Intelligent systems for decision making during operation of technological oil and gas equipment

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Abstract. The problem of intellectualization of decision support during the operation of oil and gas well equipment is considered in the paper. It is proposed to implement an intelligent approach in the form of a multicomponent information system. Combining the subsystems of such an information system requires detailed study to integrate modern methods and algorithms for intelligent data processing. Based on the results of testing the methods on data sets from real operating field objects, data were obtained that testify to the possibility of using the considered approaches and the relatively high efficiency of the artificial neural network method and collective intelligent approach.

1. Introduction
Currently, the operation of technological equipment in the oil and gas industry involves the intensive use of specialized integrated information-driven control systems. In terms of the operation of such technological equipment, information-control systems in the present state are mainly means of collecting, storing and presenting in a visual form information on the parameters of the equipment and some integral characteristics of the process of its operation [1]. Such systems also have analytical modules (subsystems), which, however, for the most parts are implemented by relatively simple algorithms and methods that perform standard statistical data processing procedures. Moreover, the volume of such data obtained at various stages of the operation of technological equipment increases significantly [1-3]. This is due to many factors, including, among others, the "multi-parameterity" of the equipment used, the increasing requirements for information security for the effective implementation of the equipment life cycle processes, the complication and intensification of processes in which the equipment is used.

The most important direction of improving decision support at the present stage is the intellectualization of data processing through the use of effective data mining techniques and building a holistic decision support scheme based on them [4-6]. In this regard, the problem of developing and researching a data processing intellectualization scheme as part of decision support in the operation of technological equipment for oil and gas fields seems urgent.

An analysis of the expected operating conditions of the developed decision support system, as well as a review of existing decisions and developments in this area, made it possible to formulate the most
common functional and non-functional requirements for the developed decision support information system during the operation of technological equipment (DSIS TE). In accordance with the developed requirements, the architectural design of such a system was carried out. A significant part of the work on building the architecture of such a system, which requires the need for numerical experimental studies, is the intellectualization of individual components of such a system, including a subsystem for collecting and preliminary analysis of “field” information and a subsystem for analyzing “historical” data.

2. Collection and preliminary analysis of information
The subsystem for collecting and analyzing “field” information is a set of software modules that collect information about the parameters of the equipment in use and perform the functions of data preprocessing [7, 8]. At the level of this subsystem, DSIS TE assumes the possibility of implementing two options for obtaining “field” information. The first option assumes that, within the framework of this subsystem, interface modules of interaction with typical blocks of hardware and technical equipment for measuring and monitoring are implemented. To do this, DSIS TE implements standard algorithms for working with input-output cards (for example, PCI Express) for data collection.

Given the significant number of options for hardware and technical implementation of monitoring and process control systems during well operation, it is also planned to implement a universal information exchange module. This implementation option requires the creation in the designed system of a special module for initializing data exchange, with the possibility of integration into the production database. It is assumed that the initialization module is used at the initial stage of system configuration and allows you to create in DSIS TE an information exchange structure with standard monitoring and diagnostic tools.

3. Subsystem for the analysis of historical data
The subsystem of historical data analysis is a collection of software modules whose main functionality is the intelligent processing of data on events and situations that took place in the system of operating technological equipment. It is supposed to use a combination of data mining methods for a posteriori analysis of situational casts in databases and building models that can be used in the future to support decision-making in similar situations.

The set of data for analysis accumulated at the implementation site and similar objects (in terms of the functionality and composition of technological equipment) in most modern systems is represented by rather large amounts of data, which makes high demands on the efficiency and intensity of data use. Analysis of research on the topic of big data processing allows us to attribute to data analysis methods that are promising from the point of view of application at this stage such data mining methods as artificial neural networks (ANNs), production rules (PR) and approach based on fuzzy logic (FL) [9-12]. It has been shown that the greatest efficiency in solving some problems is possible due to the combined use of various data analysis technologies or several copies of one of them (the so-called “ensemble approaches” (EnA)) [13, 14]. The results of a study of the effectiveness of the proposed methods on sets of tasks for analyzing data from 5 production facilities at oil fields in the Krasnoyarsk region in Section 6.

