicable even today, offering valuable insights into individual and collective decision-making across various fields.

## Conclusion

Authors conclude that, despite being developed and established in the 20th century, these theories and concepts remain relevant today to varying degrees. Models based solely on mathematical calculations, which exclude variables or additional conditions that describe changes in agents and their environment in more detail, are difficult to apply practically. However, such theories (e.g., Expected Utility Theory) serve as a solid foundation for modern research and can be technically updated and adapted to fit contemporary analytical needs.

Theories that offer greater flexibility in studying agents and their psychological aspects can still be applied in their original form. However, given the rapidly changing world – and with it, the evolving mindsets and moral values of individuals – these theories require technological modernization to improve predictive accuracy and practical application. For instance, integrating them with advanced technological fields in research could provide more precise data and insights.

This study has examined the fundamental theoretical models of decision-making under risk, allowing for a structured analysis of the decision-making process in uncertain conditions. The concepts and models reviewed emphasize the importance of rationality when selecting among alternatives – an idea that remains highly relevant across all areas of society, from sociology to large-scale business operations and government policymaking.

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