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Risk-based Decision-making System for Information Processing Systems

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Abstract: The article is dedicated to using the methodology of building a decision support system under threats and risks. This method has been developed by modifying the methods of targeted evaluation of options and is used for constructing a scheme of the decision support system. Decision support systems help to make correct and effective solution to shortage of time, incompleteness, uncertainty and unreliability of information, and taking into account the risks. When we are making decisions taking into account the risks, it is necessary to solve the following tasks: determination of quantitative characteristics of risk; determination of quantitative indicators for the effectiveness of decisions in the presence of risks; distribution of resources between means of countering threats, and means that are aimed at improving information security. The known methods for solving the first problem provide for the identification of risks (qualitative analysis), as well as the assessment of the probabilities and the extent of possible damage (quantitative analysis). However, at the same time, the task of assessing the effectiveness of decisions taking into account risks is not solved and remains at the discretion of the expert. The suggesting method of decision support under threats and risks has been developed by modifying the methods of targeted evaluation of options. The relative efficiency in supporting measures to develop measures has been calculated as a function of time given on a time interval. The main idea of the proposed approach to the analysis of the impact of threats and risks in decision-making is that events that cause threats or risks are considered as a part of the decision support system. Therefore, such models of threats or risks are included in the hierarchy of goals, their links with other system's parts and goals are established. The main functional modules that ensure the continuous and efficient operation of the decision support system are the following subsystems: subsystem for analysing problems, risks and threats; subsystem for the formation of goals and criteria; decision-making subsystem; subsystem of formation of the decisive rule and analysis of alternatives. Structural schemes of functioning are constructed for each subsystem. The given block diagram provides a full-fledged decision-making process.

Index Terms: Information system, decision support system, efficiency, information security, quantitative criterion, process modeling, information impact.

1. Introduction

Decision support information technology is the interface between a human and a computing system. Decisions are developed as a result of a cyclical process. The decision support system (DSS) is a computing device and a control object. Man is the controlling part. DSS is designed to provide information support to the decision-maker. The use of DSS is due to: the necessity for an accurate assessment of various alternatives; difficulty in making decisions; the necessity for predictive functionality; data-driven decision making, expert judgment, known limitations.

DSS scope is non-standard situations and problems associated with uncertainty and risk. They are characterized by the presence of uncertainty, which makes it almost impossible to find the best alternative solution.

Various methods are used to analyse and develop proposals in the DSS. These can be following: evolutionary computing and genetic algorithms, neural networks, information retrieval, data mining, knowledge search in databases, use of precedents, simulation modelling, situational analysis, cognitive modelling, etc.

The basic principles of the formation and use of the DSS include: providing the decision maker with the necessary information in the maximum possible volume; the ability to quickly search for information; generating alternative solutions; providing forecast estimates of the results of the implementation of possible alternatives; constant evolution of the system by increasing its capabilities.

Aspects of development and application of decision support systems are discussed in detail in the works [1,2,3,4]. The author has analysed the history of their development, field application descriptions the most common DSSs. The necessary conditions for the effectiveness of decisions are timeliness, complexity and optimality. The first of these conditions is a constraint, and the others are the defining fundamental conditions. The requirement of complexity implies the need for the fullest and most comprehensive consideration of the influence of internal and external factors and their relationships. Therefore, taking into account the factors influencing information flows by attackers is a priority for developers of information systems. Research of risks and threats to the information system requires comprehensive attention and solving the problem of functioning of the information system taking into account the threats and risks.

The main functions of the DSS are regulated by the following items [5,6,7,8]:

- comprehensive analysis of the problem on the basis of formal and informal methods of decision support;
- obtaining reliable and up-to-date information on the current state of the problem on the basis of reports, statistics, analytical reviews and monitoring systems;
- automated choice of decision support methods;
- support the development of the system;
- dynamic management in order to increase the effectiveness and validity of conclusions and recommendations in the development of management influences;
- opportunity analysis, operational management and control problem that is solved.

In general, the decision support system is a set of activities united by the unity of a global goal and common resources. The main objects of research are decision-making processes. These processes are carried out under the influence of external factors such as threats and information security risks [9,10].

When developing a decision support system, it is necessary to take into account the possibility of threats and risks, analyse their impact [11]. Based on this, we need to provide measures to counter or eliminate them.

When we are making decisions taking into account the risks, it is necessary to solve the following tasks:

- determination of quantitative characteristics of risk;
- determination of quantitative indicators for the effectiveness of decisions in the presence of risks;
- distribution of resources between means of countering threats, and means that are aimed at improving information security.

The known methods for solving the first problem provide for the identification of risks (qualitative analysis), as well as the assessment of the probabilities and the extent of possible damage (quantitative analysis). However, at the same time, the task of assessing the effectiveness of decisions taking into account risks is not solved and remains at the discretion of the expert. Moreover, the definition of damage in absolute terms is often impossible.

Thus, the task of assessing the effectiveness of countermeasures against threats in the decision support system arises.

To achieve this goal, it is necessary to develop the stages of decision support technology, taking into account threats. This technology is based on the method of targeted dynamic estimation.

These tasks are solved subject to the formation of tasks at a given time interval. The basis for them is the task of assessing the comparative effectiveness of a given set of tasks. It is proposed to evaluate the effectiveness of means of counteracting risks and threats taking into account the fact that there are means of counteraction. The proposed method is a modification of the method of target dynamic estimation of tasks on a time interval.

This technology can be used for complex programs for various purposes.

2. Review of Literature

The review of the literature [1,3,4,6] has shown that aspects of the influence of destructive factors in the decision-making are not considered in the construction of decision support systems. Moreover, the problems of including the means of countering threats to the list of objects and goals of the system itself are not considered, as well as the issues of evaluating the effectiveness of these means.

3. Construction of an Algorithm to Support Decision-making for the Managing of information Processing System Tasks

Firstly, it is necessary to build an algorithm for the DSS to solve the problem.

There are many approaches to building a DSS [12]. Classical approaches such as the logical approach, the structured approach, the evolutionary approach and the imitation approach have become widespread.

Building an algorithm for decision-making tasks is a complex procedure. It consists of formalized and informal stages. Three groups of people are involved in the construction and research process. This is a decision maker, consultant and experts.

Let's take a look at the procedure of the decision-making.

Fig. 1 depicts the decision-making procedure, which consists of eight stages. The results of the study allow obtaining an ordering of the set of acceptable solutions. It is possible to build different versions of models. The advantages and disadvantages of these models can be identified only based on their comparative analysis and practical use.