4. Decision support subsystem for emergency situations
It is proposed to develop a DSS when performing technological operations in the form of a situational analysis system. As the main goal of the construction and functioning of situational event analysis systems, a significant increase in the level of technological safety and efficiency is considered due to the possibility of processing information about technological parameters and changing the conditions for performing technological operations in a mode close to real time. It is also intended to use methods for automatically adjusting monitoring parameters and models for analyzing technological situations to the current state of a controlled automated technological system. Usually architecture of systems of
situational analysis of events is “data collection agents” - “data warehouse” - “data analysis servers” [15].

The problem of choosing the optimal set of measures to improve the industrial safety of technological systems based on the emergency development tree can be posed as follows. Taking into account a specific technological system, a formal set of actions is introduced that allows one or a given set of technological operations to be implemented. In the general case, a standard set of actions is initially considered, which is formed in one of the following ways:

- Formations in the mode of direct design of the knowledge base.
- Automated mode of forming a knowledge base.

Thus, with respect to each technological situation arising during operation, a set of the following indicators is formed:

- criticality of the situation - characterizes the degree of danger of the situation from the point of view of the formation of negative parametric trends and negative consequences associated, for example, with damage to the elements of technological equipment (residual damage) - RD;
- total costs for the implementation of the technological operation, taking into account the situation in question (System Control Cost) - CC.

Let a set be defined, consisting of n actions, allowing to perform technological operations within the framework of a solvable production task for the operation of technological equipment (System Controls):

{SC_i}, i=1, n

Let’s introduce a vector defining the application of these actions:

$\vec{T}=(T_1, T_2, ..., T_i, ..., T_n)^T, T_i=\begin{cases} 0, & \text{if the action is not carried out} \\ 1, & \text{if the action is carried out} \end{cases}$

Let’s introduce a vector that determines the cost of the implementation of measures:

$\vec{C} = (C_1, C_2, ..., C_i, ..., C_n)^T,$

$C_i$ – action cost SC_i.

It is necessary to solve the problem of multi-criteria optimization:

$$\begin{cases} \text{RD}(\vec{T}) \rightarrow \text{min} \\ \text{SCC}(\vec{T})=\sum_{i=1}^{n}(T_iC_i) \rightarrow \text{min} \end{cases}$$

Given the complexity and multi-criteria nature of the formulation of the decision support task when determining actions to manage technological situations during the operation of technological equipment, a powerful optimization algorithm was implemented in the system that proved its effectiveness in solving many practical optimization problems - the evolutionary genetic algorithm [16]. Genetic algorithms have proven effective in solving many difficult problems of search and optimization, and especially in practical applications where mathematical models have a complex structure and the application of classical methods is impossible or extremely time-consuming. The following units are designed as part of the analytical core of the expert decision support system for the operation of technological equipment:

- Genetic algorithm unit.
- Neural network unit.
- Intelligent information technologies unit.
Ensuring the high efficiency of the algorithmic kernel as a whole is possible with the effective determination of the inter-unit interactions scheme, and the productive use of the technological potential of each algorithmic unit.

5. Neural network approach of formalizing knowledge for decision support systems

In the development of intelligent systems considered in the paper, a common problem lies in the need to formulate reliable methods for supporting decision-making when choosing measures in the conditions of variability of operational situations during the operation of technological equipment. One of the main hazard factors is the variability of situations associated with failures of elements of technological equipment. This requires the construction of such models that could produce more than one solution that is optimal for a particular pattern of the technological situation, but were able to form sets of measures depending on the changing conditions of a particular situation. Accordingly, the static pattern of the choice and application of measures may turn out to be ineffective in the general case when the variability of situations is quite high. One of the possible directions is direct formation in explicit form (by an expert) of a fairly wide range of static patterns for the formation of resolution of critical operational situations. However, this seems to be very difficult for complex technical systems with a large number of elements, and therefore, options for implementing failures and emergency situations. In general, the number of possible solutions to such a problem for large technological systems is not worked out by direct expert methods.

