

# DEVELOPMENT OF EXPERT UNSTRUCTURED DECISION-MAKING SUPPORT SYSTEM

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## ABSTRACT

With the advent of data warehouses and OLAP-technology, and subsequently many other systems that output information for decision-making, all such systems began to be referred to as decision support system (DSS). Thus, the original purpose of DSS has been forgotten: the selection of an effective solution from the set of possible alternatives for poorly structured or unstructured management decision-making tasks based on mathematical methods and information technology. Therefore, it would be more correct to call systems of this class Unstructured decision-making support systems (UDMSS), and other support systems, DSS. Currently, new terms are appearing, the purpose of which is to combine DSS into certain classes; for example, System DSS, Business DSS and Intelligent DSS. Research objective is the following: to develop a new UDMSS that combines elements of expert systems, data warehouses, group DMSS, author's UDMSS, and can be called Expert UDMSS (EUDMSS). The following main results are presented in the article: features of an expert unstructured decision making support system; system architecture; decision-making method selection module (expert system shell); decision-making module, including 50 mathematical methods (decision-making methods using the majority principle, Pareto and Bayes principle, in partial and full uncertainty, in dynamic formulation, vector optimization, methods combining various principles of matching evaluations of alternatives and other methods); system functionality.

**Keywords:** *Decision Support System, Decision Table, System Knowledge Base, Methods Of Decision Theory, Unstructured Decision Making Support Systems.*

## 1. INTRODUCTION

Decision making is the leading function of management. Analytical justification of alternative decision versions is currently very relevant. The leading role in the practical implementation of this approach is given to DSS. DSS are a class of systems that combine the experience and non-formalized knowledge of the decision maker (DM), combined with the application of mathematical methods and information technology. These systems are aimed at information support of individual or several stages of the decision-making process. Providing the choice of the most preferable alternative, or decision-making, DSS should be called DMSS. Decision-making methods that combine mathematical methods of various classes and expert evaluations of specialists belong to the methods of decision-making theory.

It is quite difficult to formulate a generally accepted definition of DMSS. This is due to the fact

that their design depends significantly on the content of tasks, data representation, software capabilities and system users.

Nevertheless, we can highlight some recognized elements and characteristics of DMSS. They are interactive computer systems that help in solving poorly structured problems or those that are difficult to formalize using decision-making theory methods and models [1]. Such systems bridge the gap between analysts and DM, because their end users are DM, not technicians. They are designed for DM at various organizational levels; contain a database; can be applied for group and individual use; adapt to changes in the internal environment of the organization and its surroundings; display information in a format and terminology that is familiar to DM; selectively provide information and avoid its redundancy. Decision theory methods are built into the system's structure. The result of implementing DMSS is an increase in the efficiency of decision-making. The value for managers is to create a tool that is under their full

control and that does not try to predetermine goals or impose its decision.

The history of the creation and development of DSS and DMSS is outlined in various literary sources [2]. In the 1980s there was the development of Organization DSS (ODSS) and Group DSS (GDSS) [3]. In the 1990s, Advanced DSS were identified that allowed for 'what-if' analysis and used more advanced modeling tools [4].

Spatial DSS (SDSS) have appeared, which combined spatial and non-spatial data, the analysis and visualization functions of Geographic Information Systems (GIS), and decision models in specific domains, to compute the characteristics of problem solutions, facilitate the evaluation of solution alternatives and the assessment of their trade-offs [5-7].

In the 2000s, DSS were created; they used statistical and machine learning tools. Data Mining and Big Data, as well as knowledge-based systems or KBS [8, 9].

Analysis of the systems shows that only some of them meet the requirements to DMSS listed above, and, primarily, the criteria of focus on the choice of an effective alternative in solving unstructured problems using methods and models of decision-making theory. Therefore, the more accurate name of such systems is UDMSS. The same conclusion can be drawn from an analysis of the software over 100 DSS presented in 2021 [10]. Among the many systems under consideration, Decision Lens [11] based on the methods of hierarchy analysis and analytical networks of Saaty T.L. [12], as well as systems, which also use the method of hierarchy analysis, can be categorized as UDMSS.

Thus, the scientific gap in existing research is that there are no UDMSS containing a sufficiently large number of methods for making unstructured decisions, the mechanism of their choice depending on environmental conditions, and a knowledge base of decision-making rules consisting of two parts: conditions for decision-making methods and algorithms of methods.

This study proposes a new integrated UDMSS: Expert UDMSS (EUDMSS), which combines elements of expert systems, data warehouses, OLAP-technologies, group DMSS and is devoid of the above drawbacks.

The theoretical novelty of this study is in the statement of an unstructured decision-making problem in general form; use of the decision table (DT) model for multidimensional classification and systematization of mathematical methods of different classes; inclusion of decision-making methods in conditions of risk and uncertainty; development of combined decision-making methods that combine different principles of coordination of alternative evaluations; use of expert shell system to find the right method when addressing a particular problem.

The practical significance of the research is to create a software system that allows finding a method for solving an unstructured decision-making problem contained in the knowledge base of the system and choose an effective solution.

The research methodology is developed by the authors on the basis of well-known methodologies for creating information systems, data warehouses, OLAP-technologies, expert systems and the author's design methodology EUDMSS, where the leading role played by DT model.

As shown by the analysis of the decision-making methods currently included in UDMSS, it is mainly the methods of analysis of hierarchies and analytical networks of T.L. Saaty. There are no UDMSS, which include many methods of decision theory of various classes.

The gap in scientific research is, among other things, the lack of decision-making methods under conditions of partial and complete uncertainty in the existing UDMSS. The reason for this is the need to model problem situations of the external environment, which is essentially a very complex problem in its own right, since it is necessary to select those conditions of the external environment that directly affect the solution of a particular problem, and to model problem situations. At the same time, solving problems under conditions of complete certainty makes no sense.

