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USING EXPERT EVALUATION FOR SELECTING AN ARCHITECTURAL SOLUTION FOR A SPECIALIZED SOFTWARE SYSTEM THAT MONITORS THE STATE OF POTENTIALLY HAZARDOUS FACILITIES

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The object of this study is the software and architectural solutions for specialized systems that monitor the state of potentially hazardous facilities (hereinafter, PHF). The problem solved was the choice of a successful option for an architectural solution and the specialized software composition of such systems. A change in the architectural solutions and the composition of the software for monitoring the state of PHF is necessary because such systems are usually designed on the basis of the principle of parametric control over the main parameters of PHF. Such monitoring systems record the achievement of the pre-critical (or critical) value of one (or several) parameters characterizing the state of the object. Therefore, operational personnel have little time to implement measures to prevent accidents.

The essence of the results is that, based on the use of expert evaluation, a methodology was devised for quantitative assessment of the architecture, the composition of specialized software and methods for monitoring the state of PHF. According to this methodology, one of the three possible alternative options for building an automated system for monitoring the state of PHF was chosen.

It was possible to solve the task to choose the architecture, methods, and composition of the software for a PHF state monitoring system owing to the implementation of expert evaluation, which enabled a shift from qualitative to quantitative evaluation. The chosen option for building a system for monitoring the state of PHF is resistant to interference and allows for the detection of the threat of an emergency at the facility 1–3 hours earlier through the implementation of subsystems for forecasting changes in the state of PHF and diagnosing the state of the object. This ensures damage reduction and prevents injury to people

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1. Introduction

The war in Ukraine led to an unprecedented increase in the number of man-made accidents, disasters, and emergencies. This necessitated the rapid development of systems for monitoring the state of potentially hazardous facilities. Currently, Ukraine does not have a system for monitoring the condition of potentially hazardous facilities at the state level. Such systems exist only fragmentarily in certain regions. Systems for monitoring the state of potentially hazardous facilities allow for early detection of the possibility of emergencies and to organize the management of the object in accordance with the challenges.

The biggest losses occur as a result of accidents and emergencies at hydraulic structures. Hydraulic structures are large-scale, potentially hazardous facilities that need to be equipped with sophisticated monitoring systems.

Usually, modern monitoring systems are built on the basis of the Internet of Things (IoT). In turn, the rapid development of high-speed Internet and IoT calls for a large number of error-free information transmission channels [1]. To this end, one of the methods of interference-resistant coding for IoT networks of monitoring systems can be used, as well as algorithms and software for implementing this method.

There are standard solutions for building automated systems for early detection of the possibility of emergencies, as well as new architectural solutions for building systems that monitor the state of potentially hazardous facilities (PHF).

On the basis of these solutions, it is possible to implement a system for monitoring the state of the object with the possibility of forecasting changes in the state of the object. In addition, it is possible, based on the use of the method of organizing iterative calculations using the grid method for calculating filtration through earthen structures, as well as the corresponding algorithms and software, to organize diagnostic modeling of the monitoring object.

The question arises as to which of the architectural solution and software options could make it possible to obtain the best result when designing an automated system for monitoring the condition at regional level objects.

Choosing one method from a large number of alternative methods is a difficult task. It makes sense to evaluate the effectiveness of various project solutions adopted for monitoring systems for the condition of potentially dangerous PHF. In general, decision-making is the choice of a successful version of a project solution from a set of possible alternative project solutions. It is also advisable to conduct a joint study of the problem of resource allocation and the problem of choosing project options in a joint statement of the problem of resource allocation and option selection. Undoubtedly, to solve problems of the specified class and to make decisions, one should rely on the experience, knowledge, and intuition of experts. It can be solved using qualitative methods.

Therefore, investigating the method for decision-making regarding the choice of an architectural solution and the composition of the specialized software for the designed automated systems that monitor the state of PHF is a relevant task.

2. Literature review and problem statement

The basic principles of building systems for monitoring the state of objects, which certainly include automated systems for early detection of the possibility of an emergency and public notification (ASEDEPN), are outlined in DBN V.2.5-76:2014. These building regulations establish requirements for the design and installation of ASEDEPN. Facilities, buildings, and structures with the risk of an emergency at the national, regional, or local levels are subject to mandatory equipment with such systems. The main purpose of creating such automated monitoring systems is to obtain information from sensors located at the facility about the achievement of pre-critical values of controlled parameters of sources of man-made or natural danger. As well as preventing the controlled parameters from reaching critical values by performing certain actions. Therefore, it is stipulated that the monitoring system should form and provide information about the achievement of pre-critical or critical values of controlled parameters of sources of man-made or natural danger to the personnel working at the facility.

DBN V.2.5-76:2014 also includes the features of a threat or the emergence of an emergency, namely:

– the value of one or more interrelated parameters of sources of man-made and (or) natural danger, which have reached subcritical and (or) critical values, which leads to a violation of the normal functioning (state) of the product, device, object;

– on this basis, this situation is qualified by the system operator as threatening the life and health of people and (or) causing significant material damage.

DBN V.2.5-76:2014 formulates the following basic requirements for the functions of ASEDEPN:

1. In the event of detection of a threat or occurrence of an emergency, the system must:

– automatically inform the responsible persons about the identified threat, who are entrusted with the implementation of certain actions to prevent the occurrence of an emergency (E) or to minimize the negative consequences in the event of its occurrence;

– by the command of the system operator, notify and transmit to the centralized fire and man-made surveillance system (CFTSS) relevant alarm signals together with the identifier of the predicted emergency development scenario formalized in electronic accident cards. And in the absence of the operator's response, the worst-case scenario of the development of an emergency will automatically follow.

2. In order to ensure notification of facility employees and the public in the event of an emergency at the regional or state level, ASEDEPN must provide the necessary backup and duplication, be technically connected to the territorial automated system of centralized public notification.

3. The monitoring system at PHF and related systems must be software and hardware compatible with higher-level hierarchical structures and with each other.

4. The monitoring system at PHF must issue appropriate signals to the technical means of the systems and equipment, which are related to ensuring the safety of people at the facility in the event of a threat or occurrence of an emergency.

5. Messages used to notify the population must be transmitted in the state language and in the language used by the majority of the population in the region.

6. If there is a threat to the population living (staying) in the zone of damage (possible damage), in the event of an emergency, a local notification must be made at PHF.

The advantages of DBN V.2.5-76:2014 are a detailed consideration of possible options for building a monitoring system depending on the type of potentially dangerous object whose condition needs to be monitored, as well as a detailed description of the main functions of the monitoring system. But DBN V.2.5-76:2014 has a significant drawback: the system built in accordance with the requirements of this regulatory document will implement only parametric control of values of the main parameters of PHF state. Forecasting in any form, as well as diagnostic modeling of PHF state, will be absent. The reason is the determinism of the architectural solution of the system and the functions of the monitoring system.

An option to overcome the relevant difficulties may be the use of a new architectural solution of the monitoring system, as well as a change in the composition of specialized software. This is the approach used in work [2]. The advantage of the study is that the main shortcomings of typical systems for monitoring the state of PHF are considered, and the use of software for predicting changes in the state of PHF is proposed. A disadvantage is that forecasting based on the use of artificial intelligence is considered. An option to overcome the relevant difficulties can be the use of classical methods of forecasting, for example, the method of least squares.

