UDC 004.03:504.064.3
DOI: 10.15587/1729-4061.2018.141056

DEVELOPMENT OF DECISION SUPPORT IN THE STRUCTURE OF THE INFORMATION-ANALYTICAL SYSTEM OF ATMOSPHERIC AIR ENVIRONMENTAL MONITORING

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Основною проблемою, що визначає ефективність систем екологічного моніторингу, є недостатня обґрунтованість управлінських рішень щодо корекції екологічних ситуацій. В таких умовах необхідним є формальний універсальний базис, що описує інформаційно-аналітичну систему (ІАС) екологічного моніторингу.

Для розробки та опису складу і структури ІАС застосовано елементи теорії нечіткої логіки та нечітких множин та методи системного аналізу. На цій основі сформовано теоретичну основу для розробки універсальної структури ІАС екологічного моніторингу. Запропоновано теоретико-множинну модель інформаційно-аналітичної системи екологічного моніторингу атмосферного повітря на муніципальному рівні, що включає підсистеми моніторингу параметрів урбосистеми, підтримки прийняття рішень, інформаційний комплекс «база даних параметрів - база знань ситуацій».

Підсистему підтримки прийняття рішень представлено як модель пошуку рішень, що визначає допустимі перетворення ситуацій і набір стратегій застосування цих перетворень для вирішення задачі усунення несприятливої ситуації. Розроблено адаптивну нечітку модель розпізнавання ситуацій у процесі моніторингу екологічної обстановки, що дозволяє продукувати діагностичні висновки. Процес діагностики представлено послідовністю дій, що включає три етапи: встановлення критичності для кожної ознаки, що представляє ситуацію; визначення ступеню критичності; надання лінгвістичної ознаки. Перевагою запропонованої архітектури ІАС є можливість швидкого масштабування системи підтримки прийняття рішень. Це досягається за рахунок простого розширення словника ознак, ситуацій і бази знань, а також, гнучкого налаштування бази знань шляхом корекції вагових коефіцієнтів елементарних посилок правил. Сформовано загальний опис інформаційної технології моніторингу та підтримки прийняття оперативних рішень щодо корекції екологічно небезпечних ситуацій. Отримано результати настроювання нечіткої моделі розпізнавання ситуацій шляхом експериментального навчання системи на прикладах – конкретних результатах спостережень за станом атмосферного повітря. Встановлено здатність системи до самонавчання, що у кінцевому випадку дозволить обмежити залучення реальних фізичних осіб у якості експертів з оцінювання екологічних ситуацій за рахунок автоматизації процесу діагностики

Ключові слова: екологічний моніторинг, інформаційно-аналітична система, модель, розпізнавання ситуацій, підтримка прийняття рішень, інформаційна технологія

1. Introduction

One of the problems in attempts to increase the efficiency of environmental monitoring systems is the imperfection of observation and evaluation subsystems. This leads to the insufficient validity of conclusions in the management decision support subsystem. At the same time, the latter is directly related to quality management of environmental components [1, 2]. According to the results of a number of studies conducted on the example of a specific technogenically loaded urban system [1], the basic reasons of the imperfection of the system of environmental monitoring of atmospheric air at the municipal level are determined, namely, the lack of:

– differentiation of observation posts by the nature of the information obtained;

– proper expert evaluation of observation results;

– forecasting of weather conditions that form atmospheric pollution and warning of the population and industrial facilities about dangerous weather conditions;

– structured database of the monitoring system;

– wide public access to the analysis observation results, understandable to all segments of the population.

By the destructive effect, these basic reasons of imperfection form certain negative consequences, which ultimately affect the efficiency of the management decision-making subsystem in the system of environmental monitoring of atmospheric air. Meanwhile, the system of environmental monitoring of atmospheric air has a certain level of hierarchy and includes subsystems. The latter are separate and completely independent elements. The logical combination of functional features of subsystems will allow raising the level of reasonableness of management decisions aimed at correcting environmental situations. At the same time, the problem of intelligent support of the process of producing diagnostic conclusions in the automatic mode is relevant.