The disadvantage of the existing UDMSS is the lack of a knowledge base, which is a characteristic feature of expert systems; when answering the system's questions using the existing mechanism for the logical output of the examination results, the user gets the answer they are interested in. Expert systems are not universal, they model expert knowledge in fairly narrow and well-defined subject areas. This peculiarity means that an expert

system developed for decision making in one subject area cannot be used in another subject area; it requires reworking of the logical inference mechanism, changes in the knowledge base, etc. In the proposed study, this problem does not arise as the knowledge base can be used to find a method for solving a problem in any subject area. This is yet another novelty of this work.

It is also non-traditional to find the right decision method from a knowledge base built from DT that summarizes all the decision rules. The development of such a table was preceded by a comprehensive analysis of the literature containing descriptions of various decision theory methods. The difficulty of forming a knowledge base was, first of all, in describing the algorithms of various methods in unified terms, and secondly, in forming such an order of questions for the system users, which would provide a gradual narrowing of the original set of methods to find the appropriate one for a given problem.

The information system Expert UDMSS (EUDMSS) presented in this article is oriented to the automation of procedures for analyzing problem situations (set of decision-making conditions realizations) and choosing effective solutions.

We highlight the main features of EUDMSS:

- providing calculations to justify alternatives on the basis of economic and mathematical models and methods using expert evaluations of specialists (methods of decision-making theory);
- containing many mathematical models and methods (in a particular implementation of 50) in contrast to most UDMSS, which generally use one or two methods of decision;
- including methods of decision-making under uncertainty and risk, involving simulation of problematic decision-making situations;
- containing the knowledge base: a set of rules for selecting appropriate models and decision-making methods to justify alternatives, depending on the specific implementation of the task elements: the problem situation;
- based on the system's expert shell, it performs the procedure of finding a decision-making method by having the user select the answer (from the proposed set of answers) to the questions posed about the elements of the decision-making problem: finding the appropriate decision-making rule;

- possibility not only to choose a decision-making method for a particular problem, but also to provide a practical solution based on this method;
- containing a database to store information needed to perform calculations; describing tasks and decision-making methods; generating reports; supporting multilingual interface, adding new decision-making methods without changing the software code of the system;
- it is not problem-oriented: the problem of decision-making from any problem domain can be solved on the basis of EUDMSS;
- ensuring collegiality in decision-making, making it possible to justify decision version based on the consolidation of expert opinions;
- automation of the procedure for generating reports on the versions of solutions to the problem based on a relational database;
- multivariate analysis of tasks to be solved and generation of analytical reports using OLAP-server;
- end-user access to the system using 'Thin Client' technology (via Internet browser and web server);

EUDMSS software is developed in MS Visual C# programming language in Microsoft Visual Studio 2019. The system database functions in the RDBMS Microsoft SQL Server 2019. Analytical reporting of the system is implemented in ProClarity Analytics Server. Multidimensional data marts for analytical reporting function in Microsoft SQL Server 2019 Analysis Services.

This paper continues the actual research on the information system of special kind, which is aiming at the choice of the methods and software architecture leading to the effective realization of DSS. The main goal of the paper is making systematic generalization of the requirements to DSS formulated by the most prolific researchers over the last decades [1-13], which are briefly discussed above, as well as their proper expansion and description in such details, which are expected to be enough for further implementation. The practical part of the conducted research is the client-service realization of the real-time running system utilizing the typical set of modern software design features.

## 2. THEORETICAL BASIS

The research design used in this paper is merely descriptive including the case-study presenting the detailed examination of a particular decision-making case within a real-world context. The set of main criteria includes the functional completeness of the system as a whole, its efficacy within the scope of the problems to be solved and general agreement between their modules which allows conducting subsequent development of the system not violating its main principles.

EUDMSS includes the following modules: interactive user communication module, method selection module, decision-making module, module for operational analysis and report generation and knowledge extraction module.

The purpose of the *interactive user communication module* is to provide means of access authorization; graphical input/output of information; simultaneous access of multiple users to EUDMSS through a web-browser. The design criteria are user-friendly interface and support of the client-server architecture for remote access.

This module allows creating own tasks; editing tasks; finding tasks by keywords; entering expert evaluations needed to solve a task; sending invitations to experts; assigning expert status; selecting expert status; generating a report; assigning access rights to the task.

The purpose of the *method selection module (expert shell)* is to provide a specific method search based on the characteristics of the task using the information and reference functions provided by the system. The principal design criterion for this module is exhaustive list of the questions and answers providing to non-controversial choice of the most appropriate method out of the list of available ones.

This module reveals information about the elements of the problem to be solved through the user's choice of one of the possible answers to the questions posed by the system; eliminates inconsistencies in the sequence of individual questions, when each following question is considered as a response to the previous answers of the user; loads and transfers control to the module that implements the decision stage.

The purpose of the *decision-making module* is to ensure finding an effective solution version based on the selected method; the possibility of multivariate solution to the problem posed using various methods of decision-making theory; participation of experts in the evaluation of alternatives. The design criteria applied to this module are expandability, i.e., the ease of new method inclusion, interchangeability between methods sharing the same items of knowledge and potential ability to include the knowledge of human experts. Generally, it leads to the unification of the interfaces sharing between different methods.

The *module for operational analysis and report generation* is aimed at generating reports on tasks and analytical reporting. The main criterion applied to this module is its ability to implement such features which include the generating brief reports and comparison between outcomes obtained by different decision methods. In addition, it provides simple graphical illustrations.

Analytical reports on the basis of the multidimensional database are based on the introduction of a set of indicators in various analytical areas: number of users in the system; number of experts, number of tasks; number of task variants; number of views of the task by users; time spent on getting the answer to the solution version.

The purpose of the knowledge extraction module is to find a similar problem to use as an analogue for self-preservation.

The *decision-making method selection module*, the expert shell of the system, is a distinctive feature of EDMSS. The main assumption taken up in this paper is ability to represent the processing of non-structured data in the commonplace framework concisely written as  $\langle S, G, X, O, L, F, K, V; X^* \rangle$ , which means that the decision maker elaborates the effective decision  $X^*$  among all available set of options  $X$  with known outcomes  $O$ , provided that  $S$  is the set of problem situations,  $G$  is the set of targets,  $L$  is the set of features,  $F$  is the set of preferences,  $K$  is the criteria set and  $V$  is the set of matching principles.