Work [3] considers the issue of changing the architectural solutions and functions of the designed systems for monitoring the state of PHF. The paper examines the main shortcomings of the existing systems for monitoring the state of PHF, as well as ways to overcome them.

It should also be noted that with the creation of wireless systems for monitoring the state of PHF on the basis of IoT technologies, the issues of ensuring the organization of error-free channels of information transmission remain unresolved.

The reason for this may be objective difficulties associated with the implementation of methods for detecting and correcting multiple errors in the transmission of information. The possibility of organizing error-free transmission of information in the presence of noise was proved in [4]. The advantage of the study is the proposed solution, which involves the use of codes that allow detecting and correcting errors in the transmission of information. The study proved the existence of such codes. But the main drawback of the work is that there is no explanation of how to build these codes.

An option to overcome the relevant difficulties can be the use of Hamming codes, which detect and correct errors in the transmission of information. This is the approach used in work [5]. These codes have become widely used.

The main advantages of Hamming codes are the following:

– codes provide detection of double errors and detection and correction of single errors;

– detect and correct errors well with a low probability of group errors.

However, redundancy can be considered a significant drawback of the proposed codes. The issue of correcting multiple errors also remained unresolved. An option to overcome the relevant difficulties can be the use of an algorithm for reducing the number of redundant bits when building an extended error detection and correction code. This is the approach used in study [6]. The given research results show that it was made possible by using the original polynomial generator.

It is shown that a characteristic feature of the improved code is the reduction of the overheads arising from the alternation of redundant bits in the typical Hamming code and the length of the redundant bits that exist in the cyclic redundancy check. The proposed code minimizes the payload bit overhead compared to the Hamming code, while reducing the resource usage of the designed memory architecture. But the issues related to the complex implementation of the proposed method and the redundancy of the code remained unresolved.

Therefore, the results of study [7] are interesting, also tackling the development of an improved reliable method for detecting errors and correcting errors of information transmission based on a code with minimal redundant bits and maximum coding speed.

The advantage of the developed semi-diagonal code is greater efficiency compared to existing matrix codes. The use of a half-diagonal code reduces bit costs by at least 5.5 % and increases the encoding speed by at least 16.74 %. A disadvantage of the proposed code is a cumbersome algorithm.

Another study on the development of an improved reliable method of error detection and correction of information transmission errors is reported in [8].

Error correction codes (ECCs) have been proposed to solve this problem. The proposed encoding, based on a modified Hamming code, ensures that only the correct values are transmitted to the system output. In this case, the data is processed despite the presence of up to three bit errors. The advantage of the proposed coding method is a high level of error correction, performance, high speed, and low complexity.

An interesting approach from the point of view of building systems for monitoring the state of PHF was used in [9]. The study noted that using ECC causes encoding and decoding delays, but in some applications, fast encoding and decoding is more important than redundancy. The paper summarizes previous work on ultrafast codes and proposes new codes that combine double error detection and adjacent error correction. It also explores proposed synthetic high-speed codes that reduce encoding and decoding latency. Disadvantages of synthesized codes are traditional: redundancy and delays in encoding and decoding.

However, the problem of detecting and correcting multiple errors in information transmission has not been finally solved. All this gives reason to claim that it was appropriate to conduct a study [10] in which a method for detecting and correcting multiple errors based on the original coding scheme is proposed. The method made it possible to significantly increase the interference resistance of the information transmission channel, which was confirmed by testing the software model implemented in the Python language. The proposed method for detecting and correcting multiple errors can be used for various data transmission channels and does not depend on the bit rate. Therefore, it makes sense to apply the proposed method for detecting and correcting data transmission errors in distributed IoT systems, given their large linear dimensions and high level of electromagnetic interference of the electromagnetic field.

But the issues related to the early detection of the possibility of an emergency at the monitoring facility and, accordingly, the composition of the specialized software of the monitoring system remained unresolved. And, if it is possible to use classical forecasting methods such as the least squares method or the adaptive method to predict the change in the state of the parameters of the monitoring object, then the organization of diagnostic modeling requires separate consideration.

Pressure soil hydraulic structures are the most common type of PHF in the world. The emergence of a state of emergency at such PHF leads to large-scale consequences. Therefore, modeling methods for this type of PHF will be considered next.

A method for modeling hydrodynamic phenomena in rivers and reservoirs based on hydrodynamic simulation using the Navier-Stokes equations may be an option for overcoming the relevant difficulties.

This approach is considered in study [11]. The advantage of the method is high efficiency in the reproduction of complex hydrodynamic processes, such as turbulent flows, interaction of currents, and the formation of hydrological regimes. But this method can be used as an aid in the diagnostic modeling of pressure earthworks.

Paper [12] considered the method of mathematical modeling, such as the methods of numerical solution of the Navier-Stokes equations in order to predict the possibility of emergencies on watercraft. The advantage of the method is that it makes it possible to analyze and predict the movement of water, the distribution of pressure at different points of the system, which helps in the management and prevention of possible negative consequences, such as the destruction of hydraulic structures. The disadvantage of the method is the rather difficult formalization of the description of a specific object.

The methods considered in study [13] included the grid method, approximation methods, and numerical algorithms. The purpose of the study is to improve the accuracy of existing methods for numerical modeling of two-dimensional stationary filtration flows using the grid method. As a result of the study, it was established that the proposed method of organizing the iterative computing process turned out to be effective and useful. The advantage of the study is the detailing of the algorithm and software, sufficient for practical use. The disadvantage is the lack of a description of the data entry process for calculations.

Aspects of building a subsystem for monitoring technological processes of management and diagnostics of a modular cyber-physical system based on the IoT concept are considered in paper [14]. The proposed solution is effective but has a narrow scope of application as it is focused on monitoring electric motors taking into account the specificity of the equipment. Therefore, the issues of ensuring the application of monitoring approaches for a wide class of objects as part of PHF monitoring system remained unresolved. An option to overcome the relevant difficulties may be the use of unified software that integrates with various sensors of PHF monitoring systems.

Analysis of alternative architectures in the development of a system for monitoring the state of PHF is often performed under conditions of incomplete data and indirect estimates of the parameters of PHF functioning. Also, the task of ranking the architectures of PHF monitoring systems is characterized by a large dimensionally. Under such conditions, it is advisable to use the methods reported in paper [15], in which the problem of determining the group ranking of alternatives based on incomplete expert rankings is formalized. But the complexity and universality of the methods proposed in the work do not allow their application to PHF monitoring systems, therefore, a simplification of the approach in terms of using the method of analysis of hierarchies is needed.

To make a choice, it is also possible to use the ideas presented in [16]. That is, to carry out an expert evaluation of the choice of one of several possible options for building a system for monitoring the state of PHF. At the same time, each version of the system structure has its own architectural solution and its own composition of software that implements certain functions.

After the analysis of the existing methods for designing PHF monitoring systems, it is considered necessary to develop and implement as part of the monitoring system software modules that implement the following functions:

– detection and correction of multiple errors in information transmission;

– forecasting changes in the state of the object;

– diagnostic modeling of the state of the object;

For example, the function of predicting changes in the state of object parameters, the function of diagnostic modeling of the state of the object, and others.

3. The aim and objectives of the study

The purpose of our study is to improve the technology for developing specialized software as part of information systems for monitoring the state of PHF. This will make it possible to move from parametric control over the facility's main indicators (normal/pre-critical/critical condition) to early detection of the threat of an emergency during the operation of the designed state monitoring systems.

