ISSN-L 2664-9969; E-ISSN 2706-5448

UDC 519.86
DOI: 10.15587/2706-5448.2026.356886

Oksana Mulesa,
Olga Kachmar,
Svitlana Baloha,
Hanna Tiutiunnykova,
Dmytro Shevchuk

DEVELOPMENT OF A DECISION SUPPORT MODEL FOR MULTI-STAGE INVESTMENT DECISIONS IN PRODUCTION SYSTEMS UNDER RISK

The object of research is the process of making investment decisions in production systems under conditions of risk and uncertainty.

In modern enterprise conditions, making investment decisions requires choosing between several options for production development. Their effectiveness depends on possible states of the external environment. A feature of these processes is that investment decisions can have several stages, and their effectiveness depends on the conditions of implementation.

The work focused on developing a decision support model that takes into account the step-by-step implementation of investment projects and evaluates alternatives considering possible environmental scenarios. The analysis showed that traditional approaches are mostly based on one-stage decision models, which limits the ability to consider changes in project implementation conditions.

The model for supporting investment decision-making developed in the research combines single-stage and multi-stage approaches to evaluating the effectiveness of alternatives under conditions of risk. A feature of the obtained results is that they allow determining the expected result of applying multi-stage alternatives and identifying rational investment strategies. An approach to evaluating the efficiency reserve of investment projects in production was also proposed.

During the experimental verification, it was shown that the developed model allows taking into account the staged implementation of alternatives and the information that follows from this. Thanks to this, it provides the possibility of adjusting managerial decisions depending on the actual state of the environment at different stages of the implementation of the adopted decisions.

The developed model can be used in the process of substantiating investment decisions in production systems under conditions of risk.

Keywords: *adaptive decision-making, efficiency reserve, Bayesian decision analysis, expected utility.*

Received: 08.01.2026
Received in revised form: 11.03.2026
Accepted: 03.04.2026
Published: 30.04.2026

How to cite

Mulesa, O., Kachmar, O., Baloha, S., Tiutiunnykova, H., Shevchuk, D. (2026). Development of a decision support model for multi-stage investment decisions in production systems under risk. Technology Audit and Production Reserves, 2 (2 (88)), 92–97. https://doi.org/10.15587/2706-5448.2026.356886

1. Introduction

The processes of making managerial decisions in production systems are usually characterized by a high level of complexity and uncertainty. This is due to the presence of several competing alternatives and the possibility of changing the state of the environment [1]. Among the factors that influence the processes of making and implementing managerial decisions are dynamic changes in the market environment, technological development, etc. [2]. In many cases, the choice is made between several alternative investment decisions, which may have different expected economic results depending on the possible states of the environment in which they are implemented [3]. Therefore, the use of economic and mathematical models and information systems for decision support is relevant, which allow justifying managerial decisions based on a formalized analysis of alternatives.

The problem of making managerial decisions regarding investment activities in production under risk is the subject of research in the theory of decision-making and economic and mathematical modeling [3, 4]. In numerous scientific works, various approaches to assessing the effectiveness of alternatives in decision-making problems under risk have been proposed. In particular, such approaches are based on the use of decision theory criteria, stochastic analysis methods and models for assessing expected results [5, 6]. Decision-making criteria under risk conditions are also widely used, which allow determining a rational alternative taking into account the probabilities of possible environmental states [7, 8]. Despite their proven effectiveness, these methods have a number of limitations, including the fact that they are focused on evaluating alternatives within a single-stage selection.

An analysis of scientific sources that study investment projects in production systems has shown that strategic investment decisions are often made not once, but as a sequence of interconnected decisions. Such decisions are refined as new information is obtained about market and other conditions for project implementation [9, 10]. These approaches allow reducing risk and increasing the adaptability of management strategies for the development of production [11]. Therefore, an urgent scientific task is to develop models to support investment decision-making that allow taking into account the sequence of management actions and the relationship of results at different stages of the implementation of the investment strategy.

In [12], two-stage models of managerial decision-making under risk and uncertainty are considered. The authors propose ways to solve such problems. However, the work does not contain a generalization to the multi-stage decision-making process, and does not offer a mechanism for comparing decisions made using different approaches.