From a substantive point of view, this can be company development strategy, way of action, work plan, project version, etc.

A functional model of the decision-making process, DT [13], was used to develop the method selection module and model problem situations.

DT consists of four sections:

- conditions considered in making the decision (Section II);
- actions taken as a result of checking conditions (Section III);
- decision rules (in columns of Sections I and IV, which show which actions from among those listed in Section III are performed in each situation determined by a particular combination of condition check results).

In the simplest case, the conditions in DT are formulated in such a way that their observance is regulated by the answers “yes” (“y”) and “no” (“n”). The elements “y” and “n” are called condition inputs, their different permutations are fixed in Section I. If the result of checking a condition has no effect on the actions taken subsequently, its input will be the indifference sign “-”.

Actions in Section III can also be specified in their entirety, leaving only to specify which of them are executed in each situation. However, other elements are used as action inputs in Section IV: “x” – the need to perform the corresponding action (or Arabic numerals indicating the order of several actions); a space means that the action does not need to be performed.

In these terms, any column in the right side of DT, consisting of condition inputs and action inputs, represents a separate decision rule. Condition inputs are connected by the “AND” logical relation (results of checking first, second, etc. conditions are taken into account). The “AND” logical relation is also connected to the action inputs (first, second, etc. must be performed from the number of actions intended to be performed). These two parts of the decision rule are united by the logical relation “If ..., then ...”.

Depending on the way the conditions, actions, and their inputs are specified, there are several kinds of DT. DT with restricted input (or with restricted condition input and action input) were considered above.

If  $m$  is the number of conditions considered in decision making, then the number of columns of length  $m$ , in which different permutations of

elements “y” and “n” are given, is  $2m$ . A table with bounded condition input, which includes  $2m$  decision rules, is called complete.

DT may not list all possible solution rules. Then a contrary case rule  $E$  must be introduced, indicating which actions must be taken if a particular situation does not match any of those listed in the table. The inputs of condition  $E$  are spaces, and the inputs of actions are the same as those of the regular rule.

DT with extended condition input is defined as one in which the conditions to be checked are only partially specified in section II, and the condition inputs are any elements other than “y” and “n”. In DT with extended action input, the actions listed in section III are set in such a way that their execution cannot be reflected in a yes-no form. In this case, the corresponding inputs refine and complement the actions specified in the list. Thus, extended action inputs are represented by elements different from those used in DT with limited action input. DT in which conditions and actions are specified in a different form is called a DT with mixed input. From DT with extended input of conditions and actions, we can move to DT with restricted input. In this case, each condition and action are repeated as many times as there are extended inputs.

When developing the method selection module, a table with extended condition inputs and extended action inputs (the basis of the system's expert shell) was used. Questions about elements of the decision-making problem were entered as conditions in such a table, and condition inputs as possible answers to the questions posed (Table 1).

The order of consideration of these questions should be fixed by their numbers according to the principle that the more general ones are located above, taking into account their subordination. The hierarchy of questions is manifested in the fact that the next question can be asked or not, depending on the answer to the previous one. Thus, the question about the principle of coordinating the opinions of individual experts is appropriate in the case of a group of experts. The above 13 questions are subordinated as follows: 1, 2, 3 and 4; 6 and 7; 8, 9, 10 and 11.

The interpretation of DT in this case may be as follows. The conditions section II forms questions about the elements of the decision-making problem. The condition inputs section I forms different



realizations of the elements of the decision-making problem, or possible answers to the questions posed. The action section forms the various methods of decision-making III. The action inputs section specifies which decision-making method is chosen in each case. Thus, each column of condition inputs collectively contains the specific requirements for choosing the appropriate decision-making method: the problem situation. It is DT model that allows calculating the number of required methods.

The decision rule in this interpretation of DT shows which decision method, from among those listed in section III, should be chosen for different combinations of answers (section I) to the questions asked (section II).

The totality of such decision rules forms the system knowledge base EUDMSS. The possibility of decision-making in unique problem situations, for which the algorithm is not known in advance and is formed by the original data in the form of chains of decision-making rules from a knowledge base serves as the rationale for the chosen name of the proposed (EUDMSS).

The upper estimate of the number of decision rules (based on Table 1) is 238. However, not all combinations of answers make sense, first of all, due to the co-relation of attributes. Therefore, in fact, the number of combinations taken into account is significantly lower than this value. Consideration of various combinations of responses requires the inclusion of a huge number of decision-making methods and their corresponding programs in the system.

However, it is important to notice that one of the important limitations of the current design of DSS is a reduced number of dimensions introduced to the system. Thus, the total number of questions and answers was decreased due to insufficient volume of the knowledge base. In addition, some of the methods belonging to ELECTRE family have not been implemented in program code yet.

### 3. METHODOLOGY

In the current version of the system, the decision-making module contains 50 methods, which can be divided into eight groups: decision-making methods using the majority, Pareto and Bayesian principles, under conditions of complete uncertainty, in the dynamic formulation, multi-objective optimization

methods, methods that combine different principles of coordinating alternatives assessment and other methods.

Due to creation of the database, the possibility of copying the initial data of a problem within the limits of its various versions of the solution, which differ by the chosen method, is realized in the System. For example, if the problem is solved using the majority principle to coordinate the assessment of alternatives, then when creating a version of solution using Pareto principle, all the necessary input data can be copied from the previous version.

Moreover, since Pareto principle does not require assignment of coefficients of attributes' relative importance, experts' competence, and probabilities of problem situations for coordination of alternatives assessment, the information is not reproduced when copying the original data from the solution version of the problem using the majority principle. If, however, some data is not enough to perform calculations based on the information obtained by copying from another solution version, the system requests it additionally.

An element of novelty of EUDMSS decision-making module is the inclusion in its composition of combined decision-making methods, which are based on the use of different principles of coordination of alternatives assessment within a single task.