To achieve this goal, the following tasks were set:

– to select the quality criteria for the designed system that monitors the state of PHF;

– to check the consistency of the opinions in the formed group of experts-specialists;

– to calculate the weighting coefficients of the quality criteria of the project solutions for the system of monitoring the state of PHF;

– to determine the best version of the architectural solution and the composition of the specialized software for the monitoring system based on the results of a survey of experts.

4. The study materials and methods

The object of our study is the software and architectural solutions for specialized systems that monitor the state of potentially dangerous man-made facilities.

The main hypothesis of the study assumes that the achievement of the research goal is possible through the use of expert evaluation to choose the best option for building a system that monitors the condition of the object by implementing:

– new architectural solutions based on IoT technologies;

– methods for detecting and correcting multiple data transmission errors;

– methods for forecasting changes in the state of the monitored object;

– software for diagnostic modeling of the state of the monitored object.

The following assumptions were accepted:

1. The assumption that there is a scheme and method for encoding information based on Hamming codes, using which it is possible to detect and correct multiple errors in the transmission of a specific byte during byte-by-byte transmission of an information block.

2. When transmitting an information block, its length remains unchanged, and the problem of determining the first byte of an information block is solved at the protocol level.

3. The change in the values of the parameters that characterize the state of the monitored object can be predicted owing to mathematical methods.

4. Periodic performance of diagnostic modeling of the state of the monitored object can early detect the development of destructive processes at the man-made facilities.

Also, for the sake of simplification, only the transmission of information is considered under conditions where only transmission errors of different multiplicity occur during the transmission of a single byte. Without taking into account the interruption of transmission under the influence of interference, etc.

The process of choosing a specific option of an information system, including a system for monitoring the condition of an object, is generally characterized by a large number of criteria that, as a rule, conflict with each other (for example, the complexity of implementation – quality). Therefore, the choice of a specific option for the construction of any information system is a complex optimization problem, the solution of which largely depends on the people making the choice.

The answer to how this choice was made is given by qualimetry – the science of methods of quantitative assessment of the qualities of various objects. Quantitative assessments of the quality of objects are used to substantiate management solutions.

In this study, one of the well-known methods of qualitative assessment was used – the method of expert evaluations. This method is based on the assessment of the object's quality by a group of experts. The specified method of assessing the level of quality (for example, the quality of an information system) is usually used when it is impossible to use methods of objective measurement of the values of indicators of product properties.

Qualimetry tools make it quite easy to build mathematical models for assessing the quality of specific technical solutions that relate to objects of various purposes. Including the case when the object of assessment is an automated system for monitoring the state of PHF.

This study considered the issue of optimization when choosing different options for both an architectural solution and different options for algorithmic and software support when designing automated systems for monitoring the state of PHF.

Our study examines existing solutions and procedures used in the design of systems for monitoring the state of PHF:

– introduction of new architectural solutions;

– method of interference-resistant coding for IoT networks of monitoring systems, algorithms, and software for implementing this method;

– software for predicting changes in the state of the object;

– software for diagnostic modeling of the state of the monitored object.

In general, decision-making is the selection of the most preferred project solution option from a set of possible alternative project solutions. The task of choosing such an option is a difficult task that designers had to solve. Therefore, a joint study of the task of resource allocation and the problem of choosing project options was conducted when setting the problem of resource allocation and option selection. It is obvious that the experience, knowledge, and intuition of specialists – experts and the results of a collective examination were taken into account to solve the problems of the specified class and make a decision.

Conducting a collective examination was conditioned by the fact that it has the following characteristic features:

1. A more complete picture of the situation. Combining and comparing expert opinions make it possible to get a more complete picture of the object of examination.

2. Comparison of different points of view helps identify alternative options, the use of which is impractical.

3. The proper solutions can be offered by experts who are deeply knowledgeable in a narrow professional field. The opinion of such specialists may differ significantly from the opinion of the majority.

4. Obtaining objective assessments. The opinions of individual experts are often subjective. Therefore, a discussion of expert conclusions (which is provided by a number of expert procedures) was held to increase their objectivity.

5. Expert opinions obtained as a result of collective examinations, in many cases, turn out to be more balanced, stable when additional information is received, substantiated and reliable.

When conducting the examination, the properties of collective solutions were taken into account, which must be considered during the processing of expert information and the development of expert conclusions regarding the determination of the best version of the project solution of the information system. Namely:

1. Independence. The resulting collective expert assessment does not depend on the addition of new or the exclusion of part of the old considered options.

2. Impartiality. In the resulting collective assessment, in principle, all possible combinations of comparative preference of decision options can be implemented.

3. Monotony. If any of the experts changed their opinion in the direction of the collective, the resulting collective assessment will not change.

4. Freedom. It is always possible to choose such estimates of the comparative advantage of alternative options that in one case one alternative option will be better than the other, and in another case – vice versa.

5. Absence of dictation. There should not be a comparative evaluation of alternative options provided by one of the experts, which would be accepted as conclusive, regardless of the comparative evaluations given by other experts.

In the literature, these properties, formulated strictly mathematically, are termed Arrow conditions. But there is an Arrow's paradox: practice shows that simultaneous fulfillment of all conditions for the resulting collective assessment is impossible.

The main problem in assessing the comprehensive indicator of the quality of the system for monitoring the state of PHF is that the assessment of individual criteria cannot be carried out quantitatively. That is why the method of expert evaluations was applied, which is based on the subjective opinions of experts and is not accompanied by traditional calculations.

The purpose of using the method based on expert evaluations is to devise a mechanism for evaluating the priority of weighting factors to determine a complex indicator of the quality of technological equipment. To achieve this goal, the following stages of work were defined and implemented:

– determination of a group of specialists who will ensure the examination;

– development and organization of the expert method;

– formation of a group of experts participating in the examination;

– development of questionnaires that are oriented towards quantitative assessment;

– conducting a survey;

– analysis of questionnaires;

– generalization of the results.

The purpose of the expert analysis was to select the best project solution, namely: architectural solution, algorithmic and software for building an automated system for monitoring the state of PHF.

Taking into account the fact that the greatest losses are caused by the destruction of hydraulic structures, among which earthen dams are most often found, an expert analysis of three possible project solutions for monitoring the state of PHF – a soil dam of a reservoir and a hydroelectric power station – was performed.

The initial data for expert analysis were adopted as follows:

The project solution for PHF state monitoring system must meet the following requirements:

1. The architectural solution of the monitoring system should not contradict the requirements of DBN V.2.5-76:2014.

2. The list of controlled signals must correspond to those listed in Table 1.

3. The specific type of detectors must be determined by the project.

4. The system of monitoring the state of PHF should:

– at the command of the operator, to notify and transmit to the emergency and rescue service (ERS) the relevant alarm signals together with the identifier of the predicted scenario of the development of the emergency formalized in the electronic accident cards, and in the event of the operator's lack of response – automatically;

– ensure the necessary backup and duplication of notification transmission;

– ensure notification of facility employees and the public in the event of a regional or state-level emergency (PHF status monitoring system must be technically connected to the territorial automated system of centralized public notification);

– programmatically and hardware compatible with adjacent systems and with higher-level hierarchical structures;

– issue appropriate signals to the technical means of systems and equipment that are not part of PHF state monitoring system, but which are related to ensuring the safety of people at the facility in the event of a threat or occurrence of an emergency;

– automatically control the actions of the system operator regarding the processing of signals and messages received by the operator;

– monitor the performance of the main components of the system, communication channels and the state of the power supply;

– identify signs of the threat of an emergency by means of automation and software of PHF state monitoring system with further informing the system operator and production personnel responsible for the functioning of a potentially dangerous technological section, workshop, warehouse;

– determine the fact of the occurrence of an emergency at PHF, taking into account the assessment of the situation by the system operator based on the information s/he received about the state of the sources of potential danger and objective information received from the production personnel;

– on the basis of the received information, make a forecast of changes in the state of PHF for early detection of the possibility of an emergency;

– perform periodic calculations for diagnostic modeling of PHF state in order to prevent the occurrence of an emergency state.

