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DEVELOPMENT OF AN AUTOMATED SYSTEM FOR MAKING MULTI-STAGE MANAGEMENT DECISIONS AT INDUSTRIAL ENTERPRISES

The object of research is the process of making managerial decisions, which requires an analysis of the sequence of decisions and external factors, in the case when one set of strategies of the subject of control and states of the external environment generates another state of this type.

The study is devoted to the issues of automation of management processes of socio-economic systems, namely, the creation of a model and software implementation of the process of making multi-stage decisions at a manufacturing enterprise. The production system is a complex dynamic system, therefore it is characterized by uncertainty in its functioning, as well as a large number of heterogeneous elements and connections, multivariate development. These characteristics of the system, as well as the fundamental uncertainty of external factors of functioning, necessitate the analysis of a large amount of information, which is inherent in uncertainty and incompleteness. Therefore, it is important to create automated management decision-making support systems.

The objective of research is to create a rational choice model in a situation where there are two (or more) sequential sets of decisions, and subsequent decisions are based on the results of the previous ones. This situation assumes the presence of two (or more) multiple states of the external environment. That is, a whole chain of decisions appears, arising from each other and corresponding to events that occur with a certain probability. To solve this type of problem, the game-theoretic apparatus of multi-stage games with nature is used.

In order to carry out experiments with the model, its software implementation has been developed. The paper reviews the existing analogues, analyzes the input and output data of the model. Within the framework of the object-oriented programming methodology, an activity diagram is built, the functionality of the actors is determined, and a description of the functional model is made.

By conducting experiments with the model, it is possible to improve the validity of management decisions. The advantages of the developed automated system in comparison with known analogues: support for multi-stage management decisions, providing opportunities for saving and correcting results.

Keywords: *multi-stage solution, automated system, risk management, activity diagram, functional model.*

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1. Introduction

Making managerial decisions requires processing and analyzing a large amount of information, which determines the relevance of automating these processes. If to define the management of socio-economic systems as transferring the system from the current state to the desired state, then the perfection of information analysis is the key to the optimal way of transferring the system to the desired state.

Information about the system can come from both external and internal sources. Incompleteness and inadequacy of information, in the first case, is due to the indeterminacy of the behavior of the external environment [1, 2]. Secondly, the coincidence of the goals of the management and executive levels of the system [3].

Automation of the production management process consists in attracting programming tools for planning and controlling input, intermediate and output variables of certain material factors in order to obtain optimal profits within the capabilities and, accordingly, the general directions of the company as a whole [4].

The above facts allow to conclude that the development and software implementation of a model for making multi-stage managerial decisions at a manufacturing enterprise are relevant issues, the solution of which is devoted to this work.

2. The object of research and its technological audit

The object of research is the process of making management decisions, which requires an analysis of the sequence of decisions and external factors, in the case when one set of strategies of the subject of management and states

of the external environment generates another state of this type. The subject of research is object-oriented methods of software development.

The management process involves the distribution and redistribution of available resources (employees, time, finances, equipment, materials, etc.), that is, everything that is provided to the head within the limits of its authority. However, there are situations of threat of expenditure by the enterprise of its resources or their part, which are called risk situations. They are accompanied by the presence of uncertainty, the need to choose an alternative and the possibility of assessing the likelihood of the implementation of alternatives.

Risk arises in the decision-making process due to uncertainty and incompleteness of information. The emergence of uncertainty is due to the fact that:

– most of the processes associated with the economy are fundamentally stochastic;
– incompleteness of information can be economically determined, that is, possible losses from decision-making based on incomplete information are less than the cost of collecting and processing accurate information;
– there is «organized» uncertainty arising from conflict or hiding information by other market participants.

Risk management involves the development and implementation of measures aimed at reducing the degree of risk and determining the optimal (economically feasible) degree of risk at which decisions should be made.

3. The aim and objectives of research

The aim of research is to develop an automated system for implementing a model for making multi-stage management decisions for further analysis of possible scenarios for the development of an enterprise's functioning under conditions of risk and uncertainty. To achieve the aim, it is necessary to solve the following objectives:

1. Determine the goals of the automated system for making multi-stage decisions in relation to the user.
2. Review existing analogues.
3. Build an activity diagram and a use case diagram.