An example is the method that uses the majority principle to reconcile the assessments of alternatives given on various attributes by individual experts on an ordinal scale and the principle of pessimism is used to reconcile the assessments of alternatives given in different situations: PURrWALDPOR:

- $S = (S_1, S_2, \dots, S_j, \dots, S_J)$ ,  $j = 1 \dots J$  – unobservable problem situations;
- $X = (X_1, X_2, \dots, X_i, \dots, X_I)$ ,  $i = 1 \dots I$  – alternatives;
- $Z_l$  – coefficient of relative importance of the

$$l\text{-attribute, } l = 1 \dots L, \sum_{l=1}^L Z_l = 1;$$

- $W_d$  – competence factor of  $d$ -expert,  
 $d = 1 \dots D; \sum_{d=1}^D W_d = 1;$

- $F_{ildj}$ ,  $i=1 \dots I$ ,  $l=1 \dots L$ ,  $d=1 \dots D$ ,  $j=1 \dots J$ , – elements of the preference matrices in the ordinal scale;
- $B_{ikj}$  – elements of the generalized matrix in the  $j$ -situation, constructed using the majority principle for averaging the assessment of alternatives given by experts on individual attributes;
- $Y_{ikj}^*$  – elements of the median matrix in the  $j$ -situation;
- $a_{ij}$  – coefficients, according to which the solution versions are ordered in the  $j$ -situation;
- $F_{ij}$  – ranking matrix constructed using the majority principle as a result of averaging the assessment of alternatives by individual experts on various attributes;
- $Y_{ikj}$  – elements of the matrix of pairwise comparisons based on the  $j$ -ranking;
- $E_{ij}$  – solution coefficients;
- $K$  – pessimism criterion:  $K = \max_i \min_j E_{ij}$ .

Problem solving algorithm:

1. Initial data of the task are formed.
2. In each  $j$ -situation, the matrices of pairwise comparisons are developed with the elements  $Y_{ikldj}$ , in which the quality of  $i$ - and  $k$ -alternatives is compared based on the  $l$ -attribute by  $d$ -expert. The relationship of  $F_{ildj}$  and  $Y_{ikldj}$  assessments is expressed by the relation:  $Y_{ikldj} = 1$ , if  $F_{ildj} \leq F_{kldj}$ , and  $Y_{ikldj} = 0$ , if  $F_{ildj} > F_{kldj}$ .
3. Generalized matrices  $B_{ikj}$  are calculated in each  $j$ -situation: 
$$B_{ikj} = \sum_{l=1}^L \sum_{d=1}^D Z_l \cdot W_d \cdot Y_{ikldj}^*.$$
4. According to the majority principle, the median matrices are built in each  $j$ -situation with elements  $Y_{ikj}^*$ :  $Y_{ikj}^* = 1$  at  $B_{ikj} \geq 0.5$  and  $Y_{ikj}^* = 0$  at  $B_{ikj} < 0.5$ .

5. In each  $j$ -situation, solution versions are ordered according to the value of solution

$$\text{coefficients } a_{ij}: a_{ij} = \frac{\sum_{k=1}^I Y_{ikj}^*}{\sum_{i=1}^I \sum_{k=1}^I Y_{ikj}^*}.$$

6. Preference matrix  $F_{ij}$  is formed, comprising of the ranks of solution versions in  $j$ -situations according to the value of decision coefficients  $a_{ij}$ ,  $j=1 \dots J$ .

7. For each  $j$ -situation, a matrix of pairwise comparisons with the elements  $Y_{ikj}$  is constructed by the formula based on an

$$\text{appropriate ranking: } Y_{ikj} = \begin{cases} 1 & \text{at } F_{ij} \leq F_{kj} \\ 0 & \text{at } F_{ij} > F_{kj} \end{cases}.$$

8. Then the solution coefficients are formed  $E_{ij}$ :

$$E_{ij} = \frac{\sum_{k=1}^I Y_{ikj}}{\sum_{i=1}^I \sum_{k=1}^I Y_{ikj}}.$$

9. The most preferred solution, defined by the criterion of pessimism, is considered to be:

$$K = \max_i \min_j E_{ij}.$$

EUDMSS allows two choices for the decision-making method: by answering the questions posed by the system, and explicitly (by the name of the method).

*When choosing a method by answering the questions* the user is presented with a chain of questions with several answer choices for each question. The chosen answer leads to the fact that the system gradually removes from the full list of methods those methods that do not satisfy the chosen answers. As a result, the only method that will be used to solve the problem remains.

*Selecting a method explicitly* from the above list is used when the user knows which method should be used to solve the given problem.

*Decision-making method selection page* in EUDMSS contains several working areas.

*Question area.* This area displays the questions the answers to which lead to the choice of decision-making method. Each question contains

information about one of the elements of the decision-making problem.

*Question tips area.* This area allows getting more information (detailed explanation) about the content of a question. The tooltip appears on the screen automatically when the next question appears.

*Answer choices area.* This area contains the available answer choices for the current question. The answer choices are displayed as a list from which the user can select only one item.

*Answer choice tips area.* This area allows getting more information (detailed explanation) about the content of a particular answer choice. To display the tip on the screen we need to mark one or another answer choice by activating the appropriate switch.

*Area of acceptable decision-making methods.* This area displays a single method, i.e., satisfying all the requirements, which were set earlier by the user's answers to the questions. At the beginning of the survey all methods included in the system are analyzed, and as we move along the chain of questions and answers, their number gradually decreases, which eventually reduces the range of valid methods to a single method.

*Area of decision-making method tips.* This area allows getting more information (detailed explanation) about the conditions of the selected decision-making method.

The choice of the decision-making method is a necessary condition for the transition to the problem solution parameters description and further to the input of the problem's initial data and start of its solution.

#### 4. RESULTS

We consider the basic rules of working with EUDMSS, including logging into the system, working with problems and solutions, selecting the method, entering the necessary parameters and input data, as well as solving problems directly.

Logging in to the system is done using its Internet address, which is specified in the browser. When logging in, the user gets to the home page, which contains brief information about the system, as well as a Help link, which gives access to a detailed description of the system. It also contains

the registration and authorization functions. When registering, we enter a username (login), a password with confirmation (not less than six characters, at least one of which must be special), email address, the user's full name and real name, as well as a secret question and answer (for password recovery).