As prototypes, the following variants of the project solutions of PHF state monitoring system were considered – the soil dam of the reservoir and MHP, listed below.

A brief description of the first version of PHF state monitoring system.

This version of the state monitoring system of PHF (MHP with a pressure soil structure) provides for the construction of the system according to architectural solutions and in accordance with the requirements of the current DBN V.2.5-76:2014 "Automated systems for early detection of the threat of emergencies and public notification". ASEDEPN is intended for:

– automation of monitoring and detection of emergencies and their transition to the state of emergency;

– detection of man-made threats. by collecting, accumulating, processing, displaying, and transmitting through communication channels data on the situation on the territory of PHF;

– informing and alerting the company's personnel and the public using information and telecommunication means;

– calling emergency and rescue units.

The functioning of the state monitoring system of PHF is carried out according to the algorithm for monitoring the threat of an emergency. The result of the system's operation is a conclusion about the need to activate zonal warning systems or directly the general object warning system.

Early detection of the threat of emergencies is carried out by means of automatic control of the parameters of the sources and factors of danger with the registration of the facts of exceeding the limit (pre-critical and critical) values, which indicate the threat of emergency occurrence.

As a basic algorithm, the deviation of the current parameter values from the limit values is used. 10 % deviation from the limit is taken as pre-critical, and 20 % deviation from the limit is considered critical.

The primary (initial) information for the identification of ASEDEPN signs of the threat of an emergency and the determination of possible scenarios of its development are data from sources of primary information (SPI), RS and safety means of industrial automation.

According to DBN V.2.5-76:2014, at a facility such as an MHP with a pressure soil dam, the sources of primary information should be providers of information about the facility's parameters, which are listed in Table 1.

Table 1

List of monitored signals at hydrotechnical structures (including at hydroelectric power plants)

No. of entry	Controlled parameters
1	Deformations of building elements
2	Rotational frequencies of the shaft(s) of the hydraulic unit(s)
3	Subsidence and horizontal displacement of building elements
4	Water levels in the upper and lower bays
5	The appearance and levels of water in the premises of the observation gallery, the turbine room, the premises of the main outputs of the generators
6	The presence of a mode of passage of flood and flood waters
7	Physical and chemical parameters of water

At the same time, when developing the project, it is allowed to replace information transmitters with analog or digital output with manual detectors. In practice, this technique is most often used to control items 1, 3, 4, and 7.

The architectural solution for the system for monitoring the state of PHF corresponds to the one given in DBN V.2.5-76:2014 (Fig. 1).

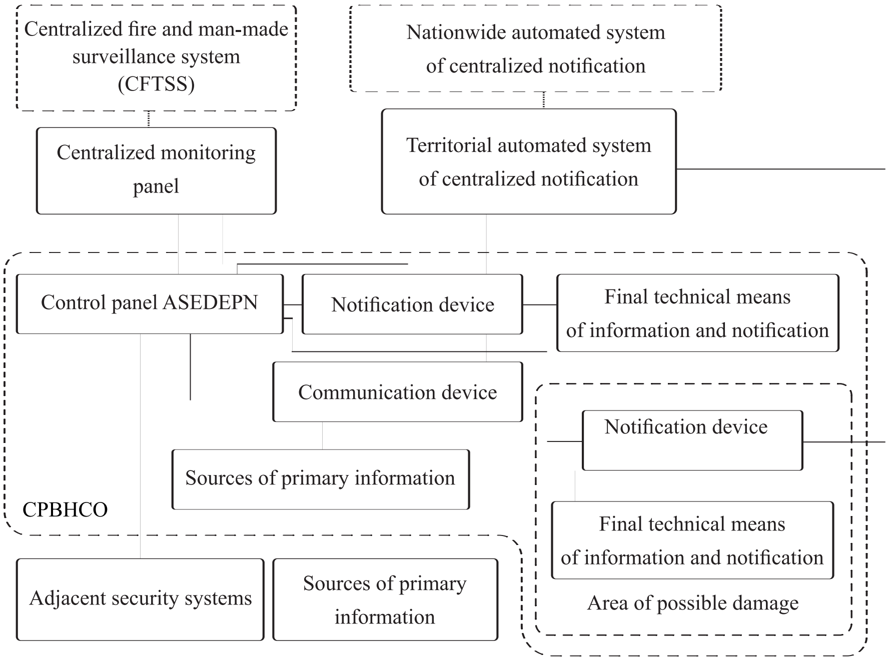

Fig. 1. A standard architectural solution for monitoring the state of potentially hazardous facilities [DBN V.2.5-76:2014]

The use of methods and software tools for information protection, detection, and correction of transmission errors, methods and software for predicting changes in the status of PHF, as well as methods and software for diagnostic modeling is not provided.

A brief description of the second version of PHF state monitoring system.

The second version of PHF state monitoring system differs from the first version in its architectural solution (Fig. 2).

It makes sense to use Edge Computing technology (peripheral computing technology) to implement PHF state monitoring system at the local level. Edge computing increases the performance of cloud computing at the local level. Edge computing and cloud technology complement each other well when used simultaneously.

And to receive information from sensors, it is better to use LoRaWAN technology – a popular and reliable wireless communication technology.

LoRaWAN provides:

– data collection from a large number of devices in a large area;

– extended service life of end devices (up to 10 years);

– ease of deployment, scaling, and maintenance.

LoRaWAN uses wideband LoRa modulation, which provides a transmission range of up to 15 km, high penetration, and signal immunity to interference.

