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DECISION-MAKING MODELS FOR COMPLEX ECO-ENERGY-ECONOMIC MONITORING SYSTEM

This article presents the development and implementation of a decision support system in a web application for complex eco-energy-economic monitoring. The study focuses on the analysis and development of decision-making methods, including decision tables, decision trees and expert systems, which ensure efficient and accurate problem-solving in complex environments. Decision tables are used for the systematic analysis of possible alternatives and select the best option based on specified criteria. Experts may use different criteria, including Wald, Bayesian-Laplace, Savage, or Hurwitz, to assess risks, averages, potential losses, or to integrate pessimistic and optimistic approaches. Decision trees provide a convenient way to model decision sequences and visualize scenarios. This method assesses the risks of each option, facilitating informed decision-making through analysis of potential future scenarios. The expert system is designed to accumulate and use knowledge in the form of rules containing conditions and actions. Knowledge engineers, working on the basis of expert experience, create a knowledge base that can be used to solve similar problems in the future. The developed decision support system allows experts to send their proposals to an analyst, who analyses the data in depth, assesses the available alternatives and formulates action programmes. The integration of decision tables, decision trees and expert systems into a single platform ensures high speed, accuracy and balanced decision making, which is essential for monitoring tasks. The system has significant practical value, providing analysts with tools for comprehensive data analysis, process optimisation and development of action strategies. Its implementation helps to improve the efficiency of management, particularly in the areas of the environment, energy and the economy, which is important for ensuring sustainable development and improving the health and quality of life of the population.
Keywords: decision support system, complex eco-energy-economic monitoring, decision table, decision tree, expert system, knowledge base, web application.

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МОДЕЛІ ПРИЙНЯТТЯ РІШЕНЬ ДЛЯ СИСТЕМИ КОМПЛЕКСНОГО ЕКО-ЕНЕРГО-ЕКОНОМІЧНОГО МОНІТОРИНГУ

У статті розглянуто розробку та впровадження системи підтримки прийняття рішень у веб-додаток комплексного еко-енерго-економічного моніторингу. Дослідження зосереджене на аналізі та розробці методів прийняття рішень, включаючи таблиці рішень, дерева рішень та експертні системи, що забезпечують ефективне та точне вирішення завдань у складних умовах. Таблиці рішень використовуються для систематизації аналізу можливих альтернатив і вибору оптимального варіанта на основі заданих критеріїв. Експерти можуть застосовувати критерії Вальда, Байєса-Лапласса, Севіджа або Гурвіца, які дозволяють оцінювати ризики, середньостатистичні показники, можливі втрати або комбінувати песимістичні та оптимістичні підходи. Дерева рішень забезпечують зручний спосіб моделювання послідовностей прийняття рішень і візуалізації сценаріїв розвитку подій. Цей метод дозволяє оцінити ризики, пов'язані з кожним варіантом, і сприяє прийняттю обґрунтованих рішень за рахунок аналізу всіх можливих шляхів розвитку ситуації. Експертна система розроблена для накопичення та використання знань у формі правил, що містять умови та дії. Інженери зі знань на основі досвіду експертів створюють базу знань, яка може бути використана для вирішення аналогічних завдань у майбутньому. Розроблена система підтримки прийняття рішень дозволяє експертам надсилати свої пропозиції аналітику, що детально вивчає отримані дані, оцінює альтернативи та формує програми заходів. Інтеграція методів таблиць рішень, дерев рішень та експертних систем в єдину платформу забезпечує високу швидкість, точність і зваженість прийняття рішень, що є ключовим для завдань моніторингу. Система має значну практичну цінність, адже забезпечує аналітиків інструментами для комплексного аналізу даних, оптимізації процесів і розробки стратегій дій. Її впровадження сприяє підвищенню ефективності управління, зокрема в галузях екології, енергетики та економіки, що є важливим для забезпечення сталого розвитку, покращення здоров'я та якості життя населення.
Ключові слова: система підтримки прийняття рішень, комплексний еко-енерго-економічний моніторинг, таблиця рішень, дерево рішень, експертна система, база знань, веб-додаток.

Introduction

Ensuring a normal quality of life and sustainable development of society requires constant monitoring and accounting, as well as effective decision-making to prevent negative environmental impacts, optimize energy and improve public health. For this purpose, the Complex Eco-Energy-Economic Monitoring system (CEEEM) has been developed. This system allows experts in various fields to collect, process and analyse data on the environmental, energy, economic and social status of the territory [1].

In the system, an expert analyst identifies a problem, sends it to various experts for analysis, and, based on their suggestions, forms a program to solve the problem. To ensure the greatest objectivity and multilateralism in decision-making, the development and implementation of a decision support system for the CEEEM application is an urgent task. Such a system should provide functionality for effective decision-making and the formation of alternatives.