Thus, the development of intelligent management decision support in the structure of the information-analytical system of environmental monitoring and the appropriate information technology is an urgent problem.

2. Literature review and problem statement

To solve the problems of management decision support, the information-analytical systems (IAS) are developed. The system approach to the design of a complex IAS in the early stages involves the development of conceptual and mathematical models that should reflect the composition, structure and architecture of the system. The authors [3] note that real-time management and decision support systems are based on complex modeling and require the use of additional software modules to ensure compliance with the prescribed terms. The paper proposes the reference architecture of the integrated decision support system. But the architecture of the system is described verbally, without the use of a mathematical apparatus, which leads to limited opportunities for repetition and scaling. Therefore, the problem of formalization of the decision support system is unresolved. In [4], it is also noted that large-scale environmental monitoring, early warning and decision support (EMEWD) systems should process massive flows of sensor data in real time. The paper estimates the suitability of four data models and the corresponding database technologies – the MongoDB document database, the PostgreSQL relational database, the Redis dictionary data server and the In fluxDB time series database – as an operational database for the EMEWD systems. The answers to the questions of how it is better to implement time series in this data model, what are permissible limits of the operational database volume and performance limitations for different types of databases are obtained. However, the development of models and algorithms of rapid processing of the obtained data is not considered in the work, which essentially narrows the possibilities of practical use of the results described by the authors. In [5], an innovative environmental monitoring platform based on cloud computing and BigData processing technologies is proposed. The prospects of the chosen approach are shown. The paper forms a conceptual approach, but there is no formal description of algorithms and mathematical support of recognition of adverse environmental situations. In [6], it is also emphasized that BigDatа technologies, as well as expanded use of cloud computing and high-performance computing, create new opportunities for the knowledge-intensive information. As in [5], the authors [6] discuss the possibilities of using new information technologies, but do not offer specific solutions with the description of models and algorithms of situation recognition. The paper [7] describes the ontology model that is designed for river water quality monitoring. At the same time, it is possible to present the semantic properties of river water quality data and build semantic value among various concepts related to river water quality monitoring. By combining the ontology model with the water quality assessment method, it is possible to obtain reasonable and complete information on water quality assessment. In this paper, the authors propose the ontology model of the domain, but do not offer a model of the analytical system. In [8], the approach to analytical decision support based on the integration of OLAP technology and formal conceptual analysis is described. The analytical model is constructed as a grid of formal cubic concepts. The model includes all possible combinations of the analyzed objects and allows manipulating them to make decisions. However, modification of the set of formal concepts can be a problem when trying to scale the system. The paper [9] deals with the development of the GroundWater spatio-temporal data analysis tool (GWSDAT). The spatio-temporal model is used for adequate interpretation of the interaction of measurement results – space and time series of groundwater solution concentrations. The graphic user interface can be used for the fast, interactive trend analysis with simplified reporting for a wide range of users. Open and decentralized technologies provide more and more opportunities for analysis and automated decision support for different types of users. However, environmental decision support systems (EDSS) are often targeted only on scientific and technical users, that is, a narrow range of decision makers. This excludes both the participation and the indirect influence of ordinary users in the decision-making process. In such contexts, EDSS need to be adapted for meeting various user requirements to guarantee that it provides relevant, convenient and up-to-date information for decision support for different types of participants. To address these problems, the paper [10] presents the basis for EDSS development, which emphasizes a better understanding of decision-making structures and iterative design of the user interface. However, there is no formalized representation of the system providing such a service.

Literature review shows that there are methodological problems in constructing environmental monitoring systems. In particular:

– the lack of a single conceptual basis for constructing information technologies and monitoring systems that function in various conditions of application and purpose;

– complication of a single formal description of various physical phenomena and processes through the application of various mathematical apparatus for various purposes of analysis;

– the presence of a large number of data representation forms and, consequently, types of models for presenting knowledge about the monitoring object due to the existence of various specialized approaches.

The analysis shows the obvious need to use modern principles based on promising intelligent information technologies for the automated collection, integration and comprehensive analysis of all types of information that characterizes the state of an ecosystem.

