# Modelling Decision Making under Uncertainty for Strategic Forecasting

**Oleksiy Korepanov, Sergey Mekhovich, Nataliya Karpenko, Olha Kryvytska, Andrii Kovalskyi, Roman Karpenko**

***Abstract*: *In current market conditions, the key to productive economic activity is the ability to provide a high-quality forecast, even in situations of insufficient information. Strategic forecasting refers to this type of activity, errors in which the actions of any company can have a detrimental effect on the fundamental level.***

***The justification and selection of specific management decisions can often be carried out in conditions of uncertainty due to the inability to clearly predict the values of the final results of these decisions.***

***The decision-making system within the framework of the strategic forecasting task should help maintain the effectiveness of actions by simplifying the picture of the real world by modelling it. While allowing to reduce the influence of the subjectivity of the personality of the decision-maker on the decision-making process itself.***

***Keywords* : *Decision making, Forecast, Modeling, Uncertainty, Strategy.***

## I. INTRODUCTION

The decision-making process is an integral part of any managerial impact. Along with information processing, decision-making is becoming a key factor determining the effectiveness of strategic planning and forecasting. At the same time, the choice of specific solutions within the framework of strategic forecasting is often closely associated with risks in the light of the unknown specific behaviour of the initial parameters, which do not allow to clearly determine the values of the final results of these decisions.

It should also be taken into account that decision-making is the result of a specific managerial activity, a creative process based on the principles of consistency and rationality, aimed at choosing the best option for action. The decision-making task arises when there is a goal that needs to be achieved, there are various ways to achieve it, and there are factors that limit the ability to achieve the goal. At its core, decision-making goes through the following steps (Fig.1).

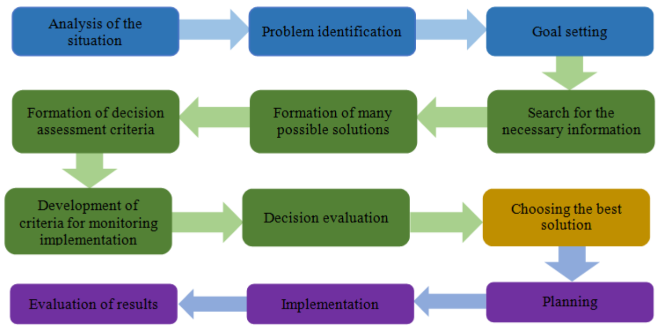


**Fig. 1.Decision-making scheme.**

When analyzing the presented scheme, it should be noted that the decision-making process is cyclical, in addition, this scheme is an idealized model, since real decision-making processes, due to the variety of situations and problems requiring solutions, usually differ from it, i.e. in fact, the structure of the managerial decision-making process is largely determined by the situation and the problem is solved.

At the same time, decisions made in the field of strategic forecasting should essentially rely on data from future periods, of course, that it is physically impossible to do this, which is why it is most often necessary to operate on data from past periods, as well as information about the current situation, extrapolating them over time. It turns out that the predicted data already contains a significant share of uncertainty due to their very nature.

Depending on the degree of unknownness of the upcoming behaviour of the initial decision-making parameters, risk conditions are distinguished, in which the probability of occurrence of individual events that affect the final result can be established with one degree or another accuracy, and uncertainty conditions, in which, due to the lack of necessary information, such probability cannot be established.

The concept of decision-making modelling is based on two essential properties that make up the very essence of the modelling process. Firstly, the model should be similar to the object being studied, and secondly, the model should be more straightforward than the object being studied so that it can be considered. Indeed, the primary purpose of the model is the possibility of conducting experiments with the model, analysis and study, which are impossible with the object under study. The process of constructing a mathematical model itself can be represented in the form of a cyclic diagram (fig.2), which is required for the research of the title.