After authorization (login and password, followed by clicking on the Login link), the user is granted DM rights and gets to a personal page.

An authorized user logs out of the system by following the Logout link located on each page of the portal. When the user logs out, they are taken to the home page.

After the user is logged in and clicks the Tasks link, a list of tasks created by them appears on the screen (My Tasks tab). Such tasks are called user's own tasks. The user can also display the list of tasks created by other users for public access (Public Tasks tab) and the list of tasks, in which this user plays the role of an expert (under Expert link).

The following is indicated for each task in the list:

- name;
- description;
- date and time of creation;
- shared access attribute.

The system provides the ability to sort the list of tasks by name and date of creation, in forward or reverse order. To sort the list, click the header link of this or that column of the table. If we use the link repeatedly, the sorting is done in reverse order.

If the task list is large, it is automatically divided into pages. An example of a personal page with a list of tasks is shown in Figure 1.

The figures are arranged in the form of a table. The date is changed to 20.01.21.

To view detailed information about a particular task, click the name of the task. Then the system goes to the task view page, where the following information is displayed:

- task name;
- task description;
- list of versions of solutions for the given problem, indicating the name, method of solution (if the method has already been



chosen), status of the problem solution version (whether the solution procedure has been passed), date and time of creation for each of them.

To create a new task, use the Create task button on the personal page with the list of tasks (Table 2). This will take us to the task information page, where we should enter the name of the task and its description, as well as specify the access attribute (whether the task is public or not).

The task name is a brief description of the task and can contain up to 100 characters. The description of the task is usually given in an expanded form, the number of characters is not limited.

Clicking the Create button saves the task and its information, after which the task is added to the general list. The new task is added to the end of the list, which can be sorted by the user if necessary.

The user can edit the information about their own tasks using the Edit button, located on the view page of the task. The correction mode allows changing the name and description of the task, as well as the attribute of the shared access. After we click Save, the changes will be saved. If we use the Cancel button, the changes will not be saved.

An example of the task view page (with detailed information about the task and a list of versions of its solution) is shown in Figure 2.

The user can delete their own tasks using the Delete Task button on the Task View page. After that they will be asked to confirm their intention. The message "Do we really want to delete this task? All versions for this task and their data will be lost!" If the answer is yes, the task is deleted along with all its solutions. When the deletion procedure is complete, the user moves to the page with the list of tasks.

#### 4.1 Working with Solution Versions

The user has the opportunity to view information about the versions of solutions of their own problems, about the versions of solutions of the tasks provided in the public domain, as well as about the versions of solutions of closed tasks, where they act as an expert.

The list of versions of problem solution is displayed on the page of problem review (we can go to it from the page of tasks by clicking the link of the problem name). Here, in addition to information about the problem, a complete list of available solutions is displayed.

If the list of versions for solving the problem is large enough, it is automatically divided into pages.

The following attributes are specified for each version of problem solution:

Problem solution version name:

- method corresponding to the problem solution version (if it is already chosen);
- status of problem solution version (whether or not the solution procedure has been passed);
- date and time of creation of the problem solution version;
- all data used in solving the problem: alternatives, situations, attributes (criteria) of comparison, experts, and evaluations.

An example of a page with detailed information about a problem solution version is shown in Figure 3.

We can manually select a method using the drop-down menu, which contains the system names (designations) of the available methods. When we select one of the methods from the suggested list, its description appears on the page automatically. If the user does not have sufficient information about the available methods and their designations, use the Selection Wizard button.

Pressing the Selection Wizard button (shown in Figure 4) brings up a sequence of screens with questions and possible answers. Once the user has decided on the answer to the next question, they activate the appropriate switch and use the Next button, which results in the selected answer being registered in the answer history. Then, based on the new information, the acceptable number of decision-making methods is reduced. If after that, two or more methods remain in the list of acceptable decision-making methods (i.e., if further clarification of the problem conditions is required after this step), the next question is automatically moved to the next one. The chain of questions is interrupted when the only method remains in the list of acceptable decision methods.

When a single method remains on the list of valid methods, its system designation is displayed on the screen. When we click Next, the screen will display full information about the solution to the problem, including the decision-making method, its description, and the chain of all questions and answers that led to the choice of this method shown in Figure 5 and continued in Figure 6. In order to save the selected method, click the Create button (the Cancel button is for cancelling the save of the method). In this case, the tabs for entering the parameters, acting as input data for solving the problem by the selected method, become available on the Solution Version view page.

## 5. DISCUSSION

The user is able to enter the values of the problem solution version parameters only for the versions of the solution of their own problems.

After the decision-making method is selected, the page of viewing the versions of problem solutions displays tabs with the parameters of the solution version for the subsequent formation of the problem's initial data, which are modelled by the system itself and are displayed automatically, without requiring the user's intervention.

Selection of the required parameter of the problem solution version for its description is made by activation of the corresponding tab, after that the transition to the page of the detailed information about the selected parameter of the problem solution version takes place automatically. This page contains both the already entered information about the selected parameter of the problem solution version and the fields for entering new information (Figure 7).

The composition of the input information about the version parameter depends on the features of this parameter:

- for Alternatives parameter – name and description of each alternative;
- for Situations parameter – name and description of each situation;
- for Attributes parameter – name and description of each attribute;
- for Experts parameter – expert's full name, type of access to the system (login via link or registered user), as well as information for accessing the system – a link (for the “login by link” access type) or the system username (for the “registered user” access type).

The information is entered line by line, the entered information is saved by using the Save or Create buttons.

The user has the ability to adjust the problem solution version's parameters for the versions of the solution of their own problems.

All adjustments are made line by line. Two types of adjustments are allowed: editing the contents of the line and deleting the line. These operations are performed by using the edit and delete buttons respectively. When we select edit mode, the row becomes available for changes. The results of changes can either be saved (Save button) or discarded (Cancel button). When we click the Delete button, the corresponding row is removed from the list.

The initial data for the problem solution means a set of information needed to perform calculations in accordance with the algorithms implemented in the system for each of the decision-making methods.