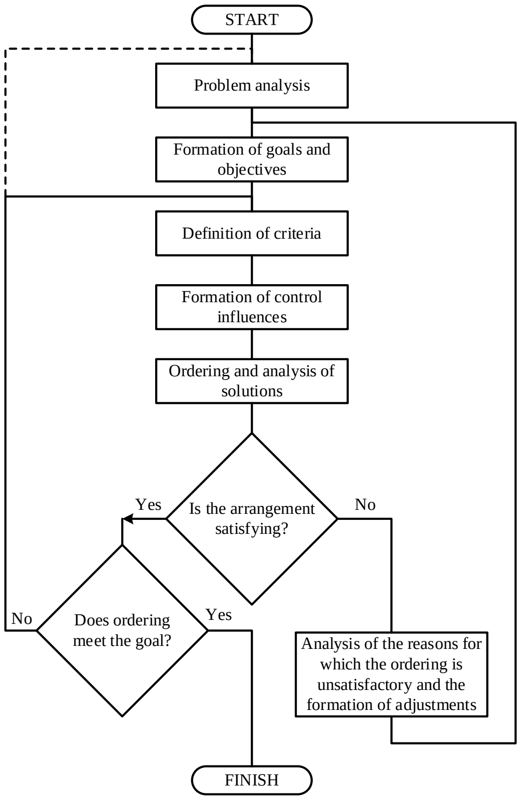

Fig.1. The block diagram of a decision-making procedure

The main feature of this procedure is that threats and risks are taken into account. Models of threats and risks are included in the hierarchy of goals, their links with other system's parts and goals are established. This is done when forming a goal

The decision support algorithm is designed to determine the optimal number of factors, alternatives and decision rules to ensure the effective functioning of the system.

The following general decision support algorithm is proposed. It consists of successive stages, goals and methods of achieving goals [13,14,15]. Table 1 presents stages of iterative algorithm.

Table 1. Stages of iterative decision support algorithm

No	The name of the stage	Goals	Methods of achieving goals
1	Problem analysis	Formulation of the problem. Defining the problem and its structure, the general structure of the system	Methods of the theory of systems for causal modelling and structural analysis
2	Formulating goals and objectives	Setting goals, constraints and system functions	Methods of structural analysis, goal trees, mathematical modelling, brainstorming, analogies
3	Definition of criteria	Defining the system of criteria	Methods of structural analysis, goal trees, mathematical modelling, brainstorming, economic analysis
4	Formation the set of alternatives	Determining the set of alternatives	Methods of structural brainstorming, economic analysis, functional-cost analysis
5	Analysis of alternatives	Identify an alternative or set of alternatives that meet the system of criteria	Theory of support-decision-making, methods of structural analysis, economic analysis
6	Formation of control influences	Implementation of the solution	Theory of support-decision-making, management theory, methods of structural cognitive analysis, economic analysis

According to the decision-making algorithm, we will consider each of the stages mentioned in it: problem analysis, formation of goals and objectives, definition of criteria, generation of alternatives, decision analysis and formation of control influences.

We need to perform the following steps to implement the first stage of problem formation and analysis:

- analyse the problem;
- perform system definitions;
- analyse the structure of the system and the problem.

The source is information about the system, threats and risks. Table 2 shows the scheme of the problem analysis.

Table 2. The stage of formulation and analysis of the problem. Sequence of actions

No	The name of the stage	Goals	Methods of achieving goals
1	Definition and formulation of tasks and problems	Formulation of the problem and definition of its structure, general structure of the system. Choice of the system description language	Methods of systems theory, Delphi method, causal modelling and structural analysis
2	System definition	Definition and classification of the system	
3	System structure analysis	General structure of the system	

The given sequence of actions allows to carry out the detailed analysis of all data received during performance of this stage, the analysis of data of the system and revealing of the general structure of a problem. The received information is used for definition of the purpose and formulation of tasks for specification of the given problem.

In the stage 2, which is called the formulation of tasks and objectives, the goals and objectives of the system are defined, the global goal and limitations are formulated. To achieve the goal of this stage it is necessary:

- define the goals of the system and supersystem;
- define the goals and limitations of the environment;
- identify threats and risks;
- define the global goal of the system;
- perform decomposition of the goals and functions of the system.

The goals of the lower levels can be obtained based on the goals of the upper levels by the method of decomposition. However, at the top level, there are usually several. It is important not to miss any of the essential ones. One technique is to use a model of super- and subsystems for a system that contains problems. This allows to take into account the goals of all stakeholders, which should be set out on a nominal scale. The use of stronger scales is a sign of lower-level goals. The transition from goals to criteria is the next stage in the implementation of decision support systems [16].

Input information is information about the system, problems, threats and risks, as well as the hierarchy of the system.

Table 3 shows the analysis of goals and performance criteria for the DSS model which is implemented in accordance with the following step.

Table 3. Analysis of goals and performance criteria

No	The name of the stage	Goals	Methods of achieving goals
1	Defining the goals of the supersystem	Objectives of the supersystem	Methods of structural analysis, goal trees, mathematical modelling, brainstorming, morphological analysis, fuzzy set theory, expert methods
2	Defining goals and constraints of the environment	The goals of the system and the constraints imposed by the environment	
3	Identification of threats and risks	Threats and risks	
4	Defining the global goal of the system	The global goals of the system	
5	Decomposition of goals and functions of the system	Goals and functions of the system	

We need to consider the following principles of a systematic approach in setting goals:

- The principle of the ultimate goal. This means the absolute priority of the ultimate goal.
- The principle of unity. This means a common consideration of the system as a whole and as a set of elements.

- The principle of connectivity. This means considering any part together with its connections with the environment.
- The principle of modular construction. This means the selection of modules in the system and its consideration as a set of modules.
- Hierarchy principle. This means the introduction of a hierarchy of elements and/or their ranking.
- The principle of functionality. This means a joint consideration of the structure and function with the priority of the function over the structure.
- The principle of development. This means taking into account the variability of the system, its ability to develop, expand, replace parts, the accumulation of information.
- The principle of decentralization. This means a combination of decisions and management of the principles of centralization and decentralization.
- Uncertainty principle. This means accounting for uncertainties and coincidences in the system.

To achieve these goals, it is necessary to form qualitative and quantitative features that characterize them, which will allow a detailed assessment of their achievement in the following stages [17].

The following sequence of actions is implemented when we are forming a system of criteria (the stage 3): definition of the system of criteria for achieving the goal, decomposition of criteria by subgoals, evaluation of the effectiveness of criteria (Table 4).

Table 4. Definition of criteria

No	The name of the stage	Goals	Methods of achieving goals
1	Defining a system of criteria for achieving the goal	A set of performance criteria	Methods of structural analysis, goal trees, mathematical modelling, brainstorming, analogies, morphological analysis, fuzzy set theory, expert methods
2	Decomposition of criteria on a subgoal	System of criteria	
3	Determination of methods for evaluating criteria based on modelling results and methods for determining system criteria	Methods for evaluating performance criteria	
4	Development of methods for evaluating the effectiveness of the system	Methods for evaluating the effectiveness of the system	

However, the definition of "criterion" can be considered not only as a criterion function, but also as any way to compare alternatives. This means that the criterion for the quality of the alternative can be any of its features. Once such a criterion is formed, it is possible to set the task of selection and optimization.

The process of forming a system of efficiency criteria is creative, poorly formalized and largely subjective, which requires in each case an individual approach [14,16]. It depends on the uncertainty of the source information, but is necessary for further analysis of alternatives and their generation.

The Stage 4 is called the formation of many alternatives.

This stage is represented by the iterative algorithm according to the general algorithm of decision support systems. Table 5 shows the formation of the set of alternatives.