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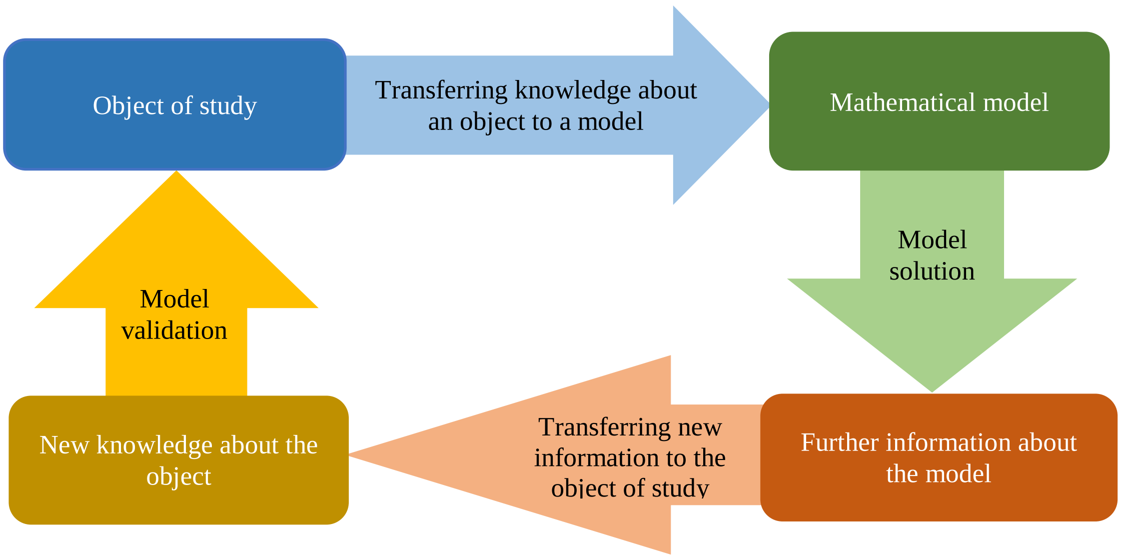


**The scheme for constructing a mathematical model of decision making.**

Modelling as a method of researching control systems is used in the development of rather complex management decisions and is the construction of models or models of the studied object for its study. The study of object models allows you to clarify the properties and characteristics of the phenomenon being studied.

Like all means and methods, the constructed model for decision making can contain errors (Fig.3). The main reason for their occurrence is the unreliability of the initial assumptions. Since any model is based on some initial assumptions and assumptions, some of them can be evaluated and can be objectively verified and calculated. At the same time, some prerequisites are not measurable and cannot be objectively verified, in particular in conditions of insufficient initial information. Since such premises are the basis of the model, the accuracy of the latter depends on the accuracy of the premises. The model cannot be used for forecasting, for example, inventory requirements if sales forecasts for the coming period are inaccurate).

In addition, information uncertainty is also possible, the cause of which may be either incompleteness or redundancy of the source data.

Decision making under conditions of uncertainty is based on the fact that the probabilities of various scenarios of the development of events to the entity making the risk decision are unknown. In this case, when choosing an alternative to a decision, the subject is guided, on the one hand, by the risk preference, and on the other, by the appropriate criterion for choosing from all alternatives according to his "decision matrix".

The task of making decisions in the face of uncertainty is the task of choosing the optimal strategy, the outcome of which, among other things, depends on many uncertain factors, as a result of which each concrete strategy (decision) corresponds not only to a single outcome but to many outcomes.