Given that the task is formulated as a multicriteria optimization problem, it seems logical to complete the stage of selecting measures precisely as solving such a problem in some automated way. An important step in solving the optimization problem is the formation of initial data for calculating the objective function. In the framework of the proposed approach, it is assumed that the initial data are generated in accordance with the models described in sections 2-4, using special software.

Since the problem to be solved for complex technical problems is a problem of high dimensionality, its solution cannot be obtained quickly - fast enough to respond in time “close to the real time of the emergency”. Even when using highly efficient methods, in particular, the genetic algorithm described above, which has proved its effectiveness in solving many practical problems of high dimension, the formation of a solution takes from several minutes to several hours. Such a time interval is not acceptable for the selection of countermeasures in operating conditions of a real technological system. Nevertheless, the solution generated by the optimization algorithm is a mathematically justified version of the rational solution of the formulated problem, and, therefore, is a source of information about possible actions for choosing measures to stabilize the emergency situation. Given the multicriteria statement of the problem of choosing countermeasures, its solution will be the set of non-dominated solutions - the Pareto set. The determination of acceptable options by choosing from the Pareto set can be carried out expertly, taking into account the maximum permissible residual risk or not exceeding the limitations on the cost of measures taken. It is also important that the optimization problem is solved under conditions of static probabilities of occurrence of defects. Therefore, such a solution is not an option for the formation of solutions in the dynamic mode, characterized by the variability of these probabilities.

Given such limitations of the optimization procedure to approximate the operability of the approach to the mode “comparable with the actual development of the emergency”, it is proposed to further develop an approach that allows “approximating” the solution of the indicated optimization problem for choosing actions in an emergency using classifiers built on the basis of artificial neural networks.

6. Experimental study

As part of an experimental study, methods for processing accumulated arrays of historical data were evaluated. The data obtained and formulated in the statement of the problem of classifying situations that arise when putting wells into operation. In the article, the data are presented in anonymized form,
as they are of commercial interest in full form. The results of a numerical study of the effectiveness of methods are presented in Table 1.

**Table 1. Average classification error obtained for approaches.**

| Approach              | Technological System 1 | Technological System 2 | Technological System 3 | Technological System 4 | Technological System 5 |
|-----------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
| Artificial neural networks | 6.6                    | 2.7                    | 2.2                    | 5.8                    | 1.0                    |
| Production rules      | 6.8                    | 2.9                    | 1.7                    | 6.7                    | 1.0                    |
| Fuzzy logic           | 8.3                    | 3.1                    | 1.9                    | 5.9                    | 1.2                    |
| Ensemble approach     | 4.6                    | 2.1                    | 1.5                    | 5.1                    | 0.8                    |

For each data set used in testing, in view of the presence of a random component, the construction of classifiers was performed 20 times with re-partitioning of the samples into training and test ones. Next, we performed a statistical evaluation of the results and their stability (ANOVA method) with a confidence probability of $p = 0.95$. According to the results of the studies, the most effective on the set of tasks considered were the method of artificial neural networks and a collective approach that combines several instances of classification models.

### 7. Conclusion

The paper considers the problem of intellectualization of decision support during the operation of oil and gas well equipment. It is proposed to implement an intelligent approach in the form of a multi-component information system (DSIS TE). Design of DSIS TE subsystems requires detailed study to integrate modern methods and algorithms for intelligent data processing. The functionality and main directions of development were determined when creating two DSIS TE subsystems - a subsystem for collecting and preliminary analysis of information and a subsystem for analyzing “historical” data. Within the framework of the last subsystem, data mining methods were implemented in the software. Based on the results of testing the methods on data sets from real operating field objects, data were obtained that testify to the possibility of using the considered approaches and the relatively high efficiency of the artificial neural network method and collective intelligent approach. Based on the results obtained, a detailed study of other DSIS TE subsystems is expected.

The problems of developing effective solutions in the field of decision support in the management of situations during the operation of technological equipment are also considered in the paper. Such a system is designed to automate and increase safety during the operation of technological equipment of oil and gas production and can significantly increase the efficiency of technological operations, for example, during work related to putting wells into operation. The formulation and formalization of the decision support task during the operation of technological equipment is considered. The criteria for choosing an action for technological situations are determined, and the corresponding optimization problem is formulated.

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