In this regard, there is a need to build models that combine the capabilities of one-stage and multi-stage analysis of investment decisions and allow for the assessment of potential efficiency reserves. Such reserves, as a rule, arise as a result of the use of more flexible decision-making strategies.

The aim of research is to develop a model to support investment decision-making in production systems based on one-stage and multi-stage analysis of alternatives under risk. This will allow for the identification of rational investment alternatives and the assessment of efficiency reserves when using multi-stage investment strategies.

The following objectives were solved during the research:

1. To perform a verbal-mathematical formulation of the problem of assessing investment alternatives under risk.
2. To develop a method for solving the problem.
3. To verify the developed method.

2. Materials and Methods

The object of research is the processes of making investment decisions in production systems under risk and uncertainty.

The subject of research is methods and models for assessing the effectiveness of investment alternatives in a multi-stage decision-making process under risk.

During the research, methods of economic and mathematical modeling were used to assess investment alternatives in production from the point of view of their potential utility, expected economic results under various possible environmental conditions.

The theoretical basis of research is the methods and tools of the theory of decision-making under risk and uncertainty. In this case, investment alternatives are considered as possible solutions, and the environment for implementing alternatives is described through a set of possible states with given probabilities of their occurrence. The key method that was put into the process of analyzing alternatives is the Bayes-Laplace criterion. This method is successfully used to analyze alternatives and their utility under various environmental conditions.

Methods of making multi-stage management decisions were used to analyze sequential decisions. This allowed to analyze the possibility of taking into account the consequences of adopting alternatives at the subsequent stages of their implementation.

3. Results and Discussion

3.1. Verbal and mathematical formulation of the problem of evaluating investment alternatives

The problem of selecting investment projects is considered in the form of a problem of analyzing data on a set of alternatives, a set of environm ental states and the corresponding economic results of implementing alternatives. In such a formulation, the problem is reduced to a problem of decision-making under risk conditions [12, 13]. It is necessary to find the most effective alternative from the point of view of the decision-maker [14]. Moreover, the alternatives will correspond to investment projects, and the environmental states characterize the possible conditions for implementing these projects.

Within the framework of this research, two problems are considered: single-stage and multi-stage decision-making problems.

Single-stage model of investment decision-making: The investment decision-making problem in a single-stage formulation will be presented in the form of a problem of choosing one alternative from a given set of possible options. Such a choice is made taking into account information about the set of possible environmental states for implementing alternatives. The main feature of problems of this type is that the alternative (investment project) is chosen once. In the process of its implementation, one of the expected states of the environment occurs, under which condition the selected project is implemented. The choice is made on the basis of estimates of the effectiveness of alternatives in the occurrence of different states and taking into account the probability of occurrence of these states. Formally, this can be written in the form (1) and Table 1

$$f:(A,S,U,P)\rightarrow E, \tag{1}$$

where $A = \{A_1,A_2,...,A_m\}$ – the set of investment alternatives; $S = \{S_1,S_2,...,S_n\}$ – the set of environmental states that can occur after choosing an alternative; $U=\{u_{ij}\}_{1=\overline{1,m},j=\overline{1,n}}$ – the matrix of utility function values for alternatives in different environmental states, where u_{ij} – the economic utility of alternative A_i provided that state S_j occurs; $P = (p_1,p_2,...,p_n)$ – the vector of probabilities of occurrence of the corresponding environmental states, where $\sum_{j=1}^{n} p_j = 1$; $E = (E_1, E_2, ..., E_m)$ – the vector of integral utilities of the corresponding alternatives.

Table 1

One-stage decision-making problem

Alternatives	Environment states			
	S_1	S_2	...	S_n
A_1	u_{11}	u_{12}	...	u_{1n}
A_2	u_{21}	u_{22}	...	u_{2n}
⋮	⋮	⋮	⋱	⋮
A_m	u_{m1}	u_{m2}	...	u_{mn}
Probabilities	p_1	p_2	...	p_n

The task is to build a model for choosing such an alternative from the set of alternatives *A*, the implementation of which involves obtaining better efficiency in a certain sense.