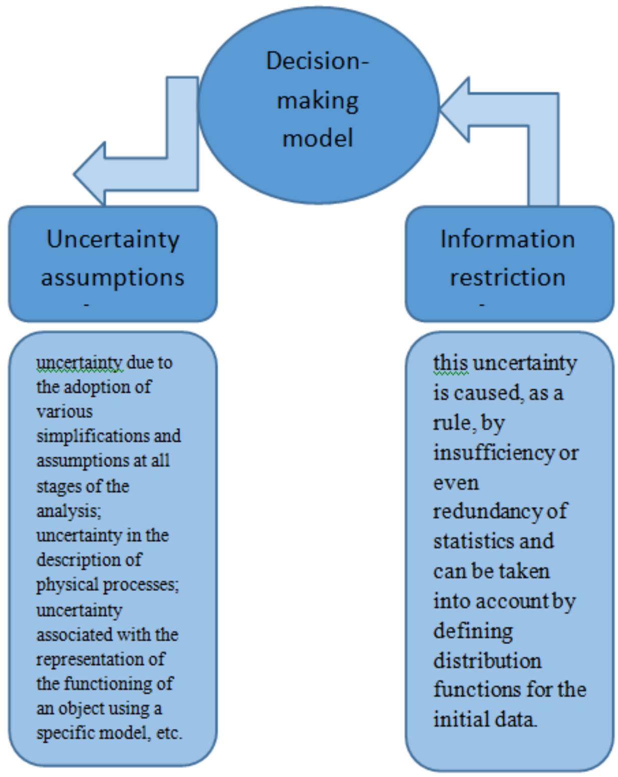


**Fig.3 Factors affecting the accuracy of a decision model**

## II. METHODOLOGY FOR MODELING DECISION MAKING UNDER UNCERTAINTY FOR STRATEGIC FORECASTING

The decision-making methodology in conditions of risk and uncertainty involves the construction of the so-called “decision matrix” in the process of substantiating risk decisions, which has the form presented in table 1.

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**Table- I: Decision matrix created for decision making under uncertainty**

| Options for decision making | Options for situations | | | |
|---|---|---|---|---|
| | $S_1$ | $S_2$ | … | $S_n$ |
| $A_1$ | $W_{11}$ | $W_{12}$ | … | $W_{1n}$ |
| $A_2$ | $W_{21}$ | $W_{22}$ | … | $W_{2n}$ |
| … | … | … | … | … |
| $A_n$ | $W_{n1}$ | $W_{n2}$ | … | $W_{nn}$ |

In this matrix, A_1 ... A_n - each of the options for decision making alternatives; values S_1 ... S_n - each of the possible variants of the situation; values W_11 ... W_nn - a specific level of decision efficiency corresponding to a particular alternative in a specific situation.

The presented decision matrix defines one of its types, denoted as the "payoff matrix", as it considers the performance indicator. It is also possible to build a decision matrix of another type, referred to as a “risk matrix”, in which instead of an efficiency indicator, an indicator of financial losses is used that corresponds to certain combinations of decision-making alternatives and possible situations.

As already indicated, decision-making under conditions of uncertainty is based on the fact that the probabilities of various scenarios of events are unknown. In this case, the choice of an alternative to the decision is determined on the one hand - by risk preference, and on the other - by the appropriate selection criterion of all alternatives according to the compiled “decision matrix”.

Criteria that can be used in decision-making under uncertainty:

***Wald's criterion*** (the criterion of greatest caution, pessimism) is based on the hypothesis: "When choosing a solution, you need to rely on the worst possible option." When accepting this hypothesis, the estimate of alternative i is the number

$$W(i) = \min_{j=1\dots n} W_{ij} \qquad (1)$$

(in each row of the utility matrix there is a minimal element) and the comparison of any two alternatives is made according to the value of the criterion W. Optimal, in this case, is the alternative that maximizes the function W, that is, the alternative i * for which:

$$W(i^*) = \max_{i=1\dots m} W(i) = \max_{i=1\dots m} \min_{j=1\dots n} Wij \quad (2)$$

The **Laplace criterion** is based on the optimistic assumption that each version of the development of the situation is equally probable, that is, if the probability distribution process is known, there is no reason to consider them different. Find the arithmetic average of the elements in the i-th row of the utility matrix and choose the best alternative with the highest score by the Laplace criterion:

$$L(i) = \frac{1}{n}\sum_{j=1}^{n} Wij \qquad (3)$$

When introducing the Laplace estimate, the best solution is provided by the alternative i * that has a large estimate by the Laplace criterion.