Table 5. Formation of the set of alternatives

No	The name of the stage	Goals	Methods of achieving goals
1	Formation of the set of alternatives	Determining the set of alternatives	Methods of structural brainstorming, fuzzy set theory, expert methods, morphological analysis
2	Structuring alternatives	Structuring alternatives	Methods of structuring alternatives
3	Formation of alternative subsets	Subsets of alternatives	Expert methods, methods of structural analysis

It is necessary to develop methods to describe the alternatives for solving the following tasks: construction of possible sets and acceptable alternatives, formation of aspects essential sets for the evaluation of alternatives, arrangement of alternatives by criteria. The process of forming a set of alternatives is based mainly on the heuristic advantages of decision-maker and the search for similar options in solving problems of a similar nature. The stage of generating solutions or forming the original set of alternatives can be divided into three successive stages: generating a set of alternatives, structuring alternatives, forming a subset of effective alternatives.

The input data are the simulation results and the system of criteria, as well as information about the system.

The Stage 5 is called analysis of alternatives. The most important stage is the analysis of solutions. During this stage, it is necessary to optimize the solution. It is based on a decision support methodology that includes a variety of technologies and techniques that can be partially or completely formalized. Different methods have different input requirements and operating conditions, but the ultimate goal of each of the rules and methods is to help the decision maker choose the best alternative.

From the point of view of system analysis, the main stages of alternative solution analysis include: analysis of solution uncertainty, choice of optimization methods and definition of decision functions, evaluation of possible solutions, selection of optimal solution. Table 6 shows the content of the analysis step of alternatives.

Further consideration of the selected alternatives is entrusted to the decision maker, who determines the degree of achievement of the objectives defined earlier, based on the proposed options. It may turn out that none of the presented options is suitable. It is possible to run the iteration of the algorithm again with the specification of some characteristics of the problem and the system, or to identify specific actions that control the implementation of the solution or solutions.

Table 6. Analysis of alternatives

No	The name of the stage	Goals	Methods of achieving goals
1	Analysis of decision uncertainty	Analysis of decision uncertainty	Theory of decision support, methods of structural analysis, economic analysis
2	Choice of optimization methods and critical functions	Choice of optimization methods and critical functions	Methods of generalized criterion, main criterion, utility functions, expert systems, game theory, fuzzy set theory
3	Evaluation of possible solutions	Evaluation of possible solutions	
4	Selection of optimal alternatives	Selection of an (set) alternative that meet the criteria	Expert methods

The stage 6 is called the formation of control impact is the final stage in the chain of stages of decision support and, in fact, is the result of actions in previous stages. At the stage of formation of administrative impact on the object of management, the decision-maker performs a number of actions aimed at implementing the recommendations provided to him, or making adjustments to the recommended impact on the management object, with subsequent application to the management object (Table 7).

Table 7. Formation of control action

No	The name of the stage	Goals	Methods of achieving goals
1	Identification of the object state and the environment	Result environmental impact	Decision support theory, control theory, expert systems, fuzzy set theory
2	Developing control action	Analysis of the impact on the system	
3	Implementation of control action	Realization	

At the stage of the control action on the object management entity that decides performs a number of actions aimed at the identification of the facility and environment required for the control action (Table 8).

Table 8. Identification of the state of the environment and the object

No	The name of the stage	Goals	Methods of achieving goals
1	Identification of the state of the object and the environment	The result of identification	Decision support theory, control theory, expert systems, fuzzy set theory
2	Forecasting the development of the environment	The result of forecasting	
3	Forecasting results provide control action on the object	Result environmental impact	

In developing the control action is important to establish informational portraits of conditions and predict correct control action on the object (Table 9).

Table 9. Development control action

No	The name of the stage	Goals	Methods of achieving goals
1	Formation of information portraits of states	Factors affecting the object	Theory of decision support, methods of structural analysis, economic analysis
2	Predicting the results of administrative impact on the object	Impact on the system	

The last step is called the implementation of the control action based on the training set and verification system model (Table 10).

Table 10. Implementation of control action

No	The name of the stage	Goals	Methods of achieving goals
1	Formation of the training sample	Training sample	Methods of support-decision theory, management theory, methods of structural cognitive analysis
2	The result of adaptation	The result of adaptation	
3	Model verification	Realization	

3.1. Description of the functioning algorithm of the decision support system

Decision support system is designed to support decision-making for various areas of technological, socio-economic and political nature.

The main functions of the decision support system are as follows:

- analyse the problem;
- comprehensive analysis of the problem on the basis of formal and informal methods of decision support;
- obtaining reliable and up-to-date information on the current state of the problem on the basis of reports, statistics, analytical reviews and monitoring systems;
- automated selection of decision support methods;
- support for the development of the managed system;
- dynamic management in order to increase the effectiveness and validity of conclusions and recommendations in the development of administrative impacts;
- the ability to analyse, manage and control the problem to be solved [18].

A standard DSS should include the following main modules and subsystems:

1. DSS database.
2. DSS knowledge base.
3. Base of models, rules and methods of decision-making.
4. Interface management system.
5. Basic functional modules.

DSS should provide the following types of support for the implementation of decision support:

- analyse the problem;
- the expert;
- automated;
- combined.

It is convenient to consider any decision support system as an automated dialog system. Such a system uses appropriate mathematical models in conjunction with databases and knowledge, as well as an interactive computer modelling process [19, 20].

The main functional modules that ensure the continuous and efficient operation of the system include the following subsystems or models [21]:

- automated;
- subsystem of analysis of problems, risks and threats;
- subsystem for the formation of goals and criteria;
- decision-making subsystem;
- subsystem of decision-making and analysis of alternatives.

The block diagram of the functioning of the decision support system is shown in Fig. 2.

This scheme provides a full-fledged decision-making process in the analysis of any type of task [22]. Consider in more detail the algorithms for the operation of individual subsystems of DSS.

3.2. Analysis of problems, risks and threats

There are four classes of the most common problems.

1. Standard problems. Problems of this class require the application of instructions established by the head of the rules for their solution.
2. Well-structured problems. Problems of this class have quantitative characteristics and indicators. Economic and mathematical methods are most often used to solve them.
3. Ill-structured problems. Problems of this class have not only quantitative but also qualitative characteristics. To solve them, as a rule, a systematic approach is used.
4. Unstructured problems. Their solution is possible on the basis of expert assessments, judgments of professionals. Problems of this class usually have as their subject little-studied processes [23].

In terms of content, the whole set of possible management tasks can be divided into the following types:

- identification;
- evaluation;
- synthesis of possible options;
- problem analysis;
- factor analysis;
- trend analysis;
- forecasting;
- planning;
- software implementation of algorithms;
- organization and operational management;
- implementation of decisions;
- control.