Multi-stage model of investment decision-making: In real conditions of implementation of investment projects in production, the decision-making process is multi-stage in nature. This is due to the fact that the implementation of such projects usually requires a sufficiently long period of time during which environmental conditions can change significantly. Such changes can affect management decisions regarding the implementation of subsequent stages of the project. In this case, the investment decision-making process can be considered as a multi-stage decision-making process, and these stages are interconnected. At the same time, at each stage, a separate management decision is made, which depends on the previous stages of project implementation and is based on information about possible subsequent changes in environmental conditions.

The process of making management decisions in multi-stage decision-making models is to some extent iterative. At the first stage, the decision maker knows the set of alternatives for this stage, the set of environmental states and the consequences of implementing a particular alternative in each state. Also, for each alternative, the stages of its implementation and the options for management decisions that will take place at each stage may be known. Thus, the decision at the first stage is made based on the analysis of all the specified information. As soon as a specific alternative is selected, all other alternatives and information about them become irrelevant and are discarded from consideration. As a result, the uncertainty regarding some of the system parameters decreases, and the process of making further decisions becomes more definite. In the process of implementing the selected alternative, a certain state of the environment occurs and the decision-making process moves to the next stage. Thus, after each stage of project implementation, information about the conditions for its implementation is clarified.

Therefore, the multi-stage process of making investment decisions can be considered as a sequence of stages, at each of which information about the state of the system is clarified and further management actions are adjusted, and depicted in the form of a decision tree (Fig. 1).

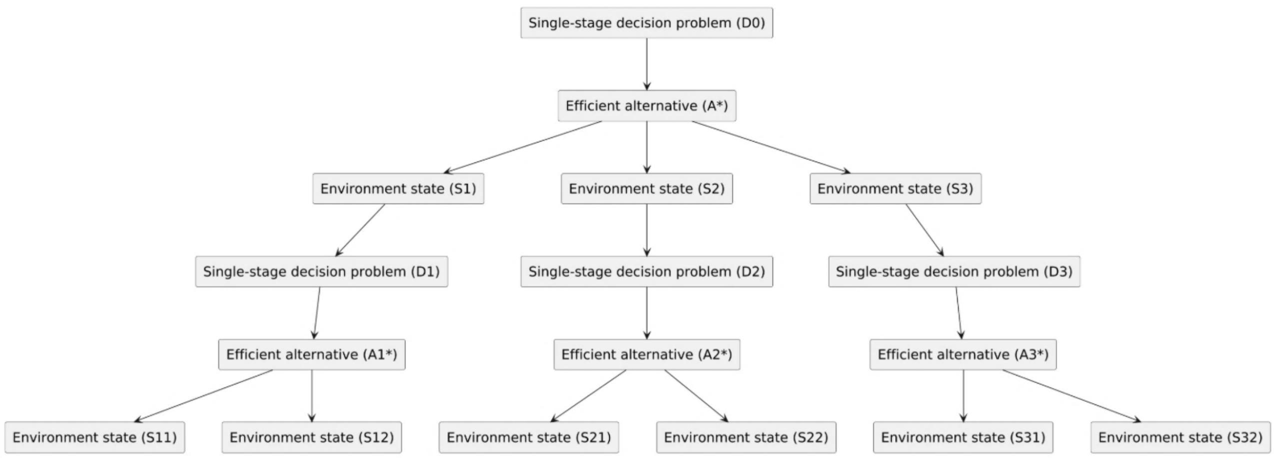

Fig. 1. Decision tree of a multi-stage investment decision-making model

As can be seen from Fig. 1, each path in such a tree corresponds to a possible scenario for the implementation of an investment project, for which the integral economic result can be estimated.

Mathematically, this problem can be presented as follows:

Let there be a multi-stage investment decision-making process, which is a sequence of T stages.