$$L(i^*) = \max_{i=1\dots m} L(i) \qquad (4)$$

**Hurwitz criterion** (criterion of "optimism-pessimism" or "alpha criterion") - allows you to be guided when choosing a risky decision in the face of uncertainty by a certain average result of effectiveness located in the field between the values according to the criteria of "maximax" and "maximin" (field between these values connected by a convex linear function). It covers various approaches to decision making - from the most optimistic to the most pessimistic (conservative). It is associated with the introduction of the indicator $0 \le a \le 1$, called the indicator of pessimism. The evaluation of alternative i is the weighted sum:

$$H_a(i) = a \max_{j=1\dots n} W_{ij} + (1-a) \cdot \min_{j=1\dots n} W_{ij} \qquad (5)$$

In this case, the best solution is one that provides:

$$W = \max_{i=1\dots m} H_a(i) \qquad (6)$$

**Savage criterion** (criterion of losses from the "minimax") - suggests that from all possible options for the "decision matrix" is selected that alternative that minimizes the size of the maximum losses for each of the possible solutions.

When using this criterion, the “decision matrix” w_ij is converted to the “loss matrix” (one of the variants of the “risk matrix”) r_ij, in which instead of the efficiency values the losses are plotted for various scenarios.

The risk in choosing alternative i in state j is the number

$$r_{ij} = B_j - w_{ij}\text{, где } B_j = \max_j w_{ij} \qquad (6)$$

For Savage criterion, the optimal alternative is the one that minimizes the maximum risk (i.e., the minimax criterion is used here for the regret matrix):

$$W = \min_{i=1\dots m} \max_{j=1\dots n} r_{ij} \qquad (7)$$

It is only logical that different criteria lead to different conclusions regarding the best solution. At the same time, the possibility of choosing a criterion gives freedom to persons making economic decisions. Any criterion should be consistent with the intentions of the person solving the problem and correspond to his character, knowledge and beliefs.

## III. APPLICATION OF THE METHODOLOGY FOR MODELING DECISION MAKING UNDER UNCERTAINTY FOR STRATEGIC FORECASTING

Consider the implementation of the described methodology for a specific example. The oil and gas transportation company must determine its development strategy for its transportation network. The company has a network of oil pipelines with a total length of 975 km, which enables pumping of crude oil from the production site (Sever-350 and

Alta Glubinnaya fields) to the oil terminals of the port, which is the key storage hub for all the oil and gas produced in the region.

The current development strategy of the company sharply raised the issue of creating intermediate oil storage. There are developed projects for the construction of oil storage facilities designed to store 20, 30, 40, 50 and thousands of barrels of crude oil. The binding of the project will cost 37 million US dollars. The cost of materials and equipment storage of 20 thousand barrels is 60 million US dollars and increases by 10% with an increase in storage volume by 10 thousand barrels.

Storage of 1 barrel of crude oil will provide the company $ 10 in revenue, the volume of oil produced and, accordingly, pumped oil ranges from 14 to 20 thousand barrels per month.

Consider the process of constructing a mathematical model of the formulated problem.

We introduce the following notation:

X - many acceptable alternatives - typical oil storage projects:

$$X = \{x\_i\} = \{20, 30, 40, 50, 60\}, i = 1, 2, 3, 4, 5.$$

S - many environmental conditions - the volume of oil produced in the region:

$$S = \{s\_i\} = \{14, 15, 16, 17, 18, 19, 20\}, j = 1, 2, 3, \dots, 7.$$

Next, we construct the set of possible outcomes in the form of a utility matrix W = (w_ij), the elements of which show a profit when making the ith decision for the jth production volume. To do this, use the following rule:

"Profit = storage fee (income) - the cost of linking the project - the cost of materials and equipment of the warehouse - the cost of operating the warehouse" or in another form:

$$w\_ij = 10 \cdot min\,(x\_i \cdot 100;\ s\_j \cdot 1430) - 37000 - [60000 + 600 \cdot (x\_i - 20)] - [10000 - - 100\,(x\_i - 20)].$$