The developed system provides a wide range of functionality for analysis and decision-making. It contains three methods that an expert can use in decision-making: a decision table, a decision tree, and an expert system. The expert chooses the most appropriate method for a particular situation, depending on the needs of the task. This functionality makes it possible to analyse in detail all possible solutions for a particular task, assess possible risks, and search the rule base if they are added to it.

Thus, the developed system allows the analyst to quickly and efficiently build decisions based on expert analysis. Therefore, research on the development of a decision support system for the application of integrated eco-energy-economic monitoring is a relevant and important area now.

Related works

Paper [2] presents a general architecture of decision support system (DSS), namely "client-server", which is suitable for creating a system in a web application. In general, a system consisting of the following elements: data manager, interface manager, and decision model manager. However, this article does not describe specific decision models. Therefore, it is necessary to consider the works that study different decision models.

Article [3] discusses decision making under uncertainty and risk. This article describes risk assessment, alternative analysis and selection of the best alternatives using a decision table. This method helps to analyse the existing alternatives for making certain decisions based on the evaluation of various factors.

The algorithm for making sequential decisions is discussed in the article [4]. This algorithm is a decision tree that helps to visualize the sequence of decisions and their possible consequences. This method can be used in cases where it is necessary to consider several sequences of decisions, to consider their consequences and to choose the most optimal one.

Paper [5] describes the architecture of an expert system. However, it does not describe the structure that ensures the storage of rules. For this purpose, a structure based on the use of rules is described in paper [6]. It is a product model based on the principle "If ..., then ...". The rules are stored in a similar way in the expert system for demand management in healthcare supply chains in the face of epidemic outbreaks described in paper [7]. This paper describes the construction of rules where the input variables are a condition under which certain actions are performed.

The paper [8] describes a DSS for environmental decision making. This DSS is based on an expert system where decision rules are stored in a knowledge base and used to model scenarios. The software has a modular structure with integration of expert rules, which ensures accuracy and speed of decision making. Data is stored in the form of knowledge and processed by rules to generate conclusions and recommendations.

After reviewing these publications, it was concluded that it is necessary to select and study decision making algorithms for management. Examples of such algorithms are the decision table and the decision tree. A decision table helps to analyse all available alternatives in depth, evaluate them, and select the alternative with the best score. However, this method is not effective when it is necessary to consider a sequence of decisions. To solve such problems, there is a decision tree, which helps to visualize the sequence of decisions, their consequences and possible outcomes. However, this method does not allow to analyse each alternative according to certain factors. Therefore, it is important to explore both methods. An expert system can also be useful, as it allows experts to make more effective decisions based on the accumulated experience of other specialists. Therefore, it is important to consider multiple decision-making methods when building a DSS. This allows experts to use the most appropriate method for each task.

Analysis of existing methods and models

To test the developed decision-making algorithms, data on the state of the Desna River, into which the Sejm flows, were used to analyse the impact on the health of the population.

In order to analyse the state of the river, data were taken from the state surface water monitoring dataset provided by the State Agency of Water Resources of Ukraine. The main indicators used to determine the impact are the following: sulphate, chloride, chemical oxygen consumption, hydrogen index, dissolved oxygen, temperature, phosphates, total iron, ammonium, ammonium nitrogen, manganese, nitrite, nickel, arsenic, lead, cobalt, total chromium, cadmium, etc [9].

The search for optimal solutions is carried out using the following methods

– decision table;
– decision tree;
– expert system.

To develop these methods, the React library was chosen. It provides powerful functionality for building website interfaces. The cytoscape.js library was also used to display the decision tree. The object-oriented programming paradigm was chosen to facilitate the construction of the decision tree. The MySQL database management system was used to develop the knowledge base, which allows the creation of tables and links between them.

Research results

As a result of the research, it was developed the functionality of a decision support system using the methods of a decision table, a decision tree, and an expert system. After the system was developed, it was tested basing on the following tasks:

– "Assess the impact of pollution from the Seim River on the waters of the Desna River and identify the necessary environmental measures to reduce damage to the ecosystem";

– "Assess the impact of pollution on the health of the population consuming water from the Desna River and implement measures to prevent epidemiological risks".