DM is able to invite experts to evaluate alternatives within the problem solution version. Invitation of experts becomes possible only after the parameters of the problem solution version have been defined and input data corresponding to these parameters have been entered, except for the arrays of expert assessments of alternatives.

To invite experts, add them to the list of experts with the access type “login by link” or “registered user”. In this case, the link will be automatically generated for the “login by link” access type, and for the “registered user” access type it is necessary to specify the system user name.

The user has the possibility to enter the initial data for versions of solution of own tasks, and in case they play the role of the expert, also for non-independent versions of the solution. If the user is an expert, the operation of entering assessments of alternatives is available only in relation to the problem, in which they act as an expert.

To enter the input data, go to the Data tab on the version view page.

To enter input data for the solution version of the problem, the user is offered a set of input forms for filling (Figure 8). The form is selected through the drop-down menu.

After completing a form, the user can either save the entered data (Save button) or go to the next form without saving the entered data.

The user is able to copy the initial data for a problem solution version from another version of solution of the same problem.

Copying of the original data can be done only if:

- the operation is applied to the versions of solution of the own tasks;
- the operation is carried out between two problem solution versions, compatible with each other in terms of the initial data composition (which, in turn, is determined by the decision-making methods);
- for the version of the problem solution, from which the data are copied, the decision-making method is chosen;
- the problem solution version, from which copying is performed, has filled arrays of initial data;
- the problem solution version, in which the copying is made, has no filled arrays of initial data.

After entering all the initial data, we can begin solving the problem. It is carried out in relation to a particular solution version, according to the decision-making method chosen for this version. The corresponding calculations are run by clicking the Solve button, which is located on the Solution tab of the problem solution version view page. This button is activated only when all the input data are entered. When the calculations are finished, the solution report is displayed on the Solution tab (Figure 9).

## 6. CONCLUSIONS

Thus, the new integrated EUDMSS that combines elements of expert systems, data warehouses, OLAP technologies, group DMSS and closes the scientific gap in existing research: lack of systems containing a sufficiently large number of methods of the theory of unstructured decision-making, including in conditions of uncertainty; mechanism of their choice depending on environmental conditions; knowledge base of decision-making rules, consisting of two parts: conditions of application and algorithms of methods.

Existing gap was eliminated through the integrated use of well-known methodologies to

create information systems, data warehouses, OLAP-technologies, expert systems and author's design methodology EUDMSS, where the leading role is played by DT model.

An essential element of the novelty of the conducted study consists in the generalization of the mathematical methods taken out of various classes into a single system. Such realization includes the creation of a knowledge base of the system and a description of their algorithms in one programming language. The development of the decision-making methods combines different principles for coordinating estimates applicable to possible alternatives and usage of the procedures for sharing the information between methods of similar classes. The development of the set consisting relevant questions and answers extends the functional ability of the system in such a way that it starts providing the best choice in the form of a single decision-making method. An important issue was the establishment of the order in which the questions should appear, that makes the analyzed methods discard gradually. The questions are structured in order to prevent the user from choosing an answer that entails choosing a method that has not been implemented in the system.

The implemented module performing the selection of decision-making method is based on the decision table model, which provides a complete enumeration of the user's answers and generates problem situations for choosing a method. The same model is used as the basis for modeling problem situations for decision-making methods in case of uncertainty. The usage of different methods for solving the same problem allows the decision maker to choose an option that is analytically correct and simultaneously corresponds to user's personal attitude. In addition, no mathematical model is assumed to be a universal one and the outcome is based on certain assumptions. The choice of the same result from the standpoint of different models serves as an analytical justification for its choice.

The next generation of UDMSS and DSS will include:

- use of portals;
- incorporating forms of artificial intelligence through agents;
- increased level of integration of data warehouses and data mining methods;
- mobile device operation;

- implementation of advanced information technology to enhance the user interface through video and audio devices, sophisticated graphics and other approaches;
- ability to process data using fuzzy sets and neural networks;
- improving the user interface through multimedia and virtual environments;
- deploying distributed knowledge base capacity using the Internet;
- DM participation in the design and development process of UDMSS and DSS;
- development of effective designs and tools for system user;
- development of UDMSS and DSS performance indicators;
- creating technologies that incorporate the cognitive aspect of human decisions;
- focusing the user's attention on choosing an effective solution rather than on technical issues.

In a sense, the development of UDMSS and DSS has not been rapid since their early days. Moreover, there is still considerable disagreement about definitions and methodologies. Experts' opinions differ on many issues: some of them emphasize the usefulness of analytical methodologies, while others advocate qualitative approaches.

Some experts emphasize technology, while others focus on managerial and organizational issues.

However, it is very important that experts agree on the key issues of creating and using UDMSS and DSS. In particular, most experts recognize the need for:

- the use of the Internet in the provision of data and for expert interaction;
- integration of subsystems within UDMSS and DSS architecture;
- UDMSS and DSS integration with other information systems;
- creation of hybrid systems combining UDMSS and DSS.

UDMSS and DSS continue to be used successfully in various organizations and will increasingly involve users in their design, development and implementation. Successful engineering examples involve application of UDMSS to synthesis of complex estimators in position location problems [14-16], software-

defined radio prototyping [17, 18], searching for better architecture of artificial intelligence systems [19, 20], analysis of electric power in arbitrary periodic cases [21], near-field electromagnetic measurements [22], superconductivity [23] and engineering education [24].

Along with new technologies and methodologies, new approaches to creating UDMSS and DSS will also emerge. Many tasks that were intended for experts can be delegated to the virtual knowledge embedded in UDMSS and DSS. In doing so, DM can pay more attention to the creative aspects of management.

The organization of virtual storage in UDMSS and DSS can reduce the need for high support staff costs. It can become more project-oriented. These changes do not occur without replacing old technology. Radical changes in technology in an organization may at first entail significant costs. However, experience has shown that the results yield a considerable return on implementation, which usually far exceeds the costs.

The growing interest in the problems of analytical justification of managerial decision-making in various fields of knowledge is emphasized by the increasing number of publications on this topic, which we currently observe [25-29].