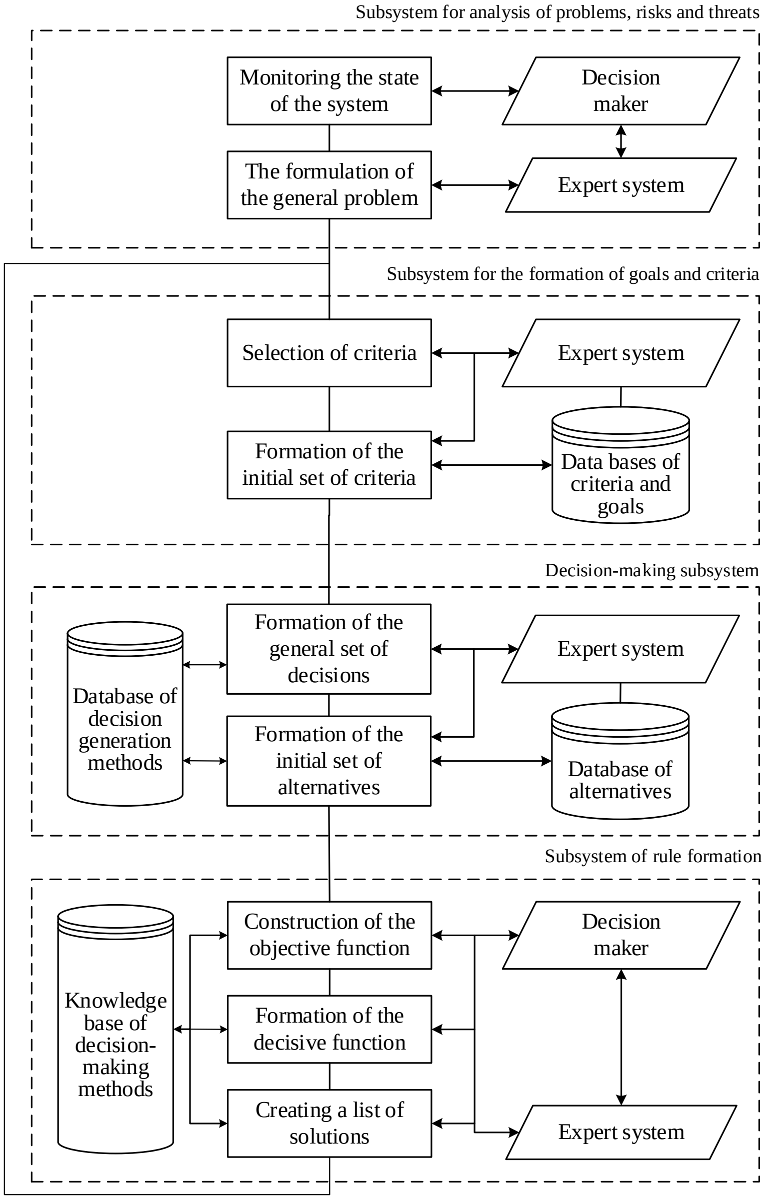

Fig.2. Block diagram of the functioning of the decision support system

The subsystem "Analysis of problems, risks and threats" [24] should provide search and formulation of the problem in order to further solve it. The main areas of operation of the subsystem are:

- monitoring of the control object;
- definition of quantitative criteria and indicators;
- identification of sources of the problem based on arguments;
- choice of method of problem formulation;
- formulation of a general problem;
- determining the degree of uncertainty of the problem;
- identification of issues within the general problem.

The block diagram of the algorithm of operation of the subsystem is presented in Fig. 3.

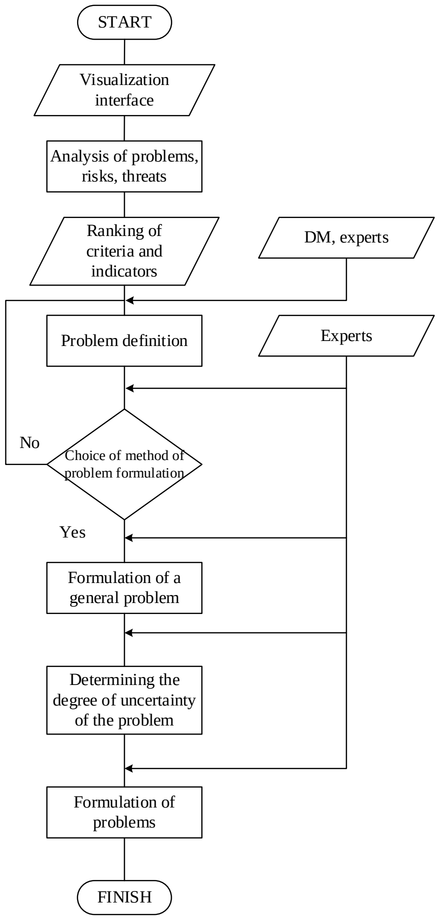

Fig.3. Block diagram of the algorithm of operation of the subsystem "Analysis of problems, risks and threats"

After identifying the problem, it is necessary to form a list of goals and a system of performance criteria to assess the problem and its subsequent solution. It is necessary to develop a subsystem "Formation of goals and criteria".

3.3. Formation of goals and criteria

Different tasks can arise when forming a goal or set of goals. These tasks can be intertwined in different ways: to unite, to contradict each other, to be mutually exclusive, etc.

Formation of goals and of criteria can be divided into:

- fundamentally new innovative goals formed by experts;
- typical goals, by analogy with goals set in similar situations, based on a combination of known partial goals, the generation of which is available to decision-making systems

The most effective way to form goals and performance criteria are software systems in collaboration with experts.

The subsystem "Formation of goals and criteria" should provide a step-by-step formation of goals and a system of criteria for the further operation of DSS:

- multilevel construction of a hierarchy of criteria and indicators;
- decomposition of criteria by sub-goals;

- determining the mathematical relationship between criteria and indicators;
- selection of scales and units of measurement for the criterion indicator.

The block diagram of the algorithm of operation of the subsystem is shown in Fig. 4.

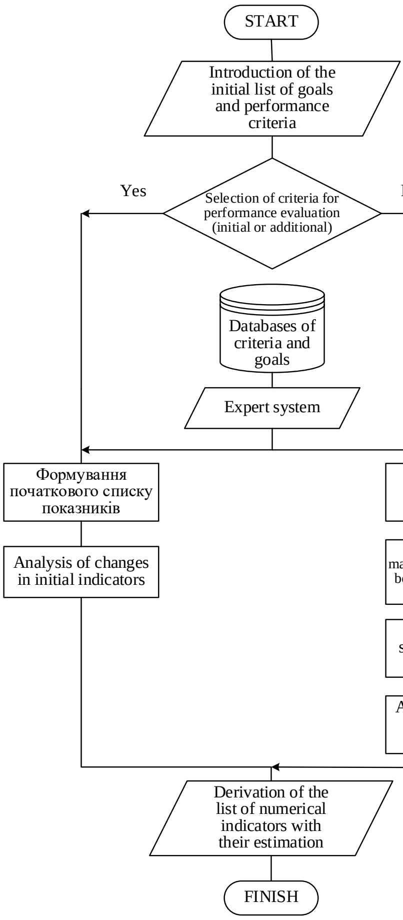

Fig.4. Block diagram of the algorithm of functioning of the subsystem "Formation of goals and system of criteria"

3.4. Decision making

For further analysis of the problem, it is necessary to form alternative solutions, which are formed in the subsystem "Decision Making".

The formation of possible solutions can be implemented using: software implementation of analytical models, using expert systems, generating scenarios by combining different operations specified by the decision maker or taken from the database, and using an approach called situational management.

The decision-making process can be divided into two types:

- innovative solutions that the computer is not yet able to develop;
- solutions based on typical scenarios, by analogy, based on a combination of known partial solutions. Note that the formation of such solutions is available to the computer.