The module functionality is shown in the diagram (Fig. 1):

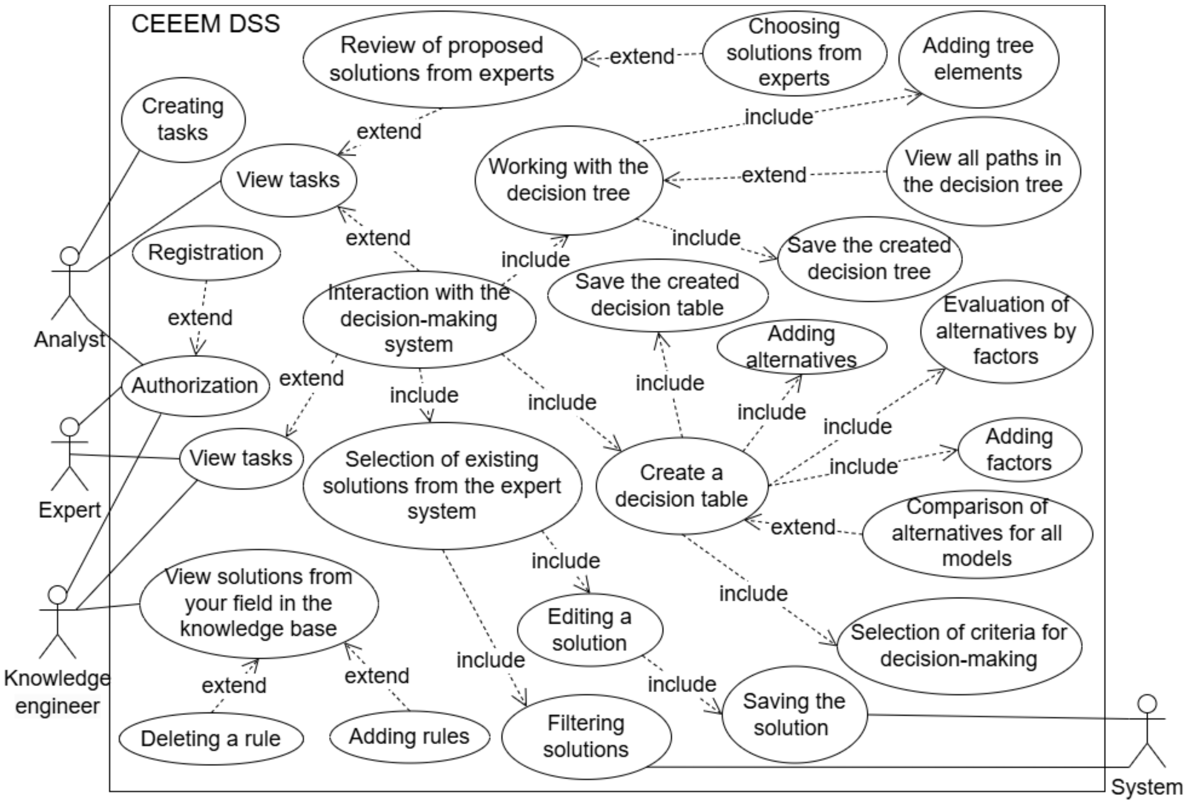

Fig. 1. DSS functionality

To implement the system there are created modules:

– decisionTable;
– decisionTree;
– expertModel ;
– DSSAnalist – an interface for analysts to view decisions from experts and create their own.

A decision table is a tool that allows expert objectively evaluate the strengths and weaknesses of each of the decision alternatives. A decision table can help in decision-making cases where there is a set of requirements for several factors in the alternatives.

The principle of operation is analysing all possible alternatives by factor. First expert considers possible alternatives and evaluates them by each factor from 1 to 10. The higher the score, the better alternative. After that, each alternative is evaluated according to one of the criteria [6]:

– Wald's criterion;
– Savage criterion;
– Hurwitz criterion;
– Bayes-Laplace criterion.

The Wald criterion is used to minimize losses in the worst case. Therefore, it is suitable for cautious selection of alternatives where the lowest risks are important. Formula of Wald's criterion:

$$W = \max_i \min_j W_{ij}, \quad (1)$$

where i – alternatives;
j – factors of alternatives;
w_{ij} – estimates of the factors of alternatives.

The Savage criterion is designed to find an alternative that may be not the best, but at the same time is not too risky. The Savage criterion is calculated using the following formula:

$$W = \min_i \max_j (W \max_j - W_{ij}), \quad (2)$$

The Hurwitz criterion helps to find an alternative between extreme pessimism and optimism. The calculation is performed using the formula:

$$W = \max_j [\alpha \min_i W_{ij} + (1-\alpha) \max_i W_{ij}] \sum_{i=1}^{n} (X_i - X)^2, \quad (3)$$

where α is the coefficient of optimism-pessimism.