At each stage t, $t=\overline{1,T}$, the decision-maker chooses an alternative from the set $A^{(t)}=\{A_1^{(t)},A_2^{(t)},...,A_{m_t}^{(t)}\}$. When choosing alternatives, the set of possible environmental states $S^{(t)}=\{S_1^{(t)},S_2^{(t)},...,S_{n_t}^{(t)}\}$, at which the selected alternative will be implemented, and the distribution of the probabilities of their occurrence depending on which environmental states occurred at the previous stages are known. At the same time, for each state $S_j^{(t)}$, $t \in \{2,3,...,T\}$, the vector of conditional probabilities $P_j^{(t)}=(p(S_j^{(t)}|S_1^{(t-1)}),p(S_j^{(t)}|S_2^{(t-1)}),...,p(S_j^{(t)}|S_{n_{t-1}}^{(t-1)}))$ is known, where $p(S_j^{(t)}|S_l^{(t-1)})$ – the probability of the occurrence of the environmental state $S_j^{(t)}$ under the condition that the state $S_l^{(t-1)}$ occurred at the previous stage. It is also worth noting that the condition for probabilities should be met

$$\forall t=\overline{2,T}, \forall l=\overline{1,n_{t-1}}: \sum_{j=1}^{n_t} p\left(S_j^{(t)}|S_l^{(t-1)}\right)=1. \quad (2)$$

For the environmental states considered at the first stage, probabilities are known, similar to the one-stage decision-making problem.

Also, for each stage, matrices of values of utility functions of alternatives $U_{A^{(t-1)}}^{(t)}=\{u_{A^{(t-1)}ij}^{(t)}\}_{i=\overline{1,m_t},j=\overline{1,n_t}}$ are known.

The task is to build a model that allows at the first stage to choose an alternative that is the most effective, taking into account the possible results of its implementation and further solving decision-making problems at the following stages.

3.2. Development of a method for solving the problem

In this research, a method for solving the problem of selecting investment projects in production was developed. This method is based on the presentation of this problem in the form of both a single-stage and multi-stage decision-making problem. During the analysis, the efficiency values of the alternatives obtained in each of the mentioned problems are compared. The components of the developed method are presented as different ways of solving the problem depending on its formulation.

Method for solving a single-stage decision-making problem: When solving a single-stage decision-making problem, data on the subsequent stages of project implementation are not taken into account. The decision-maker analyzes only the data given in Table 1 and, on their basis, determines the integral assessment of each alternative. In such a statement of the problem, each alternative from the set is considered as a separate management decision, the result of the implementation of which u_{ij} depends on the possible states of the external environment from the set S. In this case, the probabilities of the occurrence of the states of the environment p_j are additionally known. In this case, the integral estimate of each alternative can be calculated as the mathematical expectation of the economic result by the formula

$$E(A_i)=\sum_{j=1}^{n} p_j u_{ij},\ i=\overline{1,m}. \quad (3)$$

The obtained values of the integral estimates will form the vector of utility of alternatives $E=(E_1, E_2, ..., E_m)$.

Then, the optimal alternative is selected from the set A^*, which it is formed according to the rule

$$A^*=Arg\max_{i=\overline{1,m}} E(A_i). \quad (4)$$

This method of solving the problem of choosing an investment project in production allows to develop management decisions based on the analysis of their expected efficiency without taking into account the consequences of their choice at the subsequent stages of their implementation. The advantage of this method is its low resource intensity and relatively low computational complexity. Its application does not require the construction of complex scenario models of project implementation.

However, the proposed method has a number of limitations, including the fact that it does not allow taking into account information that can be obtained at subsequent stages of its implementation. As a result, the potential benefits of adaptive project management remain unused, which may lead to underestimation of the effectiveness of investment alternatives.

Thus, it is advisable to use a multi-stage approach to decision-making.

Method for solving a multi-stage decision-making problem: Similarly to single-stage decision-making, in a multi-stage problem, an integral estimate is calculated for each alternative of the first stage, taking into account the consequences of its choice at subsequent stages. The formula for calculating integral estimates is as follows

$$E_T(A_i^{(1)})=\sum_{j_1=1}^{n_1}\left(u_{ij_1}^{(1)}+\max_{A_{i_2}^{(2)},i_2=\overline{1,m_2}}\sum_{j_2=1}^{n_2}p\left(S_{j_2}^{(2)}|S_{j_1}^{(1)}\right)\times\right.$$
$$\left.\times\left(u_{A_{i_2}^{(2)}i_2j_2}^{(2)}+\cdots+\max_{A_{i_T}^{(T)},i_T=\overline{1,m_T}}\sum_{j_T=1}^{n_T}p\left(S_{j_T}^{(T)}|S_{j_{T-1}}^{(T-1)}\right)u_{i_Tj_T}^{(T)}\right)\right)p\left(S_j^{(1)}\right). \quad (5)$$

Then, the optimal alternative is selected from the set A^*, which in this case is formed according to the rule

$$A^*=Arg\max_{i=\overline{1,m_1}} E_T(A_i^{(1)}). \quad (6)$$

Using rules (5), (6) will ensure that all possible cases are taken into account in the multi-stage decision-making process.