4. Research of existing solutions of the problem

During the examination of the sources of the world scientific periodicals, the works [5, 6] were highlighted, which describe the relationship between organizational processes and managerial decision-making processes, is one of the directions for solving the problem of creating management decision support systems. However, these works do not contain specific models of the decision-making process and do not consider the issues of making rational decisions under certain operating conditions.

The work [7] is devoted to the issues of making rational decisions, which also compares different approaches to the management process and provides a description of the six stages of decision-making. The construction of a conceptual model of the effectiveness of an organizational system through the study of the processes of making rational management decisions is considered in [8]. However, these works are not considered in terms of quantitative indicators to determine the best alternatives for management decisions.

From the standpoint of resolving the problem of creating management decision support systems, interesting works [9, 10], which consider the creation of automated systems. But the research in these works has a very narrow direction, covering individual organizational systems (insurance companies, sales firms, educational institutions).

The work [11] is devoted to the creation of automated systems for decision support, but the studies described in it are of a purely technological nature and do not relate to the issues of modeling multi-stage management decisions. It is to these problems that the works [12, 13] are devoted, however, they are mainly of scientific value and can't be used for making managerial decisions at industrial enterprises. In addition, these works do not consider the issues of accounting for the risk associated with the competitive environment of the enterprise.

The authors of [14] give methods for solving the problem of accounting for incomplete information in the process of making optimal decisions. And in work [15] the author covers the issues of research of enterprise management in a competitive environment. However, these works do not relate to the issues of building a model for making multi-stage decisions, they are spaced in time, in a situation where the results of the implementation of some decisions depend on the results of the previous ones.

The results of the analysis of works devoted to the issues of decision-making show the need to study models for making multi-stage management decisions and their software implementation for further analysis of possible scenarios for the development of enterprise functioning in conditions of risk and uncertainty.

5. Methods of research

Model development tools – methods for making multi-stage decisions within the framework of the game-theoretic approach [14, 16], automated system development tools – object-oriented methods of software development [17, 18].

Let's review the existing analogues of the automated system being developed.

One of the programs for decision support is «Decision Making Service». The program allows making decisions based on the scale of importance and probability. After introducing selection alternatives and setting parameters, the user needs to enter the positive and negative sides of each option.

As a result, it is possible to see the best solution of all the alternatives, save or print the task, see the table of pros and cons. It is possible to save the task on computer in the .json format (as a solution), .xls (as an Excel table) and .png (as a picture). It is also possible to save the solution to your profile, but it is necessary to log in to do this.

This service can be used for simple tasks with predetermined positive and negative features of the management subject's strategies. In addition, this service does not provide a detailed solution to the problem or a description of the choice of solution.

Another service for making decisions under conditions of uncertainty is Games with Nature Online. Using the service, it is possible to choose the optimal strategy using decision criteria under conditions of risk and uncertainty: minimax, maximax, Bayes, Wald, Savage, Laplace, Hodge-Lehmann, Hurwitz, generalized Hurwitz criterion with calculation of efficiency. The service allows to plan the perfect experiment. The results of online calculations

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are recorded in a Word report. The disadvantages of the service are support for making only one-step decisions, as well as the significant cost of downloading and viewing the results.

Table 1 shows a comparative characteristic of the automated system under development and its analogues.

Within the framework of a game-theoretic model, the decision-making process under risk conditions can be described as a game with nature, which involves the formation of a set of states of the environment (nature) and the first player (subject of control). In this study, the set of first player alternatives consists of two elements: «Expand production» and «Sell the firm». The choice of an alternative depends on the level of product sales, in other words, on the state of the external environment in the future. To simplify the model, three options for the state of the environment have been separated: «Low sales», «Average sales» and «High sales». For each of the states, the prior probabilities were calculated [19].

Table 1

Comparative characteristics

Service name	Appointment	Administration	Database availability	Gratuitousness	Solving complex problems
«Decision making service»	Decision making service based on the scale of importance and probabilities	–	–	+	–
«Games with nature online»	Service for making decisions in the face of risk and uncertainty	–	–	+/–	+
An automated system under development	Service for making multi-stage management decisions	+	+	+	+/–

In the presence of one set of alternatives for the subject of management, the choice of the best solution can be carried out using the value of the expected monetary value, which is needed to make a decision to conduct additional marketing research (EMV):

$$EMV_i = \sum_{j=1}^{n} O_{ij} p_j, i = \overline{1...m}, j = \overline{1...n}, \quad (1)$$

where O_{ij} – gain for the i-th alternative of the enterprise when the j-th state of the external environment occurs; p_j – probability of the onset of the j-th state of the external environment; n – the number of possible states of the external environment; m – the number of possible strategies of the subject of management.