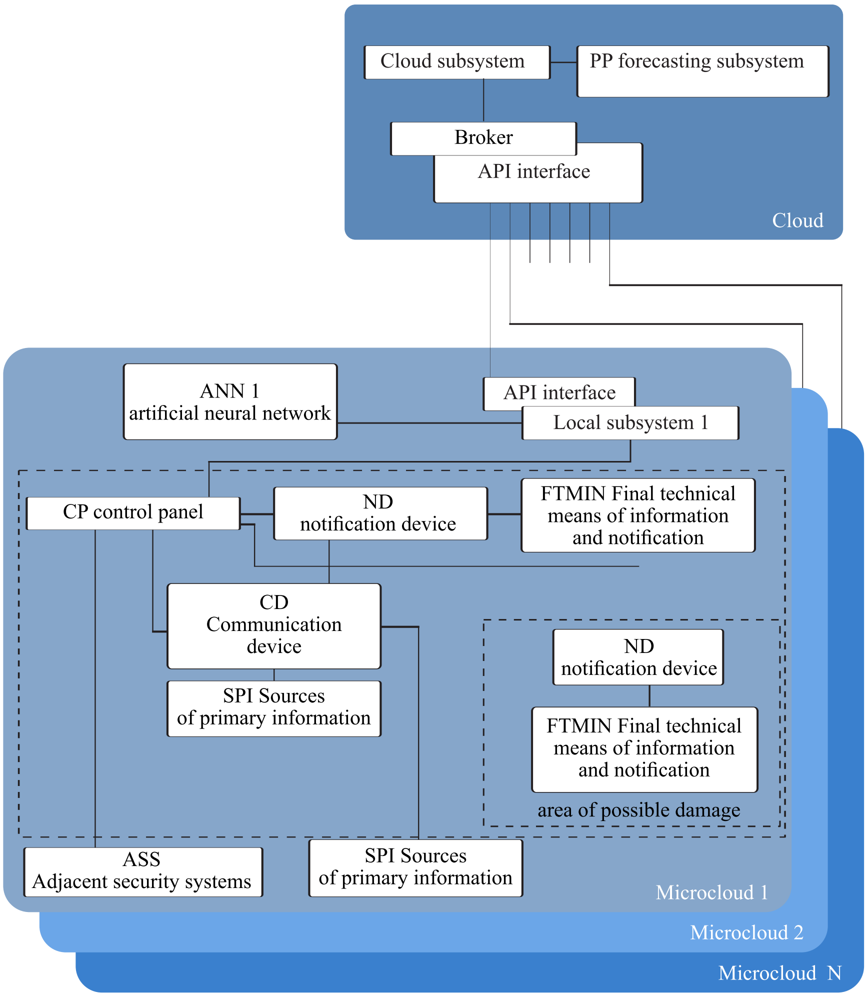

Fig. 2. New architectural solution for a regional system that monitors the state of potentially hazardous facilities [3]

It is better to use Internet of Things technologies (IoT) [4] to build a regional system for monitoring the state of PHF. Fig. 3 shows the diagram of the interaction of local servers and data storage systems in the IoT system based on micro cloud architecture. In the n-th micro cloud, data is received from sensors, processed in the V_n server, and stored in the X_n storage. Monitoring results in a separate micro cloud obtained after processing in the server V_n are sent to the cloud server V_c and to the cloud storage X_c. Cloud servers, processing monitoring information from all micro clouds, provide an opportunity to obtain a global picture on a regional scale about the state of controlled parameters [4].

Unlike the first version of the regional PHF monitoring system, the second version of the system involves the use, first of all, of software that implements the method of detecting and correcting multiple data transmission errors.

Also, during the implementation of the second version of the system, the use of the subsystem for forecasting changes in the state of PHF is provided.

A brief description of the third version of an PHF state monitoring system.

The third version of PHF status monitoring system is essentially a modification of the second version. It has the same architectural solution (Fig. 2) but it differs in that, as part of specialized software, software is used that makes it possible to implement diagnostic modeling of the state of the object. In this case, the state of filtration through the body of an earthen dam is simulated.

The organization and carrying out of expert analysis of the proposed variants of architectural solutions and the composition of the software were as follows.

The quality of expert assessment is largely determined by the level of competence of the experts involved in the survey. Therefore, the expert's high competence is the main condition for involving him/her in the development of the forecast.

The reduction of disparate single quality criteria of PHF state monitoring system to a single scale to obtain a generalized assessment from the entire set of indicators selected for comparison was carried out according to the method of analyzing hierarchies.

The essence of the system approach is the composition of the problem as the goal of the task, which is the upper (higher) level of the hierarchy, into its simpler component parts, which are the systems of this problem and are at the lower level of the hierarchy. The Law of Hierarchical Continuity requires that the elements of a lower level of the hierarchy be compared pairwise in relation to the elements of the next level, etc. Pairwise comparisons involve evaluating each property of the elements against each other using a scale of relative importance – an ordered set of gradations determined numerically for agreement results of pairwise comparisons. Since all criteria can be evaluated during the familiarization of experts with various options of project solutions of PHF state monitoring system, by a differential or complex method, they can be combined into group indicators of quality criteria. Further pairwise comparisons and all other stages will be performed on the basis of group criteria.

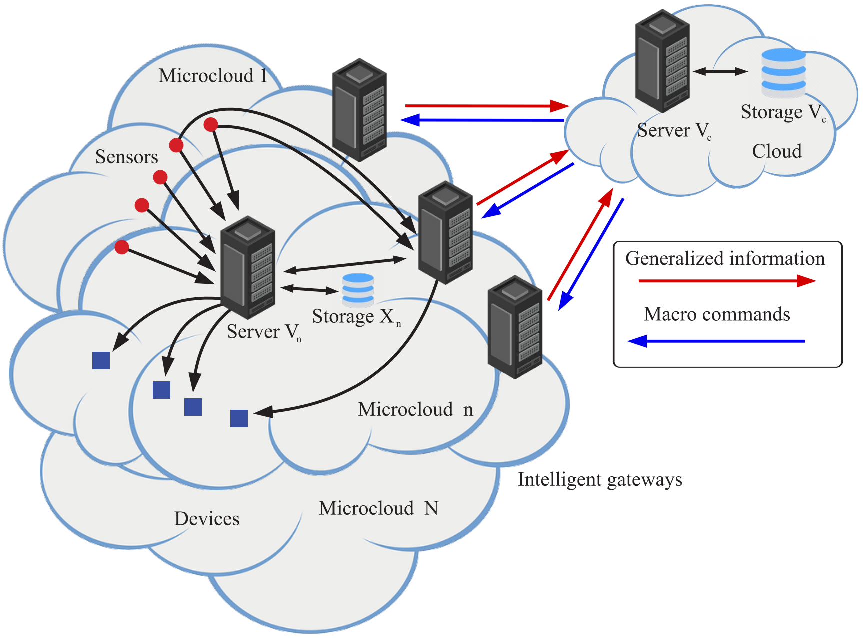

Fig. 3. Interaction of local servers and data storage systems in micro cloud architecture [3]

State-of-the-art standards for the assessment of information systems are a set of all properties that determine the possibility of its application to meet needs in accordance with its purpose. It is the quantitative characteristics of each such property that determine the main types of indicators.

As for the software quality model, the multi-level model represented by the ISO 9126 standard has become the most widely used today. This model identifies six main characteristics of software quality, and then their attributes, which include appropriate metrics for further evaluation of the entire IS.

The main types of indicators by which it is possible to assess the quality of the information environment, IS criteria are safety, reliability, and reliability.

If we talk about security, the information control infrastructure defines this property as the ability of the system to ensure maximum confidentiality, and even the integrity of all available information. That is, information is protected from any unauthorized access.

The reliability of functioning should include such a set of properties that determines the error-free transformation of information. The reliability of functioning is determined by the reliability of the source information.

Reliability refers to a set of properties that preserve the time of all parameters that are necessary to perform certain functions under appropriate conditions and specified modes.

Regarding the effectiveness of facility condition monitoring systems. Effectiveness is such a set of properties of the structure of information that makes it possible to fulfill the set goal under certain conditions with a specific quality. For efficiency indicators, the degree of adaptability of the system to the implementation of the set goals is important.