The Bayes-Laplace criterion is relevant to use in cases where the estimates of the factors in the alternatives have a small difference and small risks are assumed in the implementation. The formula for this criterion is:

$$W = \max_i \sum_{j=1}^{n} W_{ij}(A, \lambda_j), \quad (4)$$

Working with decision tables is implemented in the “decisionTable” module. The functioning of the developed module for working with decision tables is shown in figure 2:

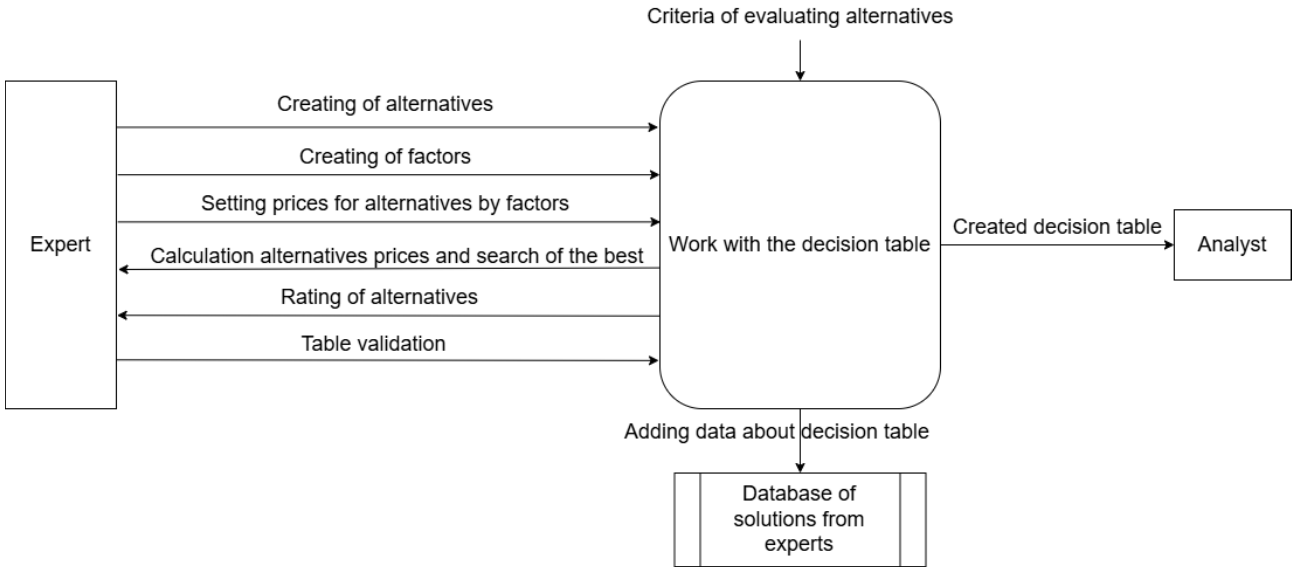

Fig. 2. Principle of operation of the decision table module

To test the system selected task “Evaluate different methods of water quality monitoring in the Desna River”. To solve it considered following alternatives:

- laboratory analysis;
- automatic monitoring stations;
- field research;
- biomonitoring;
- combined use.

The factors by which the alternatives evaluated are follows:

- risk ranking;
- accuracy
- response time;
- cost;
- compatibility with the Ministry of Health standards.

In order to take into account all possible risks, the Wald criterion was chosen to compare all methods under the worst-case scenarios. The constructed decision table for this task is as follows (Fig. 3):

Альтернативи	Фактори				Оцінка кожної альте...
	Ранжування ризику (R)	Час реагування (T)	Вартість (C)	Сумісність з стандартами	
Лабораторний аналіз	8	6	6	8	6
Автоматичні моніторингові станції	10	8	8	10	8
Польові дослідження	6	8	4	6	4
Біомоніторинг	8	6	6	8	6
Комбіноване використання	10	8	10	10	8
Нова Альтернатива					
Загальна оцінка:					8

Fig. 3. Comparison of alternatives using a decision table

As shown in the figure, the decision table analysed all the alternatives by factors, evaluated them, and selected the best score (in this case, the "Combined Use" alternative). After the expert has analysed all the alternatives, they are sent to the analyst for review.

A decision tree is a graph that helps to visualize all possible decision options and their possible consequences. This method is used to select the best course of action among those depicted in the tree [10].

A decision tree consists of the following elements [11]:

– decision node;
– decision alternatives;
– probability node;
– branch of possible events;
– result node.

The decision node indicates the task or problem to be solved. It plays a crucial role in the process of developing a sequence of actions because each decision can lead to different scenarios and consequences.

Each decision node contains from one to several alternatives, which are depicted as lines that extend from these nodes. Alternatives are options that can be chosen to solve a particular problem.

After an alternative, there may be a next decision node or a probability node, which is depicted as a circle. Such nodes represent uncertainties and risks that affect the final results. Each probabilistic node contains one to several possible outcomes, which are represented as straight lines. They indicate possible events that may affect the outcome or possible consequences of certain decisions. Each possible outcome has its own probability of occurrence.