So, the problem of developing a versatile structure of the information-analytical decision support system is not fully solved. This requires, first of all, a formal basis describing the composition and structure of such a system. In addition, it is of interest to develop a sufficiently versatile model of recognition of critical situations.

3. The aim and objectives of the study

The aim of the study is to develop intelligent management decision support in the structure of the IAS of environmental monitoring.

To achieve the aim, the following objectives should be accomplished:

– to develop a formal description of the set-theoretical model of the IAS of environmental monitoring;

– to develop an adaptive fuzzy model of recognition and determination of the criticality of environmental situations and the information technology of monitoring and decision support, which complements the description of the IAS architecture;

– to carry out practical testing of the experimental model of the model of recognition and diagnostics of environmentally dangerous situations on the example of a specific technogenically loaded urban system.

4. Methodological basis of development of decision support in monitoring systems

Experience in the development of monitoring systems of complex processes shows that the monitoring system should provide the following functions [11]:

– collection of data on primary process parameters;

– real-time simulation of the most important processes; indirect measurement of parameter values that are unavailable for direct measurements and displaying of measurement and calculation results on user monitors;

– conversion of the values of the primary process parameters into the values of the situation features;

– situation recognition and support of operational decisions on the situation correction;

– short-term forecasting of events; periodic refinement of model parameters and knowledge base replenishment;

– maintenance of the monitoring database and history of messages and recommendations for users.

In addition, when developing a monitoring system, it is necessary to be guided by the following basic principles:

1. Organizational, informational and functional unity of the monitoring system, which is based on:

– a unified system of classification of environmental situations, indicators and criteria for the ecosystem state assessment;

– basic (standard) protocols, algorithms (programs) for information collection, processing and exchange, preparation and automated support of decisions based on monitoring data;

– ensuring the integrity and consistency of information in the system.

2. Application of computing intelligence methods and models for obtaining indirect measurement data for analysis, forecasting and modeling of processes in the monitoring object.

3. Unification of software, information and technical means, ensuring the compatibility of the monitoring subsystem elements, the possibility of modular extension and modernization.

4. Subsystems should be implemented as a set of jointly functioning modules (components), the interaction between which should be carried out through a single information environment.

5. The subsystem should be developed as a set of independent but logically interrelated software modules and elements to enable structural and functional development (scaling).

5. Development of decision support in the structure of IAS of environmental monitoring

5. 1. Development of set-theoretic models for the IAS structure description

Taking into account the aforementioned and based on the results presented in [12], a set-theoretic model was developed as the basis for constructing a versatile structure of the information-analytical system of environmental monitoring (IAS EM).

In general, the IAS EM model can be represented by the set:

$$M = \langle F, PC, R \rangle, \tag{1}$$

where F is the functional IAS subsystems, PC is the complexes ensuring the IAS functioning; R is the relations combining the IAS elements into a single structure. Regarding the considered problem of IAS EM development, we detail the content of the model:

$$M = \left\langle \begin{matrix} F(MS, SAD), IC, QM, MQM, \\ MM, AC, SP, OC, R_1, R_2, R_3 \end{matrix} \right\rangle, \tag{2}$$

where MS is the monitoring subsystem of ecosystem parameters; SAD is the decision support subsystem; IC is the information complex – databases of important parameters, knowledge base of emerging situations, map databases, factual databases, reference and regulatory database; $MQ = <Q, LQ>$ is the quality model of environmental situation, where Q is the set of quality indices according to the standards; LQ is the set of allowable values of quality indices; $MQM = <Q_M, LQ_M>$ is the quality model of the situation management process, where Q_M is the set of important indices of management quality; LQM is the set of constraints on management impacts; MM is the complex of mathematical models used to solve situation monitoring and recognition problems; AC is the complex of algorithms to solve monitoring, recognition and decision support problems; SP is the complex of instrumental software tools that implement the functional tasks of the IAS EM; OC is the organizational complex of the IAS EM, that is, organizational principles and documents regulating environmental situation control; $R1 \subseteq Q_M \times Q$ is the display of a set of quality control indicators on a set of environmental situation quality indicators; $R2 \subseteq MM \times F$ is the distribution of models by subsystems; $R3 \subseteq F \times Q$ is the ratio of the influence of functional subsystems on the environmental situation quality.