Fill in the utility matrix {w_ij} (tab. 2), having performed preliminary calculations using the above formula:

$$S = \{s\_i\} = \{14, 15, 16, 17, 18, 19, 20\}, j = 1, 2, 3, \dots, 7.$$

**Table- II: Matrix of the usefulness**

| | $s_1 = 14\cdot$ | $s_2 = 15$ | $s_3 = 16$ | $s_4 = 17$ | $s_5 = 18$ | $s_6 = 19$ | $s_7 = 20$ |
|---|---|---|---|---|---|---|---|
| $x_1 = 20$ | 93 000 | 93 000 | 93 00 | 93 000 | 93 000 | 93 000 | 93 000 |
| $x_2 = 30$ | 88 200 | 102 500 | 116 800 | 131 100 | 154 400 | 159 700 | 174 000 |
| $x_3 = 40$ | 83 200 | 97 500 | 111 800 | 126 100 | 140 400 | 154 700 | 169 000 |
| $x_4 = 50$ | 78 200 | 92 500 | 106 800 | 121 100 | 135 400 | 149 700 | 164 000 |
| $x_5 = 60$ | 73 200 | 87 500 | 101 800 | 116 100 | 130 400 | 144 700 | 159 000 |

We solve the problem of the situation of risk of uncertainty in the future. Oil production data in the region show that there are significant fluctuations in production volumes, which impose corresponding restrictions on the company's revenue from the transportation of extracted oil. There are statistical data to assess the likelihood of a particular state of the environment, and this experience can be used to assess the situation in future periods. Given the known probabilities p_j for the occurrence of the state s_j, one can find mathematical expectations:

$$M\_i = \sum\_(j = 1)\text{\textasciicircum}n \ (W\_ij \times p\_j), i = 1 \dots m \qquad (8)$$

The concept of a statistical solution considers the behaviour to be optimal if it minimizes the risk in subsequent experiments, i.e., the mathematical expectation of the profit of a statistical experiment will be maximum.

Statistics from past periods make it possible to predict future oil production:

P = {0,01; 0,09; 0,1; 0,25; 0,3; 0,2; 0,05}.

Given the known probabilities p_j for the volumes s_j (j = 1, 2, ..., 7), one can find the mathematical expectation of the profit value w_i for each of the solution options (typical oil storage projects) and determine the optimal project choice that ensures maximum profit.

For example, M_2 = 88200 · 0.01 + 102500 · 0.09 + 116800 · 0.1 + 131100 · 0.25 + 154400 · 0.3 + 159700 · 0.2 + 174000 · 0.05 = 138822.

Similarly, we obtain for the rest M_i (i = 1, 3, 4, 5):

M_1 = 93000, M_3 = 133822, M_4 = 128822, M_5 = 123822.

Then, according to the selected criterion,

$$W = max\,(i = 1 \dots m)\ M\_i = max\{93000, 138822, 133822, 128822, 123822\} = 138822 = M\_2.$$

This maximum corresponds to i = 2. Thus, the calculation results showed that in the situation under consideration, it is most advisable to choose the alternative x_2 - an oil storage project of 30 thousand barrels of crude oil. In this case, the maximum profit of $ 138,822 per month is ensured.

We will solve the problem posed, even more, taking into account the Laplace criterion based on the optimistic assumption that each scenario is equally probable.

According to the Laplace criterion

$$L\,(2) = 1/7\,(88\,200 + 102\,500 + 116\,800 + 131\,100 + 154\,400 + 159\,700 + 174000) = 132385$$

Similarly, $L\,(1) = 93\,000, L\,(3) = 126\,100, L\,(4) = 121100, L\,(5) = 116\,100.$

So, according to the Laplace criterion, the optimal option is to design an oil storage facility of 30 thousand barrels with an expected profit of 132,385 US dollars per month.

According to Wald's criterion, it is necessary to choose the worst option by the profit margin for each alternative (oil storage project), and among them, we are looking for the guaranteed maximum effect.

W (1) = max (93000, 88200, 83200, 78200, 73200) = 93000.

Thus, according to Wald's criterion, an oil storage facility of 20 thousand barrels with a maximum possible profit of 93,000 US dollars per month should be built.

Let us turn to estimates by the Hurwitz criterion, specifying the degree of optimism (or pessimism) by choosing the value of α from the interval [0; one].