In order to clarify the prior probabilities of environmental conditions, additional market research can be carried out. Thus, a second set of alternative solutions of the first player arises, which consists of two elements: «Conduct market research», «Do not conduct market research». The choice from this set of alternatives precedes the choice to expand or sell production, and its results influence this choice. A chain of decisions was formed, which is usually analyzed within the framework of multistage decision-making models.

The choice between the alternatives «Conduct market research», «Do not conduct market research» is based on the value of perfect information (*EVPI*), equal to the minimum value of lost opportunities for making a decision based on incomplete information. In real conditions, the availability of one hundred percent information is impossible, therefore, any research to clarify the probabilities of the states of the environment can't cost more than this value. The formula looks like this:

$$EVPI = EV \mid PI - EMV, \quad (2)$$

$$EV \mid PI = \sum\nolimits_{j=1}^{n} p_j \left(\max_i O_{ij} \right), i = \overline{1...m},\ j = \overline{1...n}, \quad (3)$$

where $EV \mid PI$ – expected utility provided that «perfect» information is taken into account about which strategy of the subject of management is guaranteed to be better.

Since the implementation of a decision to expand production is a long-term process, it is advisable to split it into two stages:

– Stage 1 is the first year of the project implementation, which is characterized by less cash flow and a higher level of riskiness;

– Stage 2 is the subsequent years of the project, which are characterized by a higher cash flow and a lower level of riskiness. This stage corresponds to the established mode of operation, but in this case the money should be discounted.

The choice of the best alternative is determined by the maximum value of the net present value (NPV) – this is the sum of the discounted values of the payment flows given to date, calculated by the formula:

$$NPV = \frac{EMV1}{k}, \quad (4)$$

where NPV – sum of discounted values of payment flows; $EMV1$ – expected monetary value (evaluation of the decision at the first stage); k – discount coefficient.

The expected monetary value is calculated using the formula:

$$EMV1 = \sum_{j=1}^{N} DCF \cdot p_j, j = \overline{1...n}, \quad (5)$$

where DCF – discounted cash flow; p_j – probability of the j-th state of the external environment.

DCF size is calculated by the formula:

$$DCF = \frac{EMV2}{k} + CF1, \quad (6)$$

where $EMV2$ – expected monetary value (assessment of the solution at stage 2); k – discount coefficient; $CF1$ – cash flow at the first stage (the average value of the cash flow is the difference between gross income, variable, fixed costs and taxes).

Based on the theory of the time value of money, the discounting method is used to obtain the amount of the flow of payments given to the present moment in time. Thus, all cash flow amounts are reduced to their present value [1, 15].

6. Research results

The automated system under development is aimed at providing users with the ability to automatically make multi-stage management decisions. The process of registration, authorization and data entry is depicted graphically using the activity diagram [20] in Fig. 1.

The goals of developing an automated system in relation to users:

– ability to create and solve the problem of making multi-stage management decisions;

– ability to use several types of parameters, for example, the state of the external environment, sales volumes, etc.;

– ability to save the task for further editing;

– ability to administer users;

– ability to view a detailed tree of solutions for the created tasks.

Here is a description of the functional model. The functional model can be represented as a use case diagram. To build it, let's define the actors and the actions that each of them can perform in the system. Actors represent classes of people, organizations, or other systems of software devices that interact with the system that is being developed.

The use case diagram is shown in Fig. 2. In an automated system for making multi-stage decisions, the following actors can be:

– a guest whose capabilities are: solving the problem of making multi-stage management decisions using an application without the possibility of storage; check in; authorization;

– an authorized user whose capabilities are: solving the problem of making multi-stage management decisions using the application; saving created tasks for further use or editing; manage saved tasks (delete or edit);

– an administrator, whose capabilities are: managing user accounts and their saved tasks.

The input data into the management decision making system are the parameters of the problem, the analysis of which is given in Table 2 [21].

The initial data of the decision-making system are the parameters given in Table 3.