To synthesize the decision support subsystem, it is necessary to develop its model, as well as the operational decision model for the decision maker (DM). To do this, first of all, we formulate the decision problem taking into account the specifics of the subject area.

The decision problem is formulated as follows: a subset of initial states, a subset of finite states and a set of state transformation rules are given. It is necessary to find a sequence of rules that allows a managed object to move from the current state to desired or allowable.

The decision problem is determined by the model:

$$PFS = \langle PSM,\ S, S_A, S_0, S_T,\ R_T, Q_{CS} \rangle, \tag{3}$$

where PSM is the model of the problem situation in the subject area; S is the set of current states (situations); $S_A \in S$ is the subset of allowable states; $S_0 \in S$ is the subset of initial states; $S_T \in S$ is the subset of target states; $R_T{:}S \to S$ is the final set of transformation rules. Each rule $R_{Ti} \in R_T$ is a function that implements the display $R_{Ti}{:}S_i \to S$, where S_i is the definition area R_{Ti}; Q_{CS} is the set of decision quality criteria.

The composition of the decision support subsystem SAD is presented as:

$$SAD = \left\langle \begin{matrix} DSM(PSM),\ KB,\ MB,\ DB, \\ SS,\ RR,\ PM,\ AB,\ IDA,\ UI \end{matrix} \right\rangle, \tag{4}$$

where DSM is the decision model; KB is the knowledge base; MB is the database of models of physical processes to be analyzed; DB is the database; SS is the set of the situation features; $RR \subseteq Q \times SS$ is the display of a set of environmental situation indicators on a set of the situation features; PM is the process manager, which performs dispatching functions; AB is the algorithm base; IDA is the interface with the data collection subsystem; UI is the user interface unit.

The main elements of intelligent decision support systems (DSS) are models for representing problem situations, decision models. Also, means for the organization of dialogue interaction with the user (DM, expert, message sending resident) and means of communication with other information systems are important. The problem situation can be described by some selected set of features that, with the help of some structure, allows displaying various interrelations between the elements of the problem area. As such structures, any known knowledge models can be used.

The decision model determines allowable transformations of situations and a set of strategies for applying these transformations. To solve the problem of eliminating an adverse situation, the decision model is formally determined by the set:

$$\mathrm{DSM} = \langle \mathrm{PSM},\ A_{SR},\ SR, AAR \rangle, \tag{5}$$

where A_{SR} is the set of algorithms for selecting and interpreting products when choosing a decision; SR is the set of products; AAR is the algorithm of SR set replenishment during the DSS operation.

Thus, models to determine the composition and structure of the main functional elements of the IAS EM were constructed.

5. 2. Development of models of recognition and determination of criticality of environmental situations

The basis for structuring operational information is the analysis and classification of situations (quality estimates of the process state, based on the analysis of environmental parameters). The expert analysis revealed a number of situations, including a regular situation, when, for example, the state of the atmosphere is satisfactory, as well as abnormal situations, each of which is characterized by the excess of the threshold concentration values of one or more pollutants. Complicating factors related to weather conditions were also taken into account. For each situation, the features that directly or indirectly affect its occurrence were selected. Each feature, identified at the stage of qualitative analysis, was considered by experts using the paired comparison method for its significance in situation recognition. Dictionaries of situations and situation features were generated. For recognition of each situation, verbal rules were formed. The example of the rule: IF <carbon oxide concentration =>"elevated"AND>area of elevated carbon oxide concentration="5">THEN>Issue a warning to the enterprise management "XXX">.

Since the analytical system should use not only numerically, but also verbal estimates, the fuzzy classification model, which has proven itself well in solving recognition problems, was chosen.