Estimation of production reserves based on a comparison of single-stage and multi-stage models: As previously shown, in a single-stage problem formulation, the choice of an alternative is carried out without taking into account the possible existence of several stages of implementation of alternatives and the consequences of adjusting management decisions on them. In turn, in a multi-stage formulation, there is a possibility of taking into account different options for adapting a management decision in the process of implementing alternatives. In this case, the forecast values of the utility function of alternatives and the probability of occurrence of different states of their implementation environments at subsequent stages are used.

As a result, according to relations (5), (6), the expected effectiveness of solutions obtained in a multi-stage model may differ from the effectiveness of solutions determined in a single-stage problem formulation. Therefore, the difference between these values is interesting from the point of view of analysis. It can potentially characterize the additional economic effect that arises due to the use of a multi-stage approach to making investment decisions. This additional effect can be interpreted as a potential production reserve that can be used in the process of managing the investment activities of the enterprise.

Within the proposed model, a production reserve index has been developed. The idea of this indicator is to compare the results of a locally optimal solution obtained within the framework of a single-stage problem statement and a globally optimal solution determined within the framework of a multi-stage decision-making model.

The Production Reserve Index (*PRI*) is defined as the difference between the expected results of a globally optimal solution ($E_{global}(A^*_{global})$, model (3), (4)) and a solution obtained within the framework of local analysis ($E_{local}(A^*_{local})$, model (5), (6)). That is, PRI is calculated as

$$PRI = E_{global}(A^*_{global}) - E_{local}(A^*_{local}). \quad (7)$$

In the general case, the inequality holds $E_{global}(A^*_{global}) \neq E_{local}(A^*_{local})$, where $A^*_{global} \neq A^*_{local}$. This is due to the fact that, as a rule, the first stages of the implementation of investment projects in production are accompanied by unavoidable costs, while subsequent ones can bring profits. In addition, the use of only a single-stage decision-making model does not allow for the possibility of adaptive response to changing environmental conditions in the process of implementing management decisions.

For the *PRI* value, the following cases are possible:

– if *PRI* > 0, then the expected efficiency of the globally optimal solution exceeds the efficiency of the locally optimal solution. In this case, the use of a multi-stage decision-making model allows for the potential to obtain additional economic effect;

– if *PRI* = 0, then the use of a multi-stage model does not provide additional economic effect compared to the single-stage model;

– if *PRI* < 0, then the expected efficiency of the solution obtained in the multi-stage model is less than the efficiency of the solution determined within the single-stage approach. Such a situation may indicate an increased level of risk at the subsequent stages of the investment project implementation or the presence of unfavorable scenarios of the external environment development that reduce the expected economic result.

Due to the fact that the efficiency of alternatives often represents the expected profits from their implementation, it is advisable to consider relative values when calculating the production reserve index. In this case, it should be calculated as

$$PRI_{\%} = \frac{E_{global}(A^*_{global}) - E_{local}(A^*_{local})}{\left|E_{local}(A^*_{local})\right|} \cdot 100\%. \quad (8)$$

This form of the index allows to interpret it as a relative increase in efficiency achieved when using a multi-stage decision-making model compared to a single-stage one.

When comparing the global and local efficiency of optimal alternatives in the case when $E_{global}(A^*_{global}) > 0$ and $E_{local}(A^*_{local}) > 0$, their ratio shows the ratio of the expected result of the globally optimal solution to the result of the locally optimal solution. This value is defined as the Production Reserve Coefficient, which is calculated according to the rule

$$PRC = \frac{E_{global}\left(A^*_{global}\right)}{E_{local}\left(A^*_{local}\right)}. \quad (9)$$

Thus, the proposed indicators provide the possibility of quantitative assessment of production reserves and allow to determine the potential additional economic effect that can be obtained as a result of using a multi-stage decision-making model.