Each probable event is followed by a next decision node or end node. It is depicted as a rectangle and describes the result of the sequence of decisions.

Building a decision tree visualizes all possible ways to solve a problem and depicts all the risks. The expert independently reviews all possible ways and chooses the most optimal one.

Functional for decision trees is implemented in the "decisionTree" module. An expert can build a decision tree for a particular task, view the probability ratings of the tree branches, and send the created tree to an analyst.

To structure the elements of the decision tree, created a class hierarchy, as shown in figure 4:

Trees are displayed using the cytoscape.js library.

This method allows an expert visually to see all possible decision sequences and their consequences.

Experts can send the created decision trees to the analyst for review, after which he or she can review them.

The next task that is analysed using the created system is "Controlling the impact of the Seim River emissions on the Desna River" using a decision tree. This method was chosen for this task because to solve it, most likely, it is necessary to create a sequence of decisions and consider all possible events that may arise from their adoption (Fig. 5).

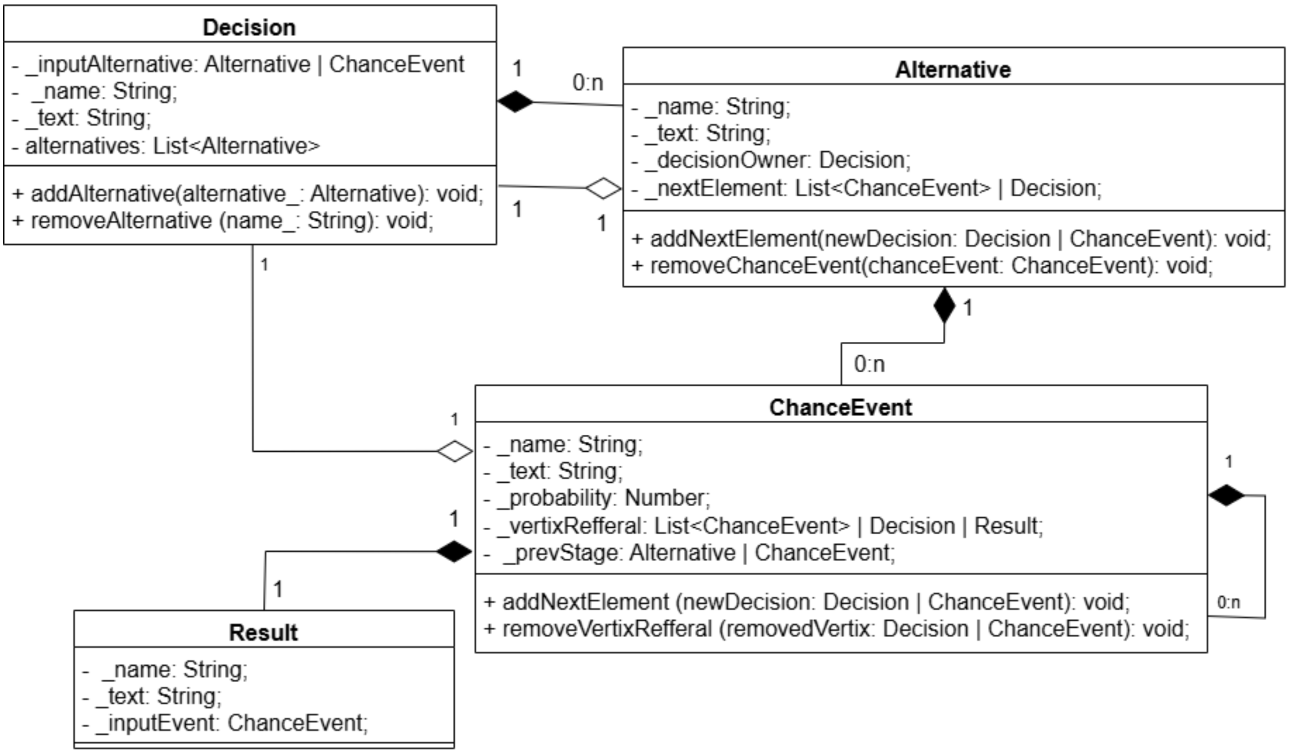

Fig. 4. Classes for building a decision tree

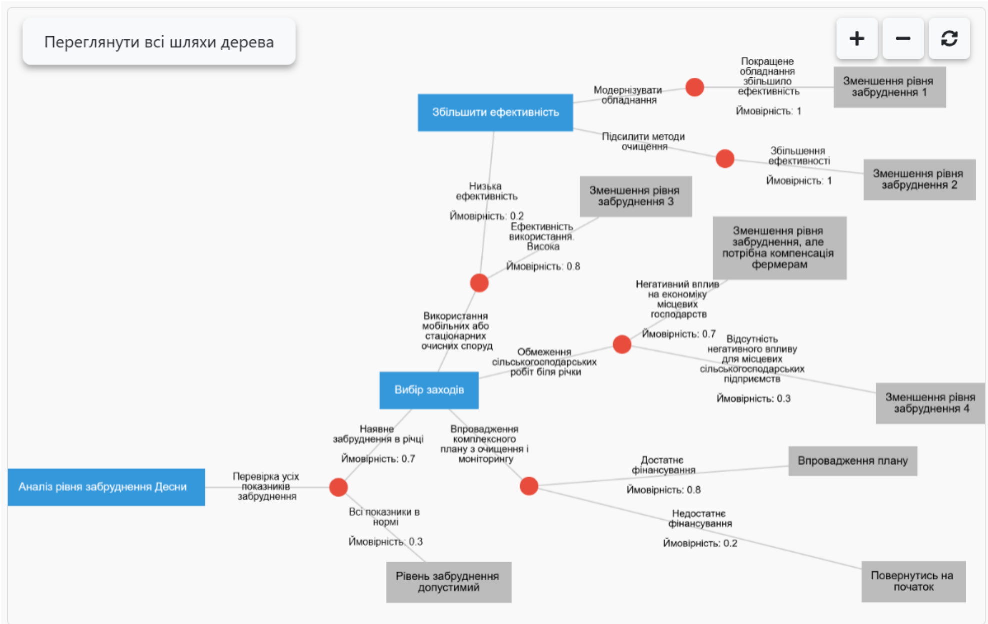

Fig. 5. The constructed decision tree

The constructed decision tree depicts all possible decision-making scenarios and their possible consequences. The expert can see this visualization, which makes it easier for him/her to have a general vision of all possible solutions to a particular problem.

An expert system was chosen to view existing solutions for experts. This is a module that allows an expert to select existing solutions. These solutions are added by a knowledge engineer (a more experienced specialist in a particular field).

These rules are stored in a knowledge base in the form of productions [12]:

$$(i); Q; P; A1, A2, \dots, An \rightarrow B1, B2, \dots, Bn; N, \quad (5)$$

This formula consists of the following elements:

– is the name of the production, which is unique for each one;
– Q is the area of knowledge that the production belongs to;

– A1, A2, ... → B1, B2, ... are the core of the production, which is the condition or antecedent (A1, A2, ..., An) under which the consequent (B1, B2, ..., Bn) is performed;

– P is a precondition of the production, if true, the core is executed;

– N is postconditions of the production, which are executed only if part B of the kernel is true.

Parts P and N are optional and may be not added to the product if they are unnecessary. In the implementation of the expert system, they are absent, since it only specifies a condition, a list of actions under it, and which are performed if the condition is not true.

The expert system contains functionality for experts to search for ready-made solutions for similar tasks and add solutions in the form of productions. They are stored in a database, as shown in figure 6:

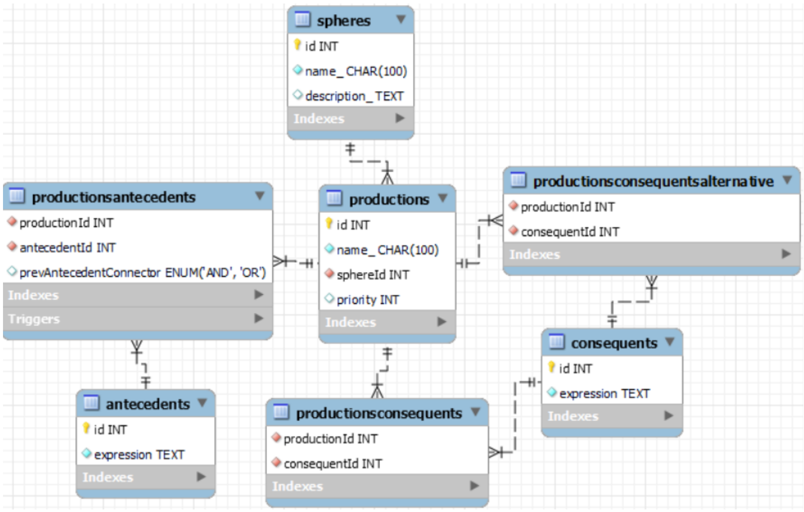

Fig. 6. Productions storage database

The spheres table stores all existing productions areas. The productions-table store basic information about the productions, such as their names, priority, and the identifier of the sphere to which the production belongs. To provide the ability to store different conditions in different products and in each of them several concretions, a many-to-many relationship is implemented between the productions and antecedents tables using the productionsAntecedents table, which also stores a logical operator with a precondition. Similar two relationships are implemented between the productions and consequents tables: one specifies the sequences that are executed when the antecedents are true (using the productionsConsequents table), the other – in the opposite case to the kernel condition (the productionsConsequentsAlternative table).