## 7. ACKNOWLEDGEMENT

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S.N. Larionova. Choosing a tool for UX/UI prototyping	Choose the most appropriate tool to create a UX/UI prototype to design a new service for company N	07.12.2020 18:26:57	Yes
S.B. Kiyamov. Choosing a decentralized storage cryptocurrency for long-term investment	Choose the most suitable decentralized storage cryptocurrency for long-term investment	01.12.2020 16:56:45	Yes
P.A. Tuchkova. Choice of feedback monitoring and analysis system	The task of choosing a system to monitor and analyze consumer reviews of the company A, posted on various Internet resources.	01.12.2020 16:46:22	Yes
V. Tichkin. Choosing an aircraft company to sell fighter jets	Task: Choose the right aircraft company for the profitable sale of Generation 4++ fighters to India	01.12.2020 16:38:21	Yes
I.D. Smirnov. Choosing a real estate company to sell real estate	Choose the right real estate company in Russia for the most profitable sale of real estate to the development company N	01.12.2020 16:34:47	Yes
P.A. Danilova. Choice of timekeeping system	Choose the most appropriate time recording system	01.12.2020 16:28:43	Yes
P.A. Bolshakov. Choosing a soccer club for the investment of sponsorship funds	Choose the most suitable soccer team for the investment of sponsorship funds	01.12.2020 16:27:22	Yes
E.M. Korolenko. Choosing a university for postgraduate study	Young man X is about to enroll in a Moscow postgraduate program in information technology. Having completed his bachelor's and master's degree in his home town, he plans to get a degree in one of the most prestigious universities in Russia.	01.12.2020 16:25:59	Yes

Figure 1: Task list page table

## Task Viewer

Name of task: P.A. Danilova. Choice of timekeeping system

Task description

Choose the most suitable time recording system

Solution versions

Name	Method	Solved	Date of Creation
LAPLPOR	LAPLPOR	Yes	03.02.2021 16:32:52
SAVAGE	SAVAGE	Yes	03.02.2021 16:36:38
PRT <sub>r</sub>	PRT <sub>r</sub>	Yes	03.02.2021 16:39:55
PRT <sub>r</sub> PUR <sub>r</sub>	PRT <sub>r</sub> PUR <sub>r</sub>	Yes	03.02.2021 16:43:45
PUR <sub>r</sub> PRT <sub>r</sub>	PUR <sub>r</sub> PRT <sub>r</sub>	Yes	03.02.2021 16:45:49
PUR <sub>r</sub> OPTIMPOR	PUR <sub>r</sub> OPTIMPOR	Yes	17.02.2021 16:26:51
PUR <sub>r</sub> WALDPOR	PUR <sub>r</sub> WALDPOR	Yes	17.02.2021 16:28:51
PUR <sub>r</sub> HURWPOR	PUR <sub>r</sub> HURWPOR	Yes	17.02.2021 16:30:11
PUR <sub>r</sub> SAVAGE	PUR <sub>r</sub> SAVAGE	Yes	17.02.2021 16:31:56
PUR <sub>r</sub> LAPLPOR	PUR <sub>r</sub> LAPLPOR	Yes	17.02.2021 16:33:35

< 1 2 3 >

Figure 2: Detailed information about the task

## Solution version review

Solution version "PUR<sub>r</sub> Calculation of alternative assessment by the PUR<sub>r</sub> method"

Method: PUR<sub>r</sub>

For task: P.A. Danilova. Choice of timekeeping system

Date of creation: 20.01.2021

Description	Solution	Alternatives	Situations	Attributes	Experts	Data	Import/Export
-------------	----------	--------------	------------	------------	---------	------	---------------

Solution version description

Decision-making method using the majority principle for the coordination of assessments of alternatives given by individual experts in an ordinal scale in different problem situations with given probabilities of their occurrence in terms of different attributes (criteria)

Method description

Decision-making method using the majority principle for the coordination of assessments of alternatives given by individual experts in an ordinal scale in different problem situations with given probabilities of their occurrence in terms of different attributes (criteria)

Figure 3: Detailed information about a problem solution version

## Method Selection



## Awareness of decision-making conditions

The actions of the decision maker (DM), aimed at achieving the goals, depend on the conditions of the decision, the specific implementation of which forms a problem situation  $S$ . If the decision-making conditions are known to the LPR, the problem situation is fully defined (in this case there is one problem situation). Much more often the uncertainty in the conditions of decision-making leads to the need to model several problem situations  $S = (S_1, S_2, \dots, S_j, \dots, S_i)$ , each of which can occur with a certain probability. In such cases, the DM attempts to estimate the probabilities of occurrence of situations  $P = (P_1, P_2, \dots, P_j, \dots, P_i)$ , or arrange the situations in descending order of probability of their occurrence. Problem situations are not always observable. However, it is possible to observe random events  $C_n$  inherent in real unobservable situations  $S_i$ , and to estimate probabilities  $P(C_n/S_i)$  of interrelation of observable events  $C_n$  with unobservable situations  $S_i$ .

- ☐ One problem situation  
☐ Several problem situations with unknown probabilities of their occurrence  
☒ Several problem situations with given probabilities of their occurrence  
☐ Several unobservable problem situations with given probabilities of correlation of observed random events with unobservable situations  
  
☐ Several problem situations, ordered by the degree of credibility of their occurrence  
☐ At the first stage of problem solving there are several problem situations with unknown probabilities of their occurrence; at the second stage there are several problem situations, the probabilities of which the DM is able to assess

Cancel

« Back

Next »

Figure 4: Decision-making method selection page using the wizard

## New solution version

For Task: Choice of timekeeping system

## Solution version parameters

Name	PURr
Description	Decision-making method using the majority principle for the coordination of assessments of alternatives given by individual experts in an ordinal scale in different problem situations with given probabilities of their occurrence in terms of different attributes (criteria)
Method	PURr <input type="button" value="Select method"/>

Figure 5: Table of PURr solution version choice

## Method description

Decision-making method using the majority principle to coordinate assessments: alternatives given by individual experts in an ordinal scale in different problem situations with given probabilities of their occurrence from the perspective of different attributes (criteria).