3.3. Application of the developed method to solving a numerical problem

The problem of choosing an investment project for the modernization of a manufacturing enterprise that plans to update technological equipment to increase production efficiency is considered.

Possible investment alternatives are as follows:

– A_1 – modernization of an existing production line;

– A_2 – introduction of a new automated production section;

– A_3 – launch of a new technological line using digital production management systems.

The economic result of the implementation of each project (the value of the utility function) depends on the necessary investments and the state of the market environment, which is determined by the demand for the enterprise's products.

Three possible states of the environment are considered:

– S_1 – low demand for products;

– S_2 – stable demand for products;

– S_3 – high demand for products.

The values of the utility function and the probability of the states are given in Table 2.

Table 2

Expected economic results of the implementation of investment projects*

Alternatives	Environment states		
	S_1	S_2	S_3
A_1	12	25	40
A_2	8	30	55
A_3	–5	28	70
Probabilities	0.3	0.5	0.2

Note: * – values are given in million UAH. Conversion: 1 EUR = = 50.96 UAH (as of 14.03.2026)

At the first stage, it is possible to consider a one-stage decision-making model. In this case, the optimal alternative is determined based on the expected value of the economic result according to formulas (3), (4). Then $E_1(A_1)$ = 24.1, $E_1(A_2)$ = 28.4, $E_1(A_3)$ = 26.5. Thus, the optimal alternative is A_2, i. e. $A^*_{local} = A_2$.

It is possible to suppose that after the implementation of the first stage and the occurrence of one of the environmental states, the enterprise can make an additional management decision:

– B_1 – operate in the basic mode;

– B_2 – adapt the production program.

The environmental states of the second stage are also known:

– T_1 – unfavorable development of conditions;

– T_2 – favorable development of conditions.

ISSN-L 2664-9969; E-ISSN 2706-5448

Then, at the second stage, a new one-stage decision-making problem arises, but already under the condition that a certain investment project A_i is selected and a certain state of the environment S_j has occurred. The data for the second stage problem are given in Table 3.

Table 3

Expected economic results of alternatives for the second stage of implementation of investment projects*

Alternatives		Environment states					
First stage	Second stage	$T_1 \mid S_1$	$T_2 \mid S_1$	$T_1 \mid S_2$	$T_2 \mid S_2$	$T_1 \mid S_3$	$T_2 \mid S_3$
A_1	B_1	1	4	3	6	5	9
	B_2	2	5	4	8	6	11
A_2	B_1	1	3	2	7	6	12
	B_2	2	4	3	8	7	13
A_3	B_1	4	8	6	11	10	18
	B_2	5	10	7	13	12	22
Probabilities		0.7	0.3	0.5	0.5	0.2	0.8

Note: * – values are given in million UAH. Conversion: 1 EUR = = 50.96 UAH (as of 14.03.2026)

Then, according to formula (5): $E_2(A_1) = 29.97$, $E_2(A_2) = 34.29$, $E_2(A_3) = 37.45$. Thus, $A^*_{global} = A_3$. According to (7)–(9): $PRI = 3.16$, $PRI_{\%} = 9.22\%$, $PRC = 1.09$.

Within the one-stage model, alternative A_2 is the most effective, while in the two-stage formulation, alternative A_3 becomes optimal. This is explained by the fact that project A_3 provides a greater potential for adapting management decisions at the second stage, especially under favorable environmental conditions. Therefore, the multi-stage model allows identifying additional production reserves that are not taken into account in the one-stage formulation.

3.4. Discussion

The results obtained demonstrated the feasibility of using the developed model of investment decision-making in production under risk conditions. In the course of solving the model problem, it was shown that the results of solving single-stage and multi-stage problems in the general case differ. This is due to the analysis of additional information in the multi-stage version. Moreover, the use of a two-stage formulation made it possible to more fully take into account changes in the conditions of project implementation at its various stages and adapt management decisions to these changes. In particular, as a result of solving the single-stage decision-making problem, alternative A_2 was chosen as the optimal one, while alternative A_3 was chosen as the solution to the two-stage problem. This demonstrates how a more complete consideration of the dynamics of investment project implementation allows rethinking the level of efficiency of alternatives.