For example, with α = 0.2, we obtain:

H_0.2 (1) = 0.2 · 93000 + 0.8 · 93000 = 93000;

H_0.2 (2) = 0.2 · 174000 + 0.8 · 88200 = 105360;

H_0.2 (3) = 100360; H_0.2 (4) = 95360; H_0.2 (5) = 90360.

Similarly, for α = 0.5:

H_0.5 (1) = 93000; H_0.5 (2) = 131100; H_0.5 (3) = 126100; H_0.5 (4) = 121100; H_0.5 (5) = 116100.

When α = 0.8:

H_0.8 (1) = 93000; H_0.8 (2) = 156840; H_0.8 (3) = 151840; H_0.8 (4) = 146840;

H_0.8 (5) = 141840.

Therefore, according to the Hurwitz criterion, we find the feasibility of choosing a project of 30 thousand barrels with an expected profit of 105360, 13110, 156840 dens, respectively. units

When approaching from the standpoint of the Savage criterion (missed opportunities and subsequent regret about it), we construct a matrix of regrets. First, we find the largest profit for each state:

$$B\_1 = 93000, B\_2 = 102500, B\_3 = 116800, B\_4 = 131100, B\_5 = 154400, B\_6 = 159700, B\_7 = 174000.$$

We calculate the values of "regrets" for each project in each scenario, i.e. we will find lost profits in comparison with the maximum possible in this development scenario.

For the project x1 = 20:

$$i = 1, j = 1, then\ r\_11 = B\_1 - w\_11 = 93000 - 93000 = 0,$$

$$i = 1, j = 2, then\ r\_12 = B\_2 - w\_12 = 102500 - 93000 = 9\,500,$$

$$r\_13 = 23800, r\_14 = 38100, r\_15 = 61400, r\_16 = 66700, r\_17 = 81000.$$

Similarly, we calculate for the remaining projects, and we will enter the data into the matrix of regrets (Tab. 3).

**Table- III: Matrix of regrets**

| | $s_1 = 14$· | $s_2 = 15$ | $s_3 = 16$ | $s_4 = 17$ | $s_5 = 18$ | $s_6 = 19$ | $s_7 = 20$ | Maximum Regret |
|---|---|---|---|---|---|---|---|---|
| $x_1 = 20$ | 0 | 9 500 | 23 800 | 38 100 | 61 400 | 66 700 | 81 000 | 81 000 |
| $x_2 = 30$ | 4 800 | 0 | 0 | 0 | 0 | 0 | 0 | **4 800** |
| $x_3 = 40$ | 9 800 | 5 000 | 5 000 | 5 000 | 14 000 | 5 000 | 5 000 | 14 000 |
| $x_4 = 50$ | 14 800 | 10 000 | 10 000 | 10 000 | 19 000 | 10 000 | 10 000 | 19 000 |
| $x_5 = 60$ | 19 800 | 15 000 | 15 000 | 15 000 | 24 000 | 15 000 | 15 000 | 24 000 |

We apply Wald's pessimistic criterion to it. To do this, in the resulting matrix, we determine for each row the largest value of "regret" and find a project with a minimum value:

$$min\,(81\,000, 4\,800, 14\,000, 19\,000, 24\,400) = 4\,800.$$

## IV. RESULT AND DISCUSSION

For our example, according to this criterion, the optimal storage design with a capacity of 30 thousand barrels, i.e. again, the choice stops at the second alternative.

Thus, the company managed to make a balanced and informed strategic decision on the construction of a new oil storage facility with a volume of 30 thousand barrels of oil, and only with very strong pessimism regarding the probable minimum oil production in the region, it is possible to adopt a project option of 20 thousand barrels of oil.

The decision-making modelling technique, taking into account various parameters and characteristics, in the face of uncertainty, justifies itself and allows for qualitative analysis and strategic forecasting of the development of the company.

Modern approaches to forecasting development make it possible to take into account as much as possible any possible options for the development of the situation, as well as to simplify the construction of the model for making informed management decisions.

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