The decision-making subsystem must provide a set of solutions in accordance with the following sequence:

- generation of many solutions using mathematical, expert methods and using cognitive maps;
- structuring of alternatives;
- formation of a finite subset of alternative solutions for further processing at the stage of analysis of alternatives and selection of the best solutions.

The block diagram of the algorithm of functioning of the subsystem "Decision formation" is given in Fig. 5.

At the final stage, the subsystem "Formation of the decision rule and analysis of alternatives" is used for the selection of decisions.

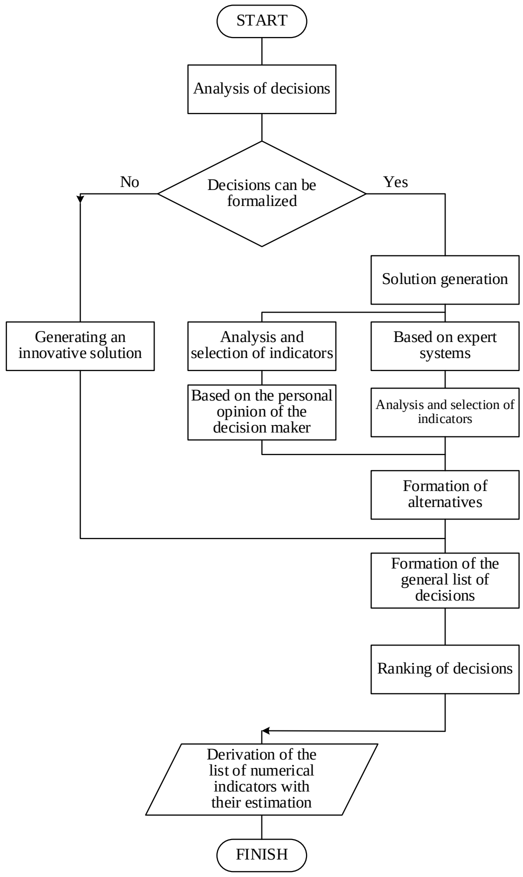

Fig.5. Block diagram of the functioning algorithm of the subsystem "Decision making"

3.5. Subsystem "Formulation of the decision rule and analysis of alternatives"

The subsystem "Formulation of the decision rule and analysis of alternatives" represents the following sequence of functional actions:

- formation of a decisive rule for the choice of a solution under the conditions of the problem. The formation of the decisive rule is carried out in an automated mode or with the involvement of a group of experts who form the decisive function depending on the problem to be solved and the system of criteria formed. The basis for the formation of the decision rule is a multi-criteria function of preference for hierarchical structures of criteria, mathematical and heuristic rules of decision support, providing the most effective selection of management decisions in the social, economic, technical and technological spheres;
- selection of the most effective solution on the basis of the formed decisive function. The analysis and choice of alternatives is carried out on the basis of the formed decisive rule. In the absence of a solution in the subsystem should provide the possibility of expert evaluation of solutions based on the views of experts in the problem-oriented industry.

The block diagram of the algorithm of operation of the subsystem is shown in Fig. 6.

The formation of the decisive rule is carried out in conjunction with the expert system on the basis of the formed knowledge base of rules, techniques and methods of decision-making depending on different situations. In parallel, there are two areas: automated formation of the decision-making rule and the choice of decisions based on expert opinions.

Automated formation of the decision rule in accordance with the initial system of criteria is based on human-machine interaction with a systems analyst, which forms the goal function based on the proposed methods. Previously formed alternatives are analysed and if the decisions satisfy the decision maker, the system stops working.

Expert formation of the goal function is determined by the interaction of experts on the basis of their opinions with the expert system. The decision is selected on the basis of the experts' choice of the best solution taking into account their weight.

The subsystem allows you to build a crucial function in parallel both in automated mode and on the basis of expert opinion. Independent application of the rules allows comparing the initial decisions obtained as a result of their operation of the subsystem.

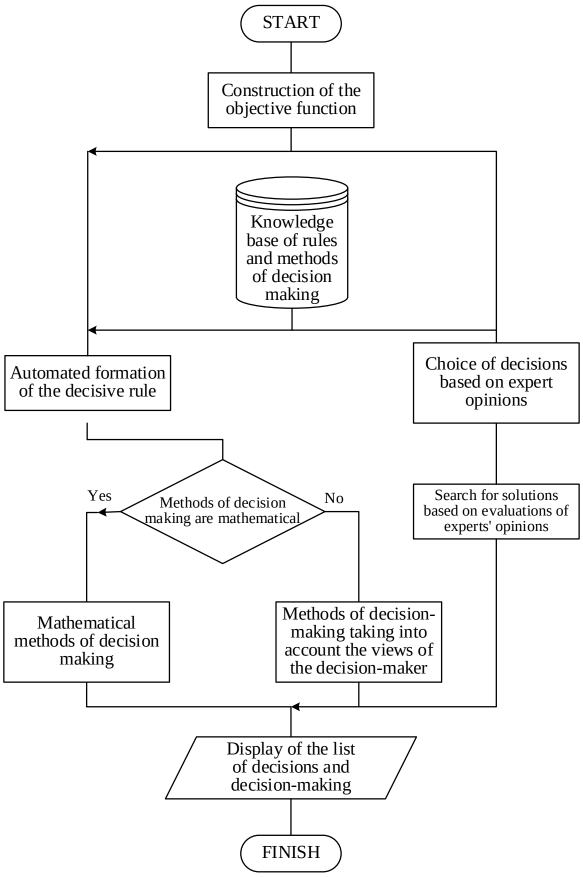

Fig.6. Block diagram of the algorithm operation subsystem "Forming decision rule and analysis of alternatives"

3.6. Expert subsystem support

Expert systems are one of the main applications of artificial intelligence and are designed to solve problems related to a specific subject area, knowledge of which is stored in the knowledge base of the system [25].

The main purpose of the expert subsystem, as the basis of DSS, is to focus on solving a large class of problems, which include the so-called partially structured or unstructured tasks.

The expert subsystem provides development and evaluation of possible alternatives by the user at the expense of the knowledge received from experts.

The expert subsystem consists of:

- knowledge base designed to store the initial and intermediate facts and store models and rules for manipulating models in the database;
- task solving unit, which provides the implementation of a rule sequences for solving a specific task based on criteria and rules, stored in databases and knowledge bases;
- an explanation subsystem that allows the user to get answers about the reasons for the decision;
- rule-making module designed to add new rules to the knowledge base and modify them;
- interface that implements the user's dialogue with the subsystem.

The core of the expert subsystem is the knowledge base, which accumulates the knowledge of experts in a particular field in the form of heuristic rules. Training and accumulation of knowledge base is based on the following principle:

- when considering a specific problem, a rule is formed that ensures its solution;
- developed rules, depending on the specifics of a particular problem area are placed in the database of rules.

The search for the required rule in the rule base is based on the semantic model.

The block diagram of the operation algorithm of the expert subsystem is shown in Fig. 7.

The sequence of actions of the algorithm is as follows.

The search for a solution takes place in the existing knowledge base in the process of obtaining information about the task. If a similar situation existed before and certain rules of decision-making, then a solution to this problem is clearly defined.