5 experts were involved in the expert analysis. The selection of experts during the formation of a group of experts was carried out according to the following criteria: erudition in related fields (which is determined by the expert's scientific and practical outlook), the ability to make scientific predictions, and the expert's knowledge of the researched field of knowledge. But the three main criteria were the following:

– availability of appropriate technical education;

– at least 10 years of work experience as a customer representative;

– objectivity in making assessments.

In order to check the adequacy of the experts' judgment, as well as to find out the consistency of the experts' opinions, a ranking of the evaluation criteria was carried out.

To conduct the analysis, with the aim of choosing one of the three possible project solutions for PHF state monitoring system, quality criteria were chosen: safety, reliability, efficiency, ease of use, cost of implementation.

Below is the procedure for expert evaluation.

After selecting the quality criteria of technological equipment, an expert ranking was performed.

At the same time, it was taken into account that:

1. Determination of weighting coefficients involves:

– determining the degree of importance of parameters by assigning them different ranks;

– checking the suitability of expert assessments for further use;

– identification and assessment of pairwise priority of parameters;

– processing of results and determination of weighting factors.

2. The coefficient, which takes into account the importance of the i-th quality criterion of PHF state monitoring system, is calculated by the method of placing priorities, according to which the priority of one quality indicator over another is determined by an expert board (in the number of 5 people). The minimum score is 1. The maximum score is the number of criteria to be evaluated.

Different criteria can have the same expert assessment.

The sum of ranks was determined from the formula:

$$Ri=\sum_{j=1}^{N} r_{ij}, \tag{1}$$

where r_{ij} is the rank of the i-th criterion determined by the j-th expert; N is the number of experts.

The average sum of ranks (T) is calculated from the following formula:

$$T=\frac{R_{ij}}{n}, \tag{2}$$

where n is the number of evaluated parameters.

Based on formula (2): $T=105/6=17.5$.

The deviation of the sum of ranks of each parameter (R_i) from the average sum of ranks (T) is calculated from the formula:

$$\Delta i = R_i - T. \qquad (3)$$

The total sum of squared deviations for each parameter (Δi^2) is calculated from the formula:

$$S = \sum\nolimits_{i=0}^{n} \Delta i^2. \qquad (4)$$

Determination of the possibility of using the results of parameter ranking for further calculations [4] was carried out on the basis of the calculation of the concordance coefficient (consistency) of expert assessments.

The following formula was used to calculate the Kendel concordance coefficient:

$$W = \frac{12S}{N^2\left(n^3 - n\right)}, \qquad (5)$$

where N is the number of experts; n is the number of forecasting quality criteria.

The following was taken into account during the research:

– in the case when the concordance coefficient is equal to or close to zero, it means a complete inconsistency of experts' opinions;

– when the concordance coefficient is close to one, we can talk about the unity of experts' opinions;

– further work with a group of experts is expedient only if the concordance coefficient is greater than or equal to 0.4.

After the formation of a group of experts who have reasonably agreed opinions on the object of evaluation, a pairwise comparison of all parameters was performed. At the same time, the results of ranking criteria were used.

The procedure for processing comparison results based on expert questionnaires was as follows:

1. The number of pairwise comparisons was calculated separately for the results "less than", "equal to", "greater than".
2. The sum of the results m_2 of pairwise comparisons that gave the result "less than" was multiplied by "−1".
3. The sum of the results m_2 of pairwise comparisons that gave the result "equals" was multiplied by "0".
4. The sum of the results m_3 of pairwise comparisons, which gave the result "more", was multiplied by "1".
5. Next, the sum of the above three products was calculated.
6. The final result was considered "less" if the amount according to clause 5 was negative, the result was considered "equal" if the sum was zero, and the result was considered "greater" if the sum was positive.

The next step was to determine the advantage coefficients as follows:

$$a_{ij} = \begin{cases} 1.5 \text{ if } x_i > x_j, \\ 1.0 \text{ if } x_i = x_j, \\ 0.5 \text{ if } x_i < x_j. \end{cases} \qquad (6)$$

The results of a pairwise comparison of the criteria are given in Table 4.

8. Based on numerical data a_{ij} in Table 4, a composite square matrix was built:

$$A = \begin{Vmatrix} a_{11}\ldots & a_{1i} \\ a_{i1}\ldots & a_{ij} \end{Vmatrix}. \qquad (7)$$

The matrix of advantage coefficients obtained in this way is given in Table 5.

Next, the calculation of the priority of the weighting factors of the quality criteria of the project solution for the system of monitoring the state of PHF was carried out. The calculation was performed by an iterative method. In this case:

$$b_i = \sum_{j=1}^{N} a_{ij}, \qquad (8)$$

where b_i is the weight of the i-th criterion based on the results of the evaluations of all experts (defined as the sum of the values of coefficients a_{ij}, determined by all experts according to the i-th criterion).

The values of the weighting factor K_i', K_i'' (first and second iterations), etc., were calculated according to the formula:

$$K_i' = \frac{b_i'}{\sum_{i=1}^{n} b_i'}, \qquad (9)$$

where

$$b_i' = a_{i1}b_1 + a_{i2}b_2 + \ldots + a_{in}b_n. \qquad (10)$$

At the same time, the following conditions were met:

$$\begin{cases} \sum\nolimits_{i=1}^{n} K_i = 1; \\ \sum\nolimits_{i=1}^{n} K_i' = 1. \end{cases} \qquad (11)$$

The final step was the determination of the numerical values of the objective functions for each variant of the implementation of the project solution of PHF state monitoring system. The results of the calculations are summarized in Table 7.

Table 7 gives the values of S_1–S_3 – these are the objective functions for each variant of the design solution for the system. The values of the objective functions were calculated from the following formulas:

$$S_1 = \sum_{j=1}^{6} K_j \cdot B_{1j}, \qquad (12)$$

$$S_2 = \sum_{j=1}^{6} K_j \cdot B_{2j}, \qquad (13)$$

$$S_3 = \sum_{j=1}^{6} K_j \cdot B_{3j}. \qquad (14)$$

The perfect option for building a monitoring system is one that corresponds to the maximum value of one of the functions S_1, S_2 or S_3.

5. Results of the analysis of possible options for the implementation of an automated system for monitoring the state of potentially hazardous facilities

5. 1. Selection and ranking of the quality criteria for the projected system for monitoring the state of potentially hazardous facilities

The following quality criteria of the monitoring system were chosen based on the experts' study of three possible options for the implementation of the planned PHF monitoring system. For convenience, the names of the quality criteria and their designations are given in Table 2.

Table 2

Selection of quality criteria for the system that monitors the state of PHF

No.	Criterion ID	Designation
1	Security	x_1
2	Credibility	x_2
3	Reliability	x_3
4	Efficiency	x_4
5	Ease of use	x_5
6	Cost of implementation	x_6

Then, based on the results of a preliminary survey of experts using questionnaires, the criteria were ranked.

Formulas (1) to (4) were used to process the results. The results of ranking the criteria based on the questionnaires of experts are given in Table 3.

The next step, based on the results given in Table 3, was to calculate the value of the concordance coefficient (formula (5)). Based on the value of the concordance coefficient, a conclusion can be drawn regarding the adequacy of experts' judgment, as well as the consistency of experts' opinions.

5. 2. Determining the consistency of experts' opinions

Since the concordance coefficient is $W=0.918$ (5), which is much greater than 0.4, further work was carried out without changing the group of experts because their opinions on the object of assessment are adequate and consistent. This is due to the fact that it is advisable to carry out further work with a group of experts only if the concordance coefficient is greater than or equal to 0.4.