The development of such a database makes it possible to reuse existing antecedents and consequents without duplicating them in the tables.

Using this functionality, an expert can search among existing solutions and select them. Using ready-made solutions can eliminate the need to build new solutions using a table or tree. Displaying existing solutions from the subject area (Fig. 7):

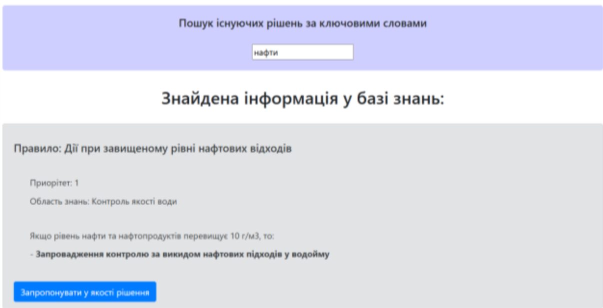

Fig. 7. Functionality for searching for existing solutions in an expert system

Solutions to tasks are added by an expert in a particular field who has extensive experience. They can add and delete existing rules in the area of expertise. The interface for working with solutions by an experienced expert (Fig. 8-9):

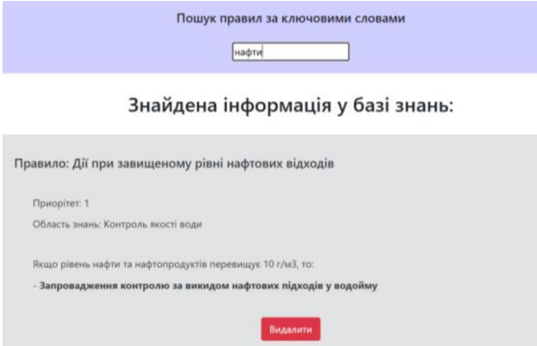

Fig. 8. Display of rules from the expert system that editable by a specialist in the relevant field of knowledge

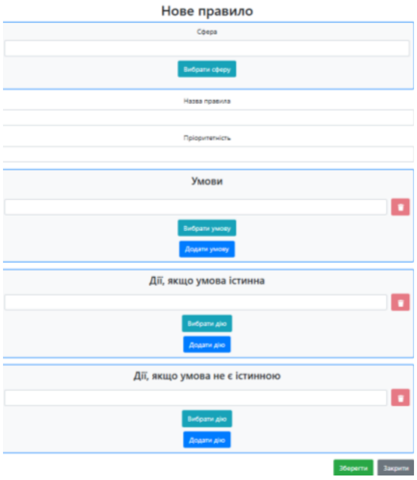

Fig. 9. Form for adding new rules to the knowledge base

After adding certain rules, they will be displayed when searching for them by the subject area of the task. An expert can review all existing solutions and choose the one that suits its needs. After that, it will be sent to the analyst for review. The solutions sent to the analyst from the experts look like this (Fig. 10):

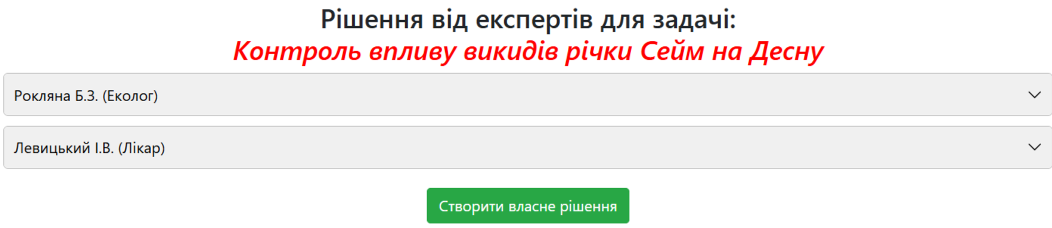

Fig 10. Output of solutions from experts to the analyst

The analyst is presented with a list of experts who suggested a solution. By clicking on a particular expert, the analyst will see the alternatives proposed by the expert using the method he or she used to create them. The analyst can choose any of them or, taking into account the opinions of experts, create his/her own using one of the three methods. This functionality allows the analyst to build his/her own decisions taking into account analysis of each expert.

Conclusions

This article presents a decision-making system for conducting complex monitoring based on a combination of different methods. This approach allows experts in the CEEEM system to evaluate potential solutions using the most effective methods for particular tasks and send them to an analyst for further consideration. The analyst is able to review the decisions from all experts and formulate a program of measures, thereby rendering the decision-making process more universal.