If the solution to the initial problem is not found, then a problem-oriented expert group is formed on the basis of semantic analysis. Then questions are sent to experts to form a decision rule based on the classification of methods and decision-making subsystems. Experts form a crucial rule for choosing the best alternative and DSS subsystem.

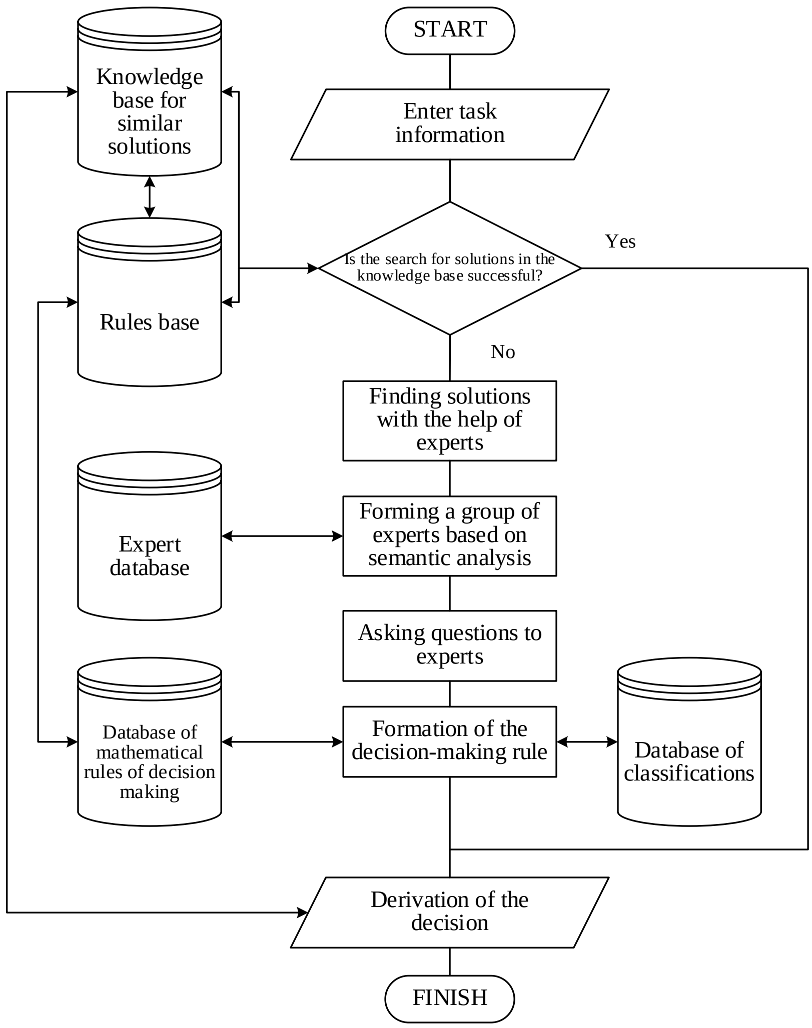

Fig.7. Block diagram of the operation algorithm of the expert subsystem

The next step is to choose the best solution. If the solution corresponds to the original problem, the rule is written to the database of rules, and the solution to the knowledge base.

This algorithm of functioning of expert system provides an opportunity of the analysis and finding of the decision on any problem from various subject areas.

4. Evaluating the Effectiveness of Means of Countering Threats and Risks

The method for evaluating the effectiveness of countermeasures against threats and risks is part of the decision support system. Let's consider it in detail.

The hierarchy of subgoals is built in three stages. The hierarchy of goals, without taking into account threats and risks, is built on the first and second stages. At the third stage, models of these factors are introduced into the hierarchy. At the same time, at the first stage, the movement is carried out from top to bottom, and at the second - in the opposite direction - from bottom to top.

The essence of the first stage consists in determining the type of subgoal: quantitative or qualitative in terms of output; quantitative, definite or indefinite.

At the second stage, the procedure of moving from the bottom up is carried out, which consists in the fact that for each subgoal all immediate supragoals are determined. Those, goals, the achievement of which is directly influenced by the achievement of the analysed subgoal.

At the last stage, threat and risk models are introduced into the hierarchy. Experts sequentially analyse the entire set of goals entered into the hierarchy at the first two stages. This is done in order to establish the influence on these elements. They determine the impact on them of the respective threat. Note that tasks that are threat models can have subgoals that serve as models of threat neutralization means. They are defined in the same way as subgoals of the regular goals.

The introduction of risk models is carried out as follows. First, the risk factors that need to be taken into account are identified. Then the goals are built, which act as indicators of the corresponding risks, and their parameters are determined. This is done in the same way as for the main hierarchy. At the last step, links are established between the introduced risk indicators and the elements of the constructed hierarchy.

The basis of the presented method is determined by two main ideas: the use of the degree of influence of the task on the degree of achievement of the main goal as an indicator of efficiency; the inclusion of objectives in the hierarchy of objectives, which are threat models or risk indicators.

The task of assessment is reduced to the degree of influence on the achievement of the main goal the task performing being assessed in the presence of these factors. Then we use the concepts of simple and complex tasks. Simple is a task that is considered as a whole. At the same time, a complex task consists of a series of interdependent simple tasks.

The partial coefficients of the influence of subgoals generally depend on time. Therefore, the degree of achievement of supra-goals, including the main one, also depends on time. Therefore, we can talk about the instantaneous values of the performance indicators of simple and complex tasks.

Definition 1. The instantaneous value $\varphi_k(t)$ of the relative efficiency indicator (ROE) of a complex task CD_k at time ***t*** from the beginning of its implementation is equal to

$$\varphi_k(t) = F\left[A_0(D)_t, A_0(D \setminus CD_k)_t\right]$$

where D is the set of all simple tasks;

$A_0(D)_t$ is the degree of achievement of the main goal at time *t*, provided that all simple tasks are included $SD_i \in D$;

$A_0(D \setminus CD_k)_t$ is the degree of achievement of the main goal at time *t*, provided that all simple tasks are included, with the exception of simple tasks that are included in a complex task CD_k;

The type of function *F* does not depend on the structure of the hierarchy and the type of goals.

Thus, a *CD* can be characterized by a set of instantaneous values of its relative efficiency indicator. *CD* is calculated for a plurality of points in time at some given interval τ. In this case, the estimation of the set *CD* is reduced to the calculation of a certain definite function *T*, which is given on the set of values of the indicators of the relative efficiency of the task at a time from the interval τ. We will use as such a function:

$$T_k = \sup_{0 \le t \le \tau}\left(\varphi_k(t)\right) \text{ or } T_k = \int_0^\tau \varphi_k(t)^* \, dt$$

where $\varphi_k(t)^*$ is the best approximation of the set of instantaneous values $\varphi_k(t)$ for times from the interval $[0, \tau]$. The approximation is the best with respect to some criterion

In addition to the task estimating of a complex task, there is a task estimating of a simple task within the boundaries of a given complex task. Therefore, for a relatively simple task, we can talk about the value of the indicator of its relative efficiency within the boundaries of a complex task. In general

$$\varphi_{ih} \ne \varphi_{ik}; h \ne k$$

Definition 2. The instantaneous value $\varphi_{ik}(t)$ of the indicator of the relative efficiency for the simple task SD_i as part of the complex task CD_i at the time t from the start of implementation CD_k is equal to

$$\varphi_{ik}(t) = F\left(\varphi_k(t), \varphi_{k\neg i}\right)$$

where $\varphi_k(t)$ is the value of the indicator of the relative effectiveness for a complex task CD_k at a time t;