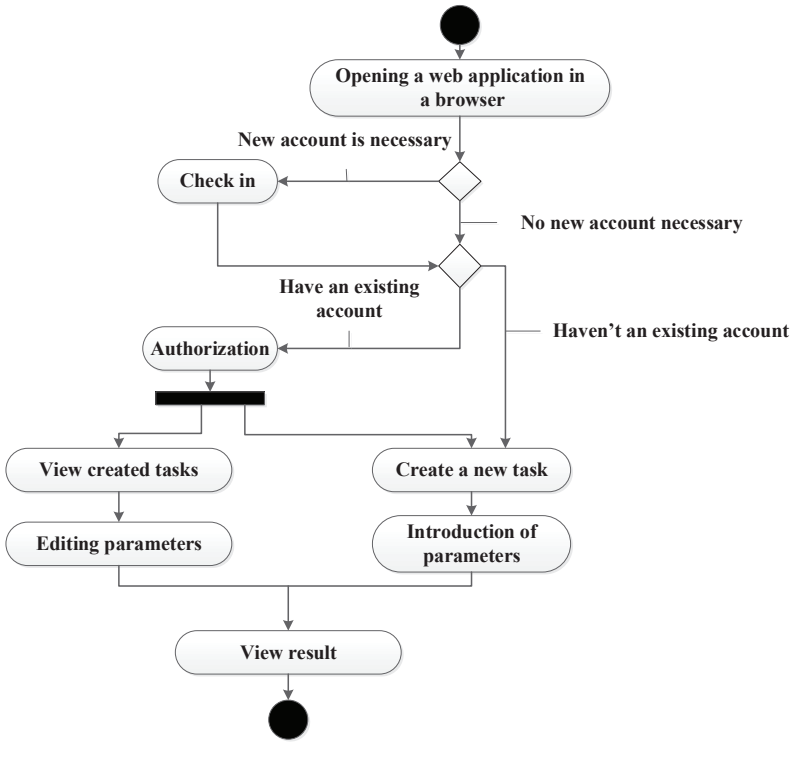

Fig. 1. Activity diagram

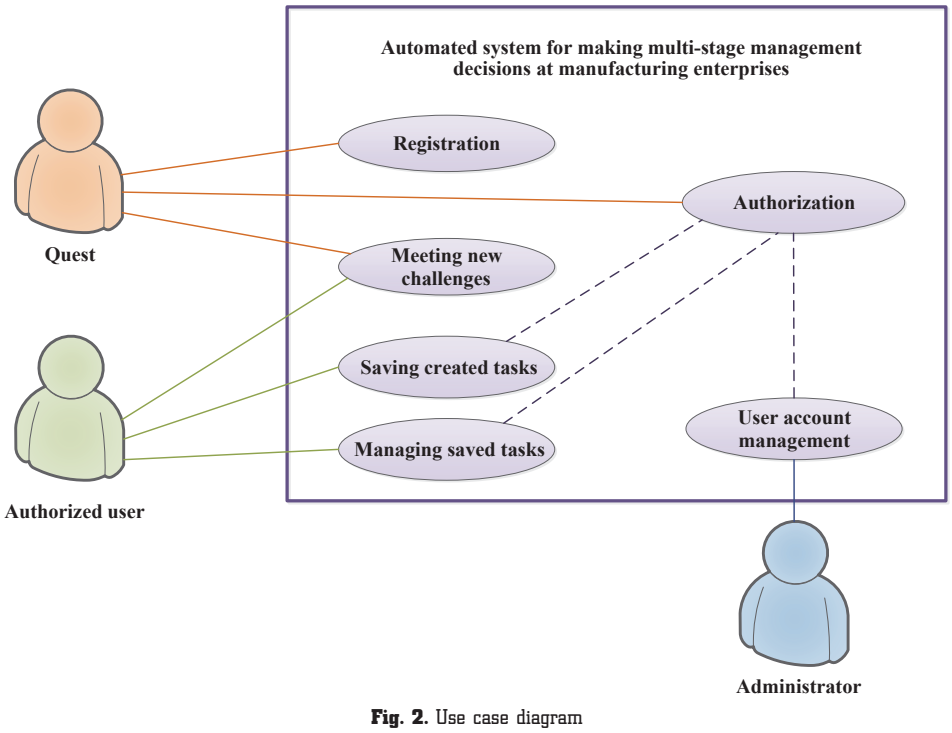

Fig. 2. Use case diagram

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Table 2

Input data

Input name	Data type	Range of change of values
Announcements of sales	Char unsigned	0…255
Gross income	Integer	–2 147 483 648…2 147 483 647
The sum of variable costs	Integer unsigned	0…4 294 967 295
Taxes	Integer unsigned	0…4 294 967 295
Fixed cost amount	Integer unsigned	0…4 294 967 295
Price from company sales	Integer unsigned	0…4 294 967 295
Investment amount	Integer unsigned	0…4 294 967 295
Percentage of sum of variable cost from gross income	Decimal (precision, scale)	1…15
Percentage of taxes from gross income	Decimal	1…15
Discount on the cost of additional research	Decimal	1…15
Discount rate and coefficient	Decimal	1…15
Percentage of change in cash flow depending on sales	Decimal	1…15
Percentage of cash flow increase in the second phase of the project	Decimal	1…15
Cash flow increase percentage due to expansion	Decimal	1…15

Table 3

Initial data

Output name	Data type	Range of change of values
Prior probabilities of the onset of the j-th state of the environment, P_j	Single	$10^{-45}…10^{+38}$
Expected monetary value of the i-th alternative, EMV_i	Integer	–2 147 483 648…2 147 483 647
Expected Lost Opportunities of the i-th Alternative, EOL_i	Integer	–2 147 483 648…2 147 483 647
The cost of perfect information, *EVPI*	Integer	–2 147 483 648…2 147 483 647
Net present value, *NPV*	Integer	–2 147 483 648…2 147 483 647
Discounted cash flow, *DCF*	Integer	–2 147 483 648…2 147 483 647
Cash flow, *CF*	Integer	–2 147 483 648…2 147 483 647

Further improvement of the automated system is planned through the creation of a web interface, with the help of which the input data comes in the form of HTTP requests through the browser, the output data comes in the form of an HTTP response with an HTML page that is displayed to the user using the browser.

7. SWOT analysis of research results

Strengths. The advantages of the automated system under development in comparison with analogues are:

– solving problems, consisting in certain better alternatives of managerial decisions, which form a chain of interrelated decisions distributed over time;

– providing the user with the opportunity to save the received solutions and edit them in the future.

Weaknesses. The weak side of the automated system being developed is the imperfection of the user interface and the absence of a graphical display of the sequence of decisions and states of the environment, indicating the corresponding probabilities and gains for any combination of alternatives and states of the environment.