After processing the experts' questionnaires, using formula (6), a pairwise comparison of all parameters was performed. At the same time, the results of ranking criteria were used. The results of a pairwise comparison of the criteria are given in Table 4.

Using the obtained results, a matrix of preference coefficients (7) was built. The specified matrix is given in Table 5.

The content of the formed matrix of advantage coefficients is the initial data for further calculations of the weighting coefficients of the quality criteria of project solutions for the system of monitoring the state of potentially hazardous facilities.

Table 3

Results of criteria ranking based on expert questionnaires

n_i	Evaluation criteria of a comprehensive quality indicator	The rank of the criterion r_{ij} as assessed by experts					$R_i=\sum r_{ij}$	$T=\sum \frac{r_i}{n}$	$\Delta i=R_i-T$	Δi^2
		Expert								
		1	2	3	4	5				
1	Security	2	2	2	2	3	11	17.50	–6.50	42.25
2	Credibility	4	4	3	3	2	16	17.50	–1.50	2.25
3	Reliability	1	1	1	1	1	5	17.50	–12.50	156.25
4	Efficiency	3	3	4	4	4	18	17.50	0.50	0.25
5	Ease of use	6	6	5	6	5	28	17.50	10.50	110.25
6	Cost of implementation	5	5	6	5	6	27	17.50	9.50	90.25
n_i	$n=6$	21	21	21	21	21	105	T	Δi	$S=401.50$

Table 4

Results of pairwise comparison of criteria

Pairs of criteria	Results of pairwise comparison of criteria					Results				
	Expert, No.:					Quantity, <	Quantity, =	Quantity, >	Total	a_{ij}
	1	2	3	4	5					
1–2	<	<	<	<	>	4	0	1	<	1.5
1–3	<	>	>	>	>	1	0	4	>	0.5
1–4	<	<	<	<	<	5	0	0	<	1.5
1–5	<	<	<	<	<	5	0	0	<	1.5
1–6	<	<	<	<	<	5	0	0	<	1.5
2–3	>	>	>	>	>	0	0	5	>	0.5
2–4	>	>	<	<	<	3	0	2	<	1.5
2–5	<	<	<	<	<	5	0	0	<	1.5
2–6	<	<	<	<	<	5	0	0	<	1.5
3–4	<	<	<	<	<	5	0	0	<	1.5
3–5	<	<	<	<	<	5	0	0	<	1.5
3–6	<	<	<	<	<	5	0	0	<	1.5
4–5	<	<	<	<	<	5	0	0	<	1.5
4–6	<	<	<	<	<	5	0	0	<	1.5
5–6	>	>	<	>	<	2	0	3	>	0.5

Table 5

Matrix of preference coefficients

Criteria, x_i		Criteria, x_i					
		x_1	x_2	x_3	x_4	x_5	x_6
Security	x_1	1.00	0.50	1.50	1.50	1.50	1.50
Certainty	x_2	1.50	1.00	1.50	1.50	1.50	1.50
Reliability	x_3	0.50	0.50	1.00	0.50	1.50	1.50
Efficiency	x_4	0.50	0.50	1.50	1.00	1.50	1.50
Ease of use	x_5	0.50	0.50	0.50	0.50	1.00	0.50
Cost of implementation	x_6	0.50	0.50	0.50	0.50	1.50	1.00

5. 3. Calculation of the weighting coefficients of the quality criteria of project solutions for the monitoring system of the state of potentially hazardous facilities

The next step was the calculation of the weighting coefficients of the quality criteria for the project solutions of PHF state monitoring systems according to formulas (9), (10), and checking conditions (11). The results are given in Table 6.

Table 6, which shows the results of the calculations of the weighting coefficients of the quality of project solutions for monitoring the state of PHF, demonstrates that it was possible to achieve such results when the next values of the relative weighting coefficients differ slightly (ε<2 %) from the previous ones only after the second step (iteration). Therefore, the values of the weighting coefficients of the quality criteria obtained after the second iteration were used for further calculations.

5. 4. Determining the best version of the architectural solution and the composition for the specialized software of the monitoring system

The final step was the determination of the numerical values of the objective functions for each variant of the implementation of the project solution for PHF state monitoring system. The results of the calculations are summarized in Table 7.

The initial data for the calculations were the estimates obtained from the questionnaire of experts. The assessment took place in the range from 0 to 100 points. Experts evaluated each quality criterion of the system for monitoring the state of PHF.

Next, the average score was calculated for each quality criterion and a pairwise comparison of system construction options was performed.

The next step was to calculate the weighting values of the *i*-th criterion based on the results of the evaluations of all experts b_i (defined as the sum of the values of coefficients a_{ij} determined by all experts according to the *i*-th criterion).

Table 6

Calculation of the weighting coefficients for the quality criteria of project solutions for monitoring the state of potentially hazardous facilities

Criteria x_i		First calculation		First iteration			Second iteration			Summary
		b_i	K_i	b'_i	K'_i	ΔK %	b''_i	K''_i	ΔK %	K'_i
Security	x_1	7.50	0.208	41.75	0.21	0.952	227.13	0.209	0.476	0.209
Certainty	x_2	6.5	0.181	34.75	0.175	3.315	188.88	0.174	0.571	0.174
Reliability	x_3	8.5	0.236	49.75	0.251	5.976	272.88	0.251	0.000	0.251
Efficiency	x_4	5.5	0.153	28.75	0.145	5.229	157.13	0.145	0.000	0.145
Ease of use	x_5	3.5	0.097	19.75	0.099	2.020	109.13	0.100	1.000	0.100
Cost of implementation	x_6	4.5	0.125	23.75	0.120	4.000	130.88	0.121	0.826	0.121
Total:		36	1.000	198.5	1.000	5.976	1086	1.000	1.000	1.000

Table 7

Calculation of the value of the objective quality functions of various project solutions for systems that monitor the state of potentially hazardous facilities