$\varphi_{k\neg i}$ is the value of the indicator of the relative efficiency for the complex task CD_k at a time t that does not contain a simple task SD_i. In general

$$\varphi_{ih} \ne \varphi_{ik}; h \ne k.$$

Thus, the dynamic evaluation of the simple task $SD_i \in CD_h$ in the course of determining the indicator of its relative efficiency at a given time interval is reduced to calculating the indicators of the relative effectiveness of two complex tasks CD_h and $CD_{h\neg i}$ at a certain set of points in time from this interval. In turn, the task of calculating the indicator of relative efficiency CD_h is reduced to calculating at these moments of time the following values:

- the degree $A_0\left(D\right)_t$ of achievement of the main goal at the moment of time t, provided that all $SD_i \in D$ are fully realized;
- the degree $A_0\left(D \setminus CD_k\right)_t$ of achievement of the main goal at the moment of time t, provided that all $SD_i \in D$, except for simple tasks that are included in CD_h. The specified conditions, under which the degree of achievement of the main goal is calculated, is determined by the set. The specified conditions under which the degree of achievement of the main goal is calculated are determined by the set. In the analysed tasks, it is convenient to set this set by the vector, $A_B = \left\{A_{B_q}\right\}$, $q = \left\{1, |D|\right\}$ degrees of implementation of tasks. The components of this vector are

$$A_{B_q} = \begin{cases} 1, if\ SD_q \in B; \\ 0, if\ SD_q \notin B. \end{cases} \tag{1}$$

Thus, the task of calculating the relative efficiency of simple and complex tasks is reduced to calculating the degree of achievement of the main goal at a set of points in time, provided that the degrees of implementation of the tasks $SD_q \in B \subseteq D$ are given by the vector A_B.

5. Method Implementation

Let us first consider the method for estimating a complex task at a given moment in time t. The task is formulated as follows.

There are specifications:

- the point in time t from the interval $\left[0, \tau\right]$;
- the directed graph of the hierarchy of goals $H(G,V)$, where $G = \left\{g_s\right\}, s = \left(0, n\right)$ is the set of vertices, each vertex g_s is denoted by the function $A_s\left(t\right)$ of the degree of goal achievement;
- for each vertex g_s, the set $G_s = \left\{G_{sz}\right\}$ of sets of compatible one-predecessor vertices is given;
- $V = \left\{v_q\right\}, q = \left(1, b\right)$ is the set of arcs, each arc has a weight (partial influence coefficient);
- the vector A_B is defined by expression (1) in accordance with the values at the time t of the random processes that set threats and risks.

It is required to determine the values of the function $A_0\left(t\right)$ of the degree of achievement for the main goal, provided that $\forall g_p \in B \subseteq D \subset G\left[A_q\left(t\right) = A_{B_q}\left(t\right)\right]$.

The determination of the vector B components at the time t instant that define the threat models is carried out in accordance with the values of the random processes that describe these factors, in the same way as the probabilities of the implementation of the remaining tasks are taken into account.

It is necessary to determine the method for calculating ROE for the most general case. According to the case is that when the network hierarchy, nonlinear, non-monotonic with positive and negative feedback is both linear and threshold goal. The search for a method for constructing an analytical expression that allows calculating the degree of achievement of the main goal seems hopeless due to the complexity of the analytical description of a graph of an arbitrary structure. This is further aggravated by the fact that in the practical application of this decision support method, it becomes necessary to evaluate the effectiveness of tasks with respect to different goals. And also, it is necessary to quickly change the hierarchy structure when maintaining the system. Therefore, the authors use a solution method based on modelling the hierarchy of goals. The hierarchy is modelled according to this algorithm.

Step 1. $x := 1; \forall 0 \le s \le m\left[A_s(t_i)^0 := 0\right]$,

where $A_s(t_i)^x$ is the function value $A_s(t_i)$ at the *x*-th iteration.

Step 2. $\forall g_p \in B \subseteq D \subset C\left[A_q(t_i)^x := A_{B_q}(t)\right]$.

Step 3. It is necessary to find a subset $G_u = \{g_s\}$ vertices of the graph for which $A_s(t_i)^x \ne A_s(t_i)^{x-1}$.

Step 4. It is necessary to find a set G_c vertices of the one-predecessor graph of the vertices $g_s \in G_u$.

It is necessary to calculate function values $A_s(t_i)^x$ to the $g_s \in G_c$.

Step 5. If $g_0 \in G_c$, then go to the Step 6, else go to the Step 7.

Step 6. If

$$\left|A_0(t_i)^x - A_0(t_i)^{x-1}\right| \le \Delta \tag{2}$$

where Δ is the acceptable value of the calculation error, then go to the Step 8, else $x := x+1$.

Step 7. $G_u = G_c$.

Step 8. Finish.

It is easy to see that with such a procedure for calculating the degree of achievement of the main goal with the complete completion of the task d_j, the degrees of achievement of subgoals $g_i \in G^*$ should be calculated.

$$G^* = \bigcup_j G_j; G_j = \bigcup_q G_{jqi},$$

where G_{jq} is the set of subgoals that enter the path *q* in the graph of subgoal hierarchies leading from the top designated by the task d_j to the top g_0 designated by the main goal.

It should be noted that, in the general case, in hierarchies of the network type $q > 1$, i.e., there may be many such paths. This means that completing the same task affects the achievement of multiple subgoals. Achievement of some subgoal, as a rule, affects the achievement of not one, but several supragoals. This creates many paths from one task or program to the main goal.

This algorithm is executed *N* times, and the number of repetitions depends on the required accuracy of calculations, after which the mathematical expectation of the value of the degree of achievement of the main goal at a time *t* is determined.

The next moment in time t_{i+1} is established from the following considerations. The degree of achievement of the main goal at this moment is uniquely determined by the degrees of achievement of all subgoals located on the paths from the tasks to which units correspond in the vector and the instantaneous values of their influence coefficients at this moment in time. Since the degrees of achievement of all subgoals calculated at a point in time t_i do not change over the interval $t_i - t_{i+1}$, the degree of achievement of the main goal can change at a point in time t_{i+1} compared to a point in time t_i only if, at the beginning of t_{i+1} at least one subgoal, the influence coefficient takes a stationary value instead of zero. Therefore, we will determine t_{i+1} from the expression $t_{i+1} = \inf_{e_j \in E_i^0}(e_j)$, where $T_i^0 = (e_j \ge t_i)$ is the set of values of system moments of time, not less than t_i in which events occur in the hierarchy (execution of a task, completion of the propagation of the influence of achieving a sub-goal).

In the presence of feedbacks in the network of subgoals, it is necessary to calculate the degree of achievement of the main goal by an infinite number of iterations, which we determine based on the acceptable accuracy of the results, i.e. from condition

$$\gamma(u+1) = \left|\mu_a(u+1) - \mu_a(u)\right| \le \Delta \ll 1 \tag{3}$$

where $\mu_a(u+1), \mu_a(u)$ are the values of the efficiency indicator of a simple task d_a, calculated at $(u+1)$ and *u* iterations, respectively; Δ the acceptable value of the calculation error.