The use of the indices introduced in the research to compare solutions to the single-stage and two-stage problem showed the possibility of determining the quantitative effect of using an adaptive management strategy. The obtained value of the production reserve index of 3.16 million UAH (62000 EUR) characterizes the potential additional potential for increasing the efficiency of investment decisions. The calculated production reserve utilization ratio is 1.09, which corresponds to a potential increase in the efficiency of the decision by approximately 9%.

Thus, the developed method and the model built on its basis allow to justify the choice of alternatives and assess potential production reserves under variable conditions of their implementation.

The practical value of the results lies in the possibility of using the model and indicators in decision support systems for managing investment projects in manufacturing enterprises. Using the production reserve index allows to identify situations in which it is advisable to apply more complex analysis models, as well as to assess the potential economic effect of adaptive management of investment processes.

The limitations of this research are associated with the consideration of a limited number of alternatives and possible environmental states for which the probability distributions of their occurrence are known. In reality, such a task may be accompanied by additional uncertainty.

The conditions of martial law in Ukraine enhance the relevance of the developed models, which allow taking into account different scenarios of events and adapting investment strategies to changes in the environment. Prospects for further research are related to scaling. In particular, in the case of more complex multi-stage investment strategies.

4. Conclusions

1. A verbal-mathematical formulation of the problem of evaluating investment alternatives in the form of a single-stage and multi-stage decision-making problem under risk conditions was performed. The multi-stage investment decision-making process was decomposed and schematically depicted in the form of a decision tree. This allowed formalizing the investment decision-making process and calculating the sequence of stages of investment project implementation.

2. An approach to evaluating investment alternatives was proposed, within the framework of which a method for solving the problem was developed. It is based on a combination of single-stage and multi-stage analysis of alternatives. Based on the developed method, an algorithm was proposed, the application of which allows not only to select optimal alternatives, but also to assess production reserves identified during the application of a multi-stage decision-making model. The novelty of the results obtained lies in the possibility of decomposing the process of making and implementing decisions into a multi-stage process; in the introduction of a production reserve index for the possibility of quantitatively assessing the additional effect of using a multi-stage model.

3. The developed method was verified. The results obtained showed that its use allows to identify more effective alternatives compared to classical methods. In particular, for the model example, the production reserve index was 62000 EUR, which corresponds to an increase in efficiency by 9%. Thus, by adapting management decisions, it is possible to ensure the selection of more effective alternatives. The results obtained showed that the use of a multi-stage model allows to take into account additional information that may appear at the subsequent stages of the investment project implementation regarding the possibility of adjusting management decisions depending on the actual state of the environment.

Conflict of interest

The authors declare that they have no conflict of interest regarding this research, including financial, personal, authorship or other nature, which could affect the research and its results presented in this article.

Financing

The research was conducted without financial support.

Data availability

Manuscript has no associated data.

Use of artificial intelligence

During the preparation of the manuscript, the authors used artificial intelligence tools, namely ChatGPT 5.3 – Instant, only for grammatical analysis and text translation. All scientific results, models, calculations and conclusions belong to the authors, and the use of AI did not affect the conclusions and research.

Authors' contributions

Oksana Mulesa: Conceptualization, Formal analysis, Investigation, Methodology, Project administration; ***Olga Kachmar***: Conceptualization, Methodology, Investigation; ***Svitlana Baloha***: Data curation, Formal analysis, Investigation; ***Hanna Tiutiunnykova***: Formal analysis, Data curation, Investigation; ***Dmytro Shevchuk***: Investigation, Methodology, Data curation.