Question	Answer
Awareness of decision-making conditions	Several problem situations with given probabilities of their occurrence
The principle of coordination of alternatives assessment in different problem situations with given probabilities of their occurrence	The majority principle
Awareness of the consequences of the decision taken	Complete certainty at one stage
Number of experts involved in solving the problem	Several experts
The principle of harmonization of alternatives assessments formed by individual experts	The majority principle
Number of attributes for assessing alternatives	Several attributes
Degree of comparability of attributes (criteria) for assessing alternatives	The attributes (criteria) are incomparable
Principles of coordinating the assessments of alternatives for individual attributes (criteria)	The majority principle
The way of setting the assessments of the criteria's relative importance	Estimates of relative importance (weighting coefficients) of attributes (criteria) are set

Create Cancel

Figure 6: Continued table of PURr solution version choice

## Viewing the Solution Version

Solution version "PURr Calculation of alternative assessment by the PURr method"

Method: PURr

For task: P.A. Danilova. Choice of timekeeping system

Date of creation: 20.01.2021

Description	Solution	Alternatives	Situations	Attributes	Experts	Data	Import/Export
Code	Name	Description					
1	Kickidler	Timekeeping system, which allows you to analyze the efficiency of using ...					
2	CrocoTime	Timekeeping system, which allows you to get a complete detailed picture of the work...					
3	StaffCop	Timekeeping system, which allows you to automatically generate detailed reports...					
4	ManicTime	Timekeeping system, which allows you to automatically record the time used					
5	Yaware.TimeTracker	Timekeeping system, which allows you to get a complete picture of the working day for personal..					

Figure 7: Entering the values of the alternative parameter



## Viewing the Solution Version

Solution version "PURr Calculation of alternative assessment by the PURr method"

Method: PURr

For task: P.A. Danilova. Choice of timekeeping system

Date of creation: 20.01.2021

Description Solution Alternatives Situations Attributes Experts Data Import/Export

Expert assessments

Select a slice for editing:

A.A. Tabunova; Budget cuts

Data editor:

	Functions	Flexibility	Simplicity	Price	Reviews
Kickidler	3	2	3	3	1
CrocoTime	1	1	2	2	3
StaffCop	5	4	4	4	5
ManicTime	4	5	5	5	4
Yaware.TimeTracker 2	3	3	1	1	2

Figure 8: Entering assessments of alternatives

## Viewing the Solution Version

Solution version "PURr Calculation of alternative assessment by the PURr method"

Method: PURr

For task: P.A. Danilova. Choice of timekeeping system

Date of creation: 20.01.2021

Description Solution Alternatives Situations Attributes Experts Data Import/Export

Problem solved. Since the solution, the initial data have not changed.

Solve You do not have access to change this solution version.

The result of solving the problem:

List of alternatives in order of preference (with the most preferred at the beginning of the list):

1. Alternative X2 (CrocoTime)
2. Alternative X5 (Yaware.TimeTracker)
3. Alternative X1 (Kickidler)
4. Alternative X4 (ManicTime)
5. Alternative X3 (StaffCop)

Mathematical record of the results of solving the problem:

$X2 > X5 > X1 > X4 > X3$

Solution coefficient values:

Name	Value
X2 CrocoTime	0,333
X5 Yaware TimeTracker	0,267
X1 Kickidler	0,200
X4 ManicTime	0,133
X3 StaffCop	0,067

Figure 9: Entering assessments of alternatives

Table 1: Questions about the elements of the decision-making task and their various implementations (answers).

Conditions (questions)	Answer No.	Condition inputs (answer choices)
1. Awareness of the decision-making conditions	1	Problem situation
	2	Several problem situations with unknown probabilities of their occurrence
	3	Several problem situations with given probabilities of their occurrence
	4	Several unobservable problem situations with given probabilities of their occurrence and probabilities of their interrelation with observable events inherent
	5	Several problem situations ordered by the degree of probability of their
	6	In the first stage of solving the problem several problem situations with unknown probabilities of their occurrence are simulated; in the second stage DM makes an attempt to assess them
2. Principle of coordination of alternatives assessment in different problem situations with given probabilities of their occurrence	1	The majority principle
	2	Bayesian principle
3. Principle of coordination of alternatives assessment in different problem situations with unknown probabilities of their occurrence	1	Pareto principle
	2	Pessimism
	3	Optimism
	4	Hurwitz principle
	5	Antagonistic player principle
	6	Savage
	7	Laplace
4. Principle of coordinating alternatives assessment in different problem situations when solving a decision-making problem in two stages	1	At the first stage, Pareto principle is applied for the coordination of alternatives assessment in different problem situations, and the Majority principle at the second stage
5. Awareness of the consequences of the decision	1	Complete certainty at one stage
	2	Partial uncertainty on a finite set of discrete stages
	3	Partial uncertainty on an infinite set of discrete stages
6. Number of experts involved in solving the problem	1	One expert
	2	Number of experts
7. Principle of coordination of alternatives assessment given by individual experts	1	Majority principle
	2	Pareto principle
	3	At the first stage, Pareto principle is applied for the coordination of alternatives assessment in different problem situations, and the Majority principle at the second stage
8. Number of attributes of alternatives assessment	1	One attribute
	2	Number of attributes
9. Degree of comparability of attributes	1	Attributes are incomparable
	2	Attributes are comparable
10. Principles of coordinating alternatives assessment by individual criteria (attributes)	1	Majority principle
	2	Pareto
	3	Consistent consideration of the criteria
	4	Problem solving in two stages: at the first stage, the principle is used for the coordination of alternatives assessments from the standpoint of different criteria (attributes)
11. Way of setting the estimates of the criteria's relative importance	1	Attribute weights are set
	2	Attributes are ordered by importance
12. Way of setting a set of alternatives	1	Set of alternatives is finite
	2	Set of alternatives is represented as a subset of the n-dimensional space
13. Way of setting preferences on the set of alternatives	1	Quantitative estimates of alternatives for each attribute are given
	2	Ordinal estimates of the alternatives for each attribute are given