To develop a fuzzy model of situation recognition, membership functions for linguistic variables – situation features, as well as the knowledge base – were constructed. In the process of clustering, it was found that the densities of different clusters of the same feature are different. In other words, there is a different information content of the features of each rule. Given that the basic subsets (clusters) are already formed by experts, the weight coefficients w^{ji} for each elementary premise in each rule are introduced in the recognition model. The values of the coefficients are limited by the range of [0.5–1]. In this case, the unit value is equivalent to one hundred percent significance of the premise. If the number of situation features is n, and the number of situations is m, then, taking into account the coefficients w^{ji}, the fuzzy knowledge base in general can be represented in the form of Table 1.

The element A_i^{jp} located at the intersection of the ith column and the j_pth row corresponds to the linguistic estimate of the parameter x_i in the row of the knowledge matrix with the number j_p. The linguistic estimate is chosen from the term sets corresponding to the variable x_i describing the state of the process, i. e. $A_i^{jp} \in T_i,\ i = \overline{1,n},\ j = \overline{1,m},\ p = \overline{1,k_j}$. Then the refined fuzzy model of situation recognition is as follows:

$$\left[\bigcap_{i=1}^{n} \left(x_i^l = a_{i\max}^{jp} \right) \right] \longrightarrow y = d_j^l, \tag{6}$$

where d_j is the diagnostic conclusion on the current situation.

Thus, the fuzzy model of situation recognition (6), which allows correcting and replenishing the knowledge base and generating messages and recommendations (management decisions) for correction of environmental situations is constructed.

The development of the algorithm of situation criticality recognition was preceded by the following steps:

1. Determination of the main list of substances, the concentration of which should first be controlled. The concentration of these substances is attributed to the main situation features on the set $X = \{x_1, x_2, \ldots, x_n\}$. Namely, for example: x_1 –carbon(II) oxide (CO); x_2 – nitrogen(II) oxide (NO); x_3 – nitrogen(IV) oxide (NO_2); x_4 – sulfur(IV) oxide (SO_2); x_5 – hydrogen sulfide; x_6 – formaldehyde; x_7 – methane; x_8 – methyl mercaptan; x_9 – ammonia; x_{10} – total of hydrocarbons; x_{11} – phenol; x_{12} – dust.

2. Measured values of pollutant concentrations are normalized to the range of [0,1] relative to the established standards of MPC and MPL.

3. Determination of codes of combinations of the concentrations of pollutant groups. These combinations are also situation features, namely, for example: x_{13} – group 6003; x_{14} – group 6004; x_{15} – group 6005; x_{16} – group 6006; x_{17} – group 6007; x_{18} – group 6010; x_{19} – group 6035; x_{20} – group 6038; x_{21} – group 6040; x_{22} –group 6043; x_{23} –group 6204.

Table 1

Structure of the fuzzy knowledge base for situation diagnostics

No.	Input variables and coefficients of individual setting of elementary premises								Output variable
	x_1		x_2		$\ldots x_i \ldots$		x_n		D
1_1	A_1^{11}	w_1^{11}	A_2^{11}	w_2^{11}	A_i^{11}	w_i^{11}	A_n^{11}	w_n^{11}	d_1
1_2	A_1^{12}	w_1^{12}	A_2^{12}	w_2^{12}	A_i^{12}	w_i^{12}	A_n^{12}	w_n^{12}	
…	…		…		…		…		
1_{k1}	$A_1^{1k_1}$	$w_1^{1k_1}$	$A_2^{1k_1}$	$w_2^{1k_1}$	$A_i^{1k_1}$	$w_i^{1k_1}$	$A_n^{1k_1}$	$w_n^{1k_1}$	
…	…		…		…		…		…
j_1	A_1^{j1}	w_1^{j1}	A_2^{j1}	w_2^{j1}	A_i^{j1}	w_i^{j1}	A_n^{j1}	w_n^{j1}	d_j
j_2	A_1^{j2}	w_1^{j2}	A_2^{j2}	w_2^{j2}	A_i^{j2}	w_i^{j2}	A_n^{j2}	w_n^{j2}	
…	…		…		…		…		
j_{kp}	$A_1^{jk_p}$	$w_1^{jk_p}$	$A_2^{jk_p}$	$w_2^{jk_p}$	$A_i^{jk_p}$	$w_i^{jk_p}$	$A_n^{jk_p}$	$w_n^{jk_p}$	
…	…		…		…		…		…
m_1	A_1^{m1}	w_1^{m1}	A_2^{m1}	w_2^{m1}	A_i^{m1}	w_i^{m1}	A_n^{m1}	w_n^{m1}	d_m
m_2	A_1^{m2}	w_1^{m2}	A_2^{m2}	w_2^{m2}	A_i^{m2}	w_i^{m2}	A_n^{m2}	w_n^{m2}	
…	…		…		…		…		
m_{km}	$A_1^{mk_m}$	$w_1^{mk_m}$	$A_2^{mk_m}$	$w_2^{mk_m}$	$A_i^{mk_m}$	$w_i^{mk_m}$	$A_n^{mk_m}$	$w_n^{mk_m}$	