The results of the development and implementation of the CEEEM system can be summarized as follows:

1. A decision-making table has been developed. It allows experts to evaluate several alternatives by all possible factors and choose the best ones. The analysis of potential solutions for the task “Evaluate different methods of water quality monitoring in the Desna River” was conducted in accordance with the Wald criterion, resulting in the selection of the "Combined use" alternative as the optimal choice.

2. A functionality for working with decision trees has been developed. It allows visualizing all possible

sequences of decision-making and their consequences, which is convenient in cases where several decisions need to be made simultaneously. An analysis of potential solutions for the task “Controlling the impact of emissions from the Seim River on the Desna River” has been conducted, which resulted in visualization of all possible scenarios.

3. A functionality for working with the expert system has been developed. This allows experts to review and select existing solutions in the knowledge base. An expert with extensive experience can add rules to the system that can be useful for transferring experience to other experts.

The decision-making system is of considerable practical value, as it provides analysts with tools for comprehensive data analysis, process optimisation and development of action strategies. Implementation of the system has been shown to improve the efficiency of management, particularly in the environmental, energy and economic sectors. This is crucial for ensuring sustainable development and improving the health and quality of life of the population.

References

1. Slipchenko V.H., Poliahushko L.H., Krush O.Ie. Systema kompleksnoho eko-enerho-ekonomichnoho monitorynhu dlia optymizatsii upravlinskykh rishen (oblasti, raionu ta mista). Visnyk Skhidnoukrainskoho natsionalnoho universytetu imeni Volodymyra Dalia. 4(268), 2021. S. 13-20. DOI: *10.33216/1998-7927-2021-268-4-13-20*.
2. Ostapchenko K., Lisovychenko O., Evdokimov V. Funktsionalna orhanizatsiia systemy pidtrymky pryiniattia rishen orhanizatsiinoho upravlinnia. Adaptyvni systemy avtomatychnoho upravlinnia. 2020. T. 1, № 36. S. 17–31. DOI: *10.20535/1560-8956.36.2020.209753*
3. Kabachenko D.V. Pryiniattia upravlinskykh rishen v umovakh nevyznachenosti ta ryzyku. Ekonomichnyi visnyk Natsionalnoho hirnychoho universytetu. 2017. № 2 (58). S. 107–115.
4. Kravchenko M., Holiuk V. Pryiniattia upravlinskykh rishen: sutnist ta suchasni tendentsii rozvytku. Economy and Society. 2022. № 40. DOI: *10.32782/2524-0072/2022-40-37*.
5. Shevchuk O.B. Pedahohichni pryntsypy proektuvannia ta rozrobky ekspertnykh system navchannia. Naukovi zapysky Ternopilskoho natsionalnoho pedahohichnoho universytetu imeni Volodymyra Hnatiuka. Seriia: pedahohika. 2016. № 1. S. 38–43.
6. Holyk O. Intelektualni systemy pidtrymky pryiniattia rishen : metod. vkazivky do vykonannia prakt. zaniat dlia studentiv den. ta zaoch. formy navchannia za. spets.: 151 “Avtomatyz. ta komp.-intehrovani tekhnolohii”, 141 “Elektroenerhetyka, elektrotekhn. ta elektromekhan.” Kropyvnytskyi : TsNTU, 2020. 59 s.
7. Govindan K., Mina H., Alavi B. A decision support system for demand management in healthcare supply chains considering the epidemic outbreaks: A case study of coronavirus disease 2019 (COVID-19). Transportation Research Part E: Logistics and Transportation Review. 2020. Vol. 138. P. 101967. DOI: *10.1016/j.tre.2020.101967*.
8. Osoblyvosti stvorennia intelektualnoi systemy pidtrymky pryiniattia ekolohichnykh rishen / O. Mashkov ta in. Materialy mizhnarodnoi naukovo-praktychnoi konferentsii "Ekolohiia. Liudyna. Suspilstvo". 2024. S. 250–257. DOI: *10.20535/ehs2710-3315.2024.303623*.
9. Slipchenko V., Poliahushko L., Krush O., Rudyk V. Investigation of approaches to designing complex database structures in systems of integrated monitoring of environmental, economic, energy and social parameters of the territory. Technology Audit and Production Reserves. 2024. № 2/2(76), P. 38-43. DOI: *10.15587/2706-5448.2024.302396*
10. McNellis R. T. Training Decision Trees for Optimal Decision-Making. *Columbia University*, 2020. 155 p.
11. Decision and Inhibitory Trees / F. Alsolami et al. Decision and Inhibitory Trees and Rules for Decision Tables with Many-valued Decisions. Cham, 2019. P. 91-103. DOI: *10.1007/978-3-030-12854-8_6* .
12. Fazlollahtabar H. Knowledge Engineering. Boca Raton, FL : CRC Press, 2020. : CRC Press, 2020. DOI: *10.1201/9781003055006* .

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