The components of vector *B* are determined in a similar manner to that described above. For this, the mode of estimating the relative efficiency of the vector is used. This mode is suitable for tasks that do not serve as threat models. After that, the indicators of the relative effectiveness of each of the goals are determined.

Evaluation of the relative effectiveness of means of countering risks and threats, taking into account the fact that there are means of countering risks and threats - tasks, is carried out similarly to the assessment of tasks considered above.

6. Conclusions

The authors of the article have proposed the structural scheme of the decision support system for the information processing system in terms of risks. The main functional modules that ensure the continuous and efficient operation of the system include the following subsystems or models.

This scheme provides a full-fledged decision-making process in the analysis of any type of task.

The stages of decision support technology have been developed, taking into account threats and risks, which are based on the method of targeted dynamic assessment of tasks. These tasks are solved subject to the formation of tasks for a given time interval. The algorithm for solving this problem has been developed taking into account threats and risks.

The presented algorithm fully allows determining the whole sequence of stages of decision support in order to optimize and find the most optimal options for solving problems of different classes and nature. At each stage, appropriate mathematical and heuristic methods and rules are used to determine the effective organization of the entire decision support algorithm.

The relative efficiency in supporting measures to develop measures has been calculated as a function of time given on a time interval. The main idea of the proposed approach to the analysis of the impact of threats and risks in decision-making is that events that cause threats or risks are considered as a part of the decision support system. Therefore, such models of threats or risks are included in the hierarchy of goals, their links with other system's parts and goals are established.

This technology can be used for complex programs for various purposes.

References

[1] Thomas L. Saaty: Fundamentals of Decision Making and Priority Theory With the Analytic Hierarchy Process. RWS Publications. – p. 478. (2000).

[2] Thomas L. Saaty, Kirti Peniwati: Group Decision Making: Drawing Out and Reconciling Differences. RWS Publications. – p. 385. (2013).

[3] Thomas L. Creative Thinking, Problem Solving and Decision Making. RWS Publications; Fourth Printing edition. – p. 267. (2004).

[4] Bidiuk O. P. Kompiuterni systemy pidtrymky pryiniattia rishen: [navchalnyi posibnyk] / O. P. Bidiuk, O. P. Hozhyi, L. O. Korshevniuk. – Mykolaiv: Vyd-vo ChDU im. Petra Mohyly, 2012. – 380 s. [In Ukrainian]

[5] Romanov V.P. Intellektual'nye informacionnye sistemy v jekonomike: Uchebnoe posobie / M: "Jekzamen", 2003. – 496 s. [In Russian]

[6] Bryan Hosack, Dianne J Hall, David B. Paradice, James F. Courtney. A Look Toward the Future: Decision Support Systems Research is Alive and Well. Journal of the Association for Information Systems 13(5):315-340. (2012). doi: 10.17705/1jais.00297. Available at: https://aisel.aisnet.org/jais/vol13/iss5/3

[7] Fraud detection: A systematic literature review of graph-based anomaly detection approaches. https://doi.org/10.1016/j.dss.2020.113303

[8] F. Burstein, C. Holsapple. Handbook on Decision Support Systems 1. Springer-Verlag Berlin Heidelberg. p. 854. (2008). doi:10.1007/978-3-540-48713-5

[9] Zhengbing Hu, Viktor Gnatyuk, Viktoriia Sydorenko, Roman Odarchenko, Sergiy Gnatyuk,"Method for Cyberincidents Network-Centric Monitoring in Critical Information Infrastructure", International Journal of Computer Network and Information Security, Vol.9, No.6, pp.30-43, 2017.

[10] Zhengbing Hu, Sergiy Gnatyuk, Tetiana Okhrimenko, Sakhybay Tynymbayev, Maksim Iavich, "High-Speed and Secure PRNG for Cryptographic Applications", International Journal of Computer Network and Information Security, Vol.12, No.3, pp.1-10, 2020.

[11] Zhengbing Hu, Roman Odarchenko, Sergiy Gnatyuk, Maksym Zaliskyi, Anastasia Chaplits, Sergiy Bondar, Vadim Borovik, "Statistical Techniques for Detecting Cyberattacks on Computer Networks Based on an Analysis of Abnormal Traffic Behavior", International Journal of Computer Network and Information Security, Vol.12, No.6, pp.1-13, 2020.

[12] Schuff D., Paradice D., Burstein F., Power D.J., Sharda R. (Eds.). Decision Support. Springer-Verlag New York. P. 224. (2011). doi: 10.1007/978-1-4419-6181-5

[13] Robert E. Shannon. Systems Simulation: The Art and Science. Prentice-Hall. p. 387. (1975).

[14] Gerasimov, B. M. Cheloveko-mashinnye sistemy prinjatija reshenij s jelementami iskusstvennogo intellekta / B. M. Gerasimov, V. A. Tarasov, I. V. Tokarev, Akad. nauk USSR. In-t kibernetiki im. V.M. Glushkova . – Kiev: Naukova dumka, 1993. – 183 s. [In Russian]

[15] Wayne T. Graybeal, Udo W. Pooch. Simulation, Principles and Methods. Winthrop Publishers, p. 249. (1980)
[16] V.O. Khoroshko, S.V. Zybin. Otsinka yakosti funktsionuvannia kompleksnykh system tekhnichnoho zakhystu y system pidtrymky ukhvalennia rishennia v yikhnomu skladi. // Pravove, normatyvne ta metrolohichne zabezpechennia systemy zakhystu informatsii v Ukraini, vyp. 2 (24), 2012 r. – S. 7-15. [In Ukrainian]
[17] Charles S. Wasson. System Engineering Analysis, Design, and Development. Wiley; 2nd edition. P.880. (2015)
[18] Ostrouh A.V., Nikolaev A.B. Intellektual'nye informacionnye sistemy i tehnologii. - Izdatel'stvo "Lan'". – 2019. – 308 s. [In Russian]
[19] Trahtengerc Je.A. Komp'juternaja podderzhka formirovanija celej i strategij. Serija "Sistemy i problemy upravlenija". – M.: SINTEG, 2005. – 224 s. [In Russian]
[20] Eom S.B. Desicion support systems research: reference disciplines and a cumulative tradition // The International Journal of Management Science, - 1995. - Vol. 23. N 5. - P. 511-523.
[21] Smart Choices. A Practical Guide to Making Better Decisions. With John S. Broadway Books, New York, p. 256. (2002).
[22] Keeney, R.L. Developing Objectives and Attributes, Advances in Decision Analysis, W. Edwards, R.F. Miles, Jr., and D. von Winterfeldt, eds., Cambridge University Press, New York. (2007).
[23] Ralph L. Keeney. Applying Value-Focused Thinking. Military Operations Research Volume 13 Number 2. (2008). DOI: 10.5711/morj.13.2.7
[24] Acceptable Risk.With B. Fischhoff, S. Lichtenstein, P. Slovic, and S. Derby, Cambridge University Press, New York. p. 202. (2010).
[25] Clyde W. Holsapple, Andrew B. Whinston / Decision support systems: a knowledge-based approach. p. 716 p. (1996).

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