To determine the total concentrations of these groups normalized relative to the MPC, it is necessary to perform preliminary calculations by the formula:

$$C_S = \sum_{l=1}^{L} C_N^l, \quad l = 1..L, \tag{7}$$

where L is the amount of substances in the group, C_N^l is the normalized value of the current measured concentration of the lth substance.

4. Determination of an additional factor (feature) – x_{24}, which affects the integrated assessment of atmospheric air pollution. For example, the conditions for the dispersion of substances in the atmosphere – the presence of stable inversion under a cyclone or an anticyclone according to the weather report, as well as the values of critical wind speeds and directions.

5. Experimental determination of fuzzy ranges characterizing normal, precritical and critical concentrations. Accordingly, these ranges are designated by the terms: T1="Norm", T2="Precritical", T3="Critical".

6. To reduce the size of the knowledge base tables, the latter were divided into two parts. The first contains fuzzy estimates of the normalized values of the parameters x_1… x_{12} as antecedents, the second – fuzzy estimates of the normalized values of the parameters x_{13}…x_{23}. Both tables also contain the feature x_{24}.

On this basis, the rules that allow recognizing the class of the situation and issuing relevant messages and recommendations are developed.

The situation (current level of atmospheric air pollution) recognition algorithm is given below:

Step 1. Obtaining initial parameter values from field devices.

Step 2. Calculation and recording of situation features from the set X in the arrays of the normalized values.

Step 3. Calculation of the current values of membership degrees for the terms T1, T2, T3 by all features of the set X and recording of fuzzification results in the inference matrices.

Step 4. Calculation of the truth degrees of the left-hand sides of the rules in the inference matrices for situation recognition taking into account the weight coefficients of each elementary premise of each rule.

Step 5. Accumulation of the results obtained in step 4 in each table of the KB. Accumulation of partial results obtained for each table of the KB. Definition of the rule, having the highest truth degree.

Step 6. Generation of the message for the operator indicating the current situation, criticality and practical recommendations.

End.

We describe the procedures for the knowledge base correction.

The knowledge base should be corrected or replenished in two cases:

1. Upon detection of a critical situation, which is not taken into account in the knowledge base (KB replenishment).

2. Upon detection of the known critical situation, the values of the features of which differ from the values of the features available in the KB.

KB replenishment occurs as follows. During the daily (or operational) monitoring cycle, data on all controlled parameters are stored in a separate database table and, after the end of the cycle, monitoring data are archived. During the next daily cycle, the archive of the previous cycle is processed. Herewith:

1. Vectors of the values of the parameters preceding an adverse situation are identified.

2. The recognized situation gets a name, and a new rule containing new fuzzy values of the features is recorded manually in the KB table.

For the second case, the following algorithm is developed:

Step 1. Recording a new set of linguistic values and truth values of the features in the known critical situation. For each input variable x_i^k, the term a_i^p for which the membership function $\mu^{a_i^p}(x_i^l)$ has the maximum value $\mu^{a_{i\max}^p}(x_i^l)$ is searched. For the output variable, the term d_j^l, which corresponds to the recognized situation is recorded.