References

1. Stanton, M. C. B., Roelich, K. (2021). Decision making under deep uncertainties: A review of the applicability of methods in practice. *Technological Forecasting and Social Change, 171,* 120939. https://doi.org/10.1016/j.techfore.2021.120939
2. Teece, D. J., Pisano, G., Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal, 18 (7),* 509–533. https://doi.org/10.1002/(sici)1097-0266(199708)18:7<509::aid-smj882>3.0.co;2-z
3. Rosenhead, J. (1968). Introduction to Operations Research. *Journal of the Operational Research Society, 19 (3),* 329–330. https://doi.org/10.1057/jors.1968.78
4. Saaty, T. L., Vargas, L. G. (2013). *Decision making with the analytic network process: Economic, political, social and technological applications with benefits, opportunities, costs and risks.* Vol. 195. Springer, 363. https://doi.org/10.1007/978-1-4614-7279-7
5. Kahneman, D., Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. *Econometrica, 47 (2),* 263–292. https://doi.org/10.2307/1914185
6. Izonin, I., Tepla, T., Danylyuk, D., Tkachenko, R., Duriagina, Z., Lemishka, I. (2020). Towards an Intelligent Decision Making of Ti-based Powders Selection for Medical Manufacturing. *2020 International Conference on Decision Aid Sciences and Application (DASA).* IEEE, 1–5. https://doi.org/10.1109/dasa51403.2020.9316866
7. Hou, H. (Cynthia). (2025). Utility Theory Application in Decision-Making Behavior for Energy Use and Management: A Systematic Review. *Energies, 18 (8),* 2125. https://doi.org/10.3390/en18082125
8. Bakır, N. O., Tekin, S., Keleş, B. (2026). Expected utility-based maintenance planning under risk aversion for a two-state deterioration model. *Reliability Engineering & System Safety, 270,* 112169. https://doi.org/10.1016/j.ress.2025.112169
9. Wu, F., Li, H. Z., Chu, L. K., Sculli, D., Gao, K. (2008). An approach to the valuation and decision of ERP investment projects based on real options. *Annals of Operations Research, 168 (1),* 181–203. https://doi.org/10.1007/s10479-008-0365-7
10. Castro, J., Tito, E., Brandão, L. (2021). Optimization of a Portfolio of Investment Projects: A Real Options Approach Using the Omega Measure. *Journal of Risk and Financial Management, 14 (11),* 530. https://doi.org/10.3390/jrfm14110530
11. Panayi, S., Trigeorgis, L. (1998). Multi-stage real options: The cases of information technology infrastructure and international bank expansion. *The Quarterly Review of Economics and Finance, 38 (3),* 675–692. https://doi.org/10.1016/s1062-9769(99)80096-9
12. Mulesa, O., Snytyuk, V., Myronyuk, I. (2019). Optimal alternative selection models in a multi-stage decision-making process. *EUREKA: Physics and Engineering, 6,* 43–50. https://doi.org/10.21303/2461-4262.2019.001005
13. Berger, J. O. (1985). *Statistical Decision Theory and Bayesian Analysis.* Springer Series in Statistics. Springer New York. https://doi.org/10.1007/978-1-4757-4286-2
14. Hnatiienko, H., Tmienova, N., Kruglov, A.; Shkarlet, S., Morozov, A., Palagin, A. (Eds.) (2020). Methods for Determining the Group Ranking of Alternatives for Incomplete Expert Rankings. *Mathematical Modeling and Simulation of Systems (MODS'2020).* Springer, 217–226. https://doi.org/10.1007/978-3-030-58124-4_21

✉***Oksana Mulesa,*** *Doctor of Technical Sciences, Professor, Department of Physics, Mathematics and Technologies, University of Prešov, Prešov, Slovakia; Department of Software Systems, Uzhhorod National University, Uzhhorod, Ukraine, e-mail: oksana.mulesa@unipo.sk, ORCID: https://orcid.org/0000-0002-6117-5846*

Olga Kachmar, *PhD, Associate Professor, Independent Researcher, Uzhhorod, Ukraine, ORCID: https://orcid.org/0009-0007-5139-7801*

Svitlana Baloha, *PhD, Associate Professor, Department of Computer Systems and Networks, Uzhhorod National University, Uzhhorod, Ukraine, ORCID: https://orcid.org/0000-0002-1221-9072*

Hanna Tiutiunnykova, *Senior Lecturer, Department of Computer Systems and Networks, Uzhhorod National University, Uzhhorod, Ukraine, ORCID: https://orcid.org/0000-0003-0859-6382*

Dmytro Shevchuk, *PhD Student, Department of Computer Systems and Networks, Uzhhorod National University, Uzhhorod, Ukraine, ORCID: https://orcid.org/0009-0003-6518-9473*

✉*Corresponding author*