Opportunities. The introduction of an automated support system for making multi-stage decisions will reduce the time for processing and analyzing information, as well as the ability to view various scenarios for the development of an enterprise for possible changes in the external parameters of its functioning.

Threats. The failure of an automated system can occur when software or hardware threats are implemented. The inadequacy of the parameters entered into the system by the user, or a fuzzy understanding of the essence of the parameters, which are the input and output data of the system, can lead to incorrect calculations and conclusions. The latter threat can be partially eliminated due to restrictions on the input data, which should be described in the user manual and on-screen forms of the interface.

8. Conclusions

1. In the course of the research, the goals of the automated system for making multi-stage decisions for the user were determined: providing the ability to create and solve the problems of making multi-stage management decisions based on several types of parameters, as well as saving the task for further editing. Since the development of an automated system for making multi-stage managerial decisions at manufacturing enterprises ensures effective decision-making and calculating the average return on business, and on this basis – a stable position in the market in a competitive environment.

2. A review of existing counterparts was carried out and found that none of them provide the capabilities that are defined by the goals of the system. Unlike analogs, the system being developed provides for the input of the values of several parameters of the problem. The result of the system operation is a chain of decisions that are the best

for the entered parameter values. The system takes into account the discounting of money for the period of implementation of the specified chain of decisions. The technical differences of the system are given; it is its advantages over known analogues.

3. Based on the methods of object-oriented programming, an activity diagram was constructed and a description of the functional model was developed, for which the classes of possible users of the system and their capabilities were determined. One of the classes of users of the system is a guest, whose capabilities are limited to solving the problem, registration and authorization. Another class is an authorized user, whose capabilities are enhanced by the functions of saving and managing created tasks. The class administrator is highlighted, who has the ability to manage user accounts and their saved tasks. The constructed activity diagram and use case diagram ensure the correct development of the functionality of the automated system and effective writing of program code.

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