Step 2. On the basis of the model (6), a rule is formed that binds the linguistic values $a_{i\max}^1, a_{i\max}^2, \ldots, a_{i\max}^{l_i}$ of the input variables with the linguistic value of the output variable d_j^l.

Step 3. For the antecedent of the rule obtained, the truth degree is calculated:

$$R^l = \prod_i \mu^{a_{i\max}^p}(x_i^l). \tag{8}$$

Step 4. If the antecedent with the number t_j with the same values $a_{i\max}^1, a_{i\max}^2, \ldots, a_{i\max}^{l_i}$ and d_j^l, already exists in the accumulated knowledge base and the condition $R^l > R^t$ holds, then the coefficients $w_i^{jk_t}$ of the premises of this rule are corrected:

$$w_i^{jk_t} = \begin{Bmatrix} w_i^{jk_t} + k\left(1 - w_i^{jk_t}\right), \text{ if } w_i^{jk_t} < 1 \\ 1, \text{ otherwise} \end{Bmatrix}, \tag{9}$$

where $0 < k \leq 0.5$.

Otherwise, if the antecedent number t_j with the values $a_{i\max}^1, a_{i\max}^2, ..., a_{i\max}^{l_i}$ for the situation recognition rule S_j does not exist, it is added in the corresponding rule with the sign of disjunction. End.

The algorithm of automated knowledge base correction allows adapting the DSS to various situations and extends the scope of its application. Correction of the weight factors of elementary premises is carried out when preparing the knowledge base for use in the DSS or by obtaining a new subsample of examples. Each example contains the pair "input-output" <*X**, *d**>, that is, the vector of the values of situation features and the number of the known situation as a template. The selection of values of weight coefficients is carried out using an evolutionary algorithm that generates a population of decisions, implements mutation, selection and refinement of the coordinates of leading decisions. Learning takes place as a new subsample of examples is accumulated during the operation of the system.

In the case of introduction of the above-mentioned components of the IAS at the municipal level, the basis for the integrated monitoring system will be formed, which will ensure its efficiency. The branching of direct interrelations of the subsystems in the complex should ensure the unity of the monitoring system for rational implementation of the tasks set, which is essential for the development of the information monitoring technology. The general scheme and description of the information technology of monitoring and support of operational decisions on environmental safety management in the processes of recognition and correction of environmental situations are presented in [13].

5. 3. Practical implementation of the operational decision support system

Practical application of the experimental model of recognition and diagnostics of environmentally hazardous situations is implemented on the example of the technogenically loaded urban system of the city of Kremenchuk (Ukraine). Within the framework of production environmental monitoring at the enterprises of Kremenchuk, the content control of the following toxic pollutants in emissions is carried out: solids, carbon(II)oxide, nitrogen(IV) oxide, sulfur(IV)oxide, hydrocarbons (total), light organic compounds (total), as well as methane (in the framework of monitoring of greenhouse gas emissions). The emissions of the main greenhouse gas, carbon(IV)oxide, are estimated by calculation. The somewhat broader list of pollutants in the atmosphere are monitored in the framework of environmental monitoring: solid sedimented particles not differentiated by composition, soot, carbon(II)oxide, nitrogen(IV) oxide and nitrogen(II)oxide, sulfur(IV)oxide, heavy metals, hydrocarbons (total), volatile organic compounds (total), hydrogen fluoride, phenol, benzene, toluene, total of xylenes, benzo(a)pyrene. The above-mentioned pollutants are considered as a priority for environmental and sanitary-hygienic control, taking into account the danger to the environment and human health.

Based on the above, a dictionary of factors – situation features is formed. It includes the actual values of surface concentrations of substances: carbon(II)oxide (CO), nitrogen(II)oxide (NO), nitrogen(IV)oxide (NO_2), sulfur(IV) oxide (SO_2), hydrogen sulfide, formaldehyde, methane, methyl mercaptan, ammonia, hydrocarbons, phenol, dust (solid sedimented particles not differentiated by composition), as well as the level of background ionizing radiation, wind direction and the number of residents' complaints by areas [14].