Criteria		Option	Expert ratings					Mean value	Pairwise comparison of variants				b_i	B_{ij}	K'_i	K_iB_{1j}	K_iB_{2j}	K_iB_{3j}
			1	2	3	4	5			B1	B2	B3						
Security	x_1	1	15	25	35	20	30	25.0	B1	0	0.5	0.5	1	0.167	0.209	0.035	↓	↓
		2	35	45	40	40	45	41.0	B2	1.5	0	0.5	2	0.333	0.209	↓	0.070	↓
		3	40	55	45	85	93	63.6	B3	1.5	1.5	0	3	0.500	0.209	↓	↓	0.104
Final values:													6	1.000	...	↓	↓	↓
Credibility	x_2	1	15	20	25	15	35	22.0	B1	0	0.5	0.5	1	0.167	0.174	0.029	↓	↓
		2	20	25	35	30	45	31.0	B2	1.5	0	0.5	2	0.333	0.174	↓	0.058	↓
		3	25	35	45	20	55	36.0	B3	1.5	1.5	0	3	0.500	0.174	↓	↓	0.087
Final values:													6	1.000	...	↓	↓	↓
Reliability	x_3	1	35	45	35	40	42	39.4	B1	0	0.5	0.5	1	0.167	0.251	0.042	↓	↓
		2	35	45	35	40	43	39.6	B2	1.5	0	0.5	2	0.333	0.251	↓	0.084	↓
		3	35	45	35	75	43	46.6	B3	1.5	1.5	0	3	0.500	0.251	↓	↓	0.126
Final values:													6	1.000	...	↓	↓	↓
Effectiveness	x_4	1	70	65	75	80	77	73.4	B1	0	1.5	0.5	2	0.333	0.145	0.048	↓	↓
		2	60	60	55	70	57	60.4	B2	0.5	0	0.5	1	0.167	0.145	↓	0.024	↓
		3	75	75	80	85	87	80.4	B3	1.5	1.5	0	3	0.500	0.145	↓	↓	0.072
Final values:													6	1.000	...	↓	↓	↓
User-friendliness	x_5	1	65	70	75	62	75	69.4	B1	0	1.5	1.5	3	0.500	0.100	0.050	↓	↓
		2	55	45	50	60	54	52.8	B2	0.5	0	0.5	1	0.167	0.100	↓	0.016	↓
		3	60	65	65	55	63	61.6	B3	0.5	1.5	0	2	0.333	0.100	↓	↓	0.033
Final values:													6	1.000	...	↓	↓	↓
Cost of implementation	x_6	1	85	85	80	80	87	83.4	B1	0	1.5	0.5	2	0.333	0.121	0.040	↓	↓
		2	80	75	70	70	75	74.0	B2	0.5	0	0.5	1	0.167	0.121	↓	0.020	↓
		3	90	95	97	70	93	89.0	B3	1.5	1.5	0	3	0.500	0.121	↓	↓	0.061
Final values:													6	1.000	Sum:	0.244	0.272	0.483
Value of objective functions:																S_1	S_2	S_3

The value of B_{ij} was calculated as the ratio of b_i to the sum of all b_i. The value of K_i' was calculated from formulas (9), (10) under the condition of meeting (11).

Table 7 gives the values of S_1, S_2, S_3 – these are the objective functions for each variant of the project solution for the system. The values of the objective functions were calculated according to formulas (12) to (14):

$$S_1 = \sum_{j=1}^{6} \left(K_j \cdot B_{1j} \right) = 0.244,$$

$$S_2 = \sum_{j=1}^{6} \left(K_j \cdot B_{2j} \right) = 0.272,$$

$$S_3 = \sum_{j=1}^{6} \left(K_j \cdot B_{3j} \right) = 0.483.$$

According to the results of the expert analysis, there are reasons to claim that the third option is the best option for the implementation of the regional system for monitoring the state of PHF.

This option involves the use of an architectural solution, which is shown in Fig. 2, as well as the interaction of local servers and data storage systems in the micro cloud architecture according to Fig. 3.

Regarding the composition of the specialized software, the selected option employs:

– software that implements the method for detecting and correcting multiple data transmission errors;

– software that makes it possible to implement forecasting of changes in the state of PHF;

– software for diagnostic modeling of the state of the object.

Thus, the decision-making procedure regarding the architectural solution and the composition for the specialized software for the designed automated systems that monitor the state of PHF at the regional level has been completed.

This procedure has confirmed the main research hypothesis.

6. Discussion of results based on the analysis of possible options for the implementation of an automated system for monitoring the state of potentially hazardous facilities

In this study, using a specific example, a method for choosing an architectural solution and the composition of specialized software for the automated system that monitors the state of PHF at the regional level is considered.

The results of the study prove that the typical method for building such systems, given in DBN V.2.5-76:2014, does not meet current requirements for such information systems.

The generalized expert solution confirms that promising systems that monitor the state of PHF should be based on the proposed architectural solutions and should also have software that allows forecasting changes in the state of PHF, as well as periodic diagnostic modeling of the state of the monitored object.

Our results can be explained by the fact that a group of specialists familiar with the issues of decision-making in the design of complex specialized information systems was involved in the expert analysis. Achieving consensus results regarding decision-making regarding the architecture and composition of the software became possible owing to the use of the expert analysis procedure, one of the methods of qualimetry, to assess the quality of the designed system. Formulas (1) to (14) are the basis of the results processing procedure, which in general is the basis of the expert evaluation method.

The main advantages of the proposed decision-making method regarding the architectural solution and the composition of software can be explained by the features of the method on which this research is based – the method of expert evaluation. This method provides an objective description of the qualitative and quantitative aspects of the object (architectural solution and software composition) based on the processing and analysis of a set of individual opinions of experts.

The quality of expert assessment, its reliability and validity depend to a decisive extent on the consistency of experts' opinions and the processing of individual expert assessments. To this end, the calculation of the Kendel coefficient (5) was used.

Unlike known methods for assessing the quality of information systems based, for example, on the "brainstorming" method, the advantage of the expert method is its relative simplicity, as well as the possibility of making the right decision under conditions of incomplete information.

Also, the advantage of the proposed method is the possibility of quantitative assessment of the quality of the system.

It is owing to the results, namely the selection of one of the three possible options for the implementation of PHF state monitoring system, that a significant problem regarding the early detection of the possibility of an emergency at a facility was solved.

This became possible through the introduction of qualitative methods for assessment and decision-making in the design of information systems.

In the process of expert evaluation, after the expert group was formed, the following steps were performed:

1. The selection of quality criteria for PHF state monitoring system was performed. The results are given in Table 2.
2. Ranking of quality criteria was performed on the basis of a preliminary survey of experts. The ranking results are given in Table 3. Based on these results, the consistency of experts' opinions was checked by calculating the concordance coefficient (5): $W=0.918$. Such a value of the coefficient indicates the consistency of the experts' opinions.
3. Based on expert questionnaires, a pairwise comparison of quality criteria was performed according to (6). The results are given in Table 4.
4. Based on Table 4, a matrix of preference coefficients was built in accordance with (7) (Table 5). This matrix contains data on the basis of which it is possible to calculate the weighting coefficients of the quality criteria for the project solutions of PHF state monitoring system.
5. Using formulas (8)–(10), and the results given in Table 5, the weighting coefficients of the quality criteria for the project solutions of PHF state monitoring system were calculated by an iterative method. Table 6 shows how the weighting coefficients of the quality criteria changed during the iteration process. The calculation process has good convergence as two iterations were enough.
6. On the basis of the weighting coefficients of the quality criteria for the monitoring system, as well as using expert evaluations obtained as a result of the questionnaire, a calculation of the value of the target quality functions of various project solutions that monitor the state of PHF was performed. The initial data for this calculation, intermediate results, final values, and values of the objective functions are given in Table 7.
7. Analysis of the summary results given in Table 7, namely the values of the objective functions S_1, S_2, S_3, allows us

to conclude that the best option for building a monitoring system is the third option.

This is an important result, which indicates that for the further development of monitoring systems, specialized software should, in addition to implementing the functions of parametric control over object parameters, provide the functions of forecasting changes in the state of the object and diagnostic modeling of the state of the object. It is also important to introduce programs into the software of monitoring systems that realize the detection and correction of multiple errors of information transmission.

It is also important to consider that the proposed method for evaluating the quality of information systems in order to make a decision and choose a specific architecture and composition of specialized software has certain limitations.

The scope of application of the proposed decision-making method can be considered the main limitation. This method is almost impossible to use for evaluating heuristic branches of creativity, especially for evaluating tasks that are weakly or even completely informalized.

The main drawback of the proposed method for evaluating the quality of information