According to the above detailed algorithm for building the knowledge base, the matrix that contains fuzzy rules of situation recognition, the matrix of compatibility of situations and the decision matrix are developed. The volume of the paper does not allow showing the indicated matrices, the structure of which, however, is not original.

In general, based on the results of recognition of actual environmental situations, the knowledge base with 10 diagnostic conclusions was formed.

For setting the fuzzy model of situation recognition, 90 examples were used and another 90 – for testing. On average, 10–15 examples for each of the 10 situations were used.

The task of setting the model with the main purpose of verifying the self-learning ability of the DSS was implemented in software in the console version. Fig. 1 shows the share of recognized situations before learning (the values of all weight coefficients are 1) and after learning. After learning (yellow columns), the model recognizes the situation much better. The risk of errors of the first and second kind in all situations was considered the same.

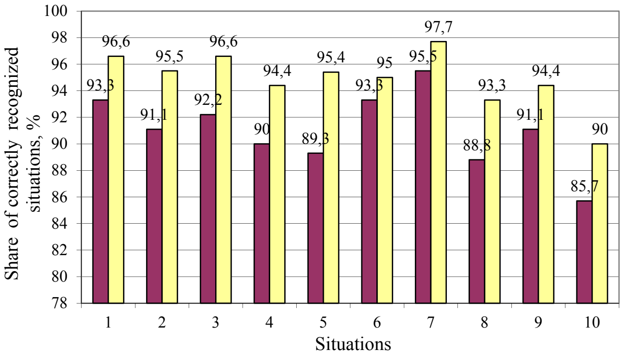

Fig. 1. Share of recognized situations before and after model learning

Thus, it is found that after learning the number of correct diagnostic conclusions increases from 1.7 to 6.1 % in the range of the test sample (10 situations), which confirms the self-learning ability of the system. This will ultimately allow limiting the involvement of real individuals as experts in the assessment and diagnostics of environmental situations by automating the process.

6. Discussion of the results of the research on the development of decision support in the IAS EM structure

The developed set of models for the IAS EM allowed, firstly, taking into account the diversity of system functions, composition and interrelations of individual elements at the structural level. Secondly, analytical means of situation recognition were developed using the adaptive fuzzy model, which includes algorithms of fuzzy knowledge base replenishment and system learning.

This allowed further development and testing of the information technology of recognition of environmental situations and development of diagnostic conclusions on the state of the atmospheric air.

The advantage of the proposed architecture is the ability of fast system scaling. This is achieved, firstly, by simply expanding the feature dictionary, the situation dictionary and the knowledge base. Secondly, flexible adjustment of the knowledge base by correction of weight coefficients of elementary premises of the rules can increase the share of correctly recognized situations, which, in turn, increases the efficiency of environmental situation management.

The system minimizes the actions of the DM, who in most cases does not need to think about the situation and make decisions. The results of the research can be implemented during the creation of environmental monitoring systems at the municipal level for specific technogenically loaded urban systems.

The disadvantage of the architecture at this stage is the lack of a mechanism for the automated detection of conflicting rules in the knowledge base. This disadvantage is partially compensated by the possibility of continuous learning of the system based on the existing precedents.

7. Conclusions

1. The theoretical basis for the development of a versatile structure of the IAS EM is formed. The set-theoretical model of the information-analytical system of environmental monitoring of atmospheric air at the municipal level, which includes the subsystems of urban system parameters monitoring, decision support, the information system “parameter database – situation knowledge base” is proposed.

2. The adaptive fuzzy model of situation recognition in the process of environmental monitoring, which consists of the knowledge base containing fuzzy rules of situation recognition and recommendations for decision-making is developed. The algorithms of procedures for the correction and replenishment of the knowledge base are proposed, which extends the system capabilities and scaling ability.

3. The results of the work were applied in the development of the information-analytical system of monitoring and support of decision-making on environmental safety at the level of a specific technogenically loaded urban system. The results of experimental learning of the subsystem of recognition and diagnostics of environmental situations on specific examples are obtained. It is found that after learning the number of correctly recognized situations increases from 1.7 to 6.1 % in the range of the test sample, which confirms the self-improvement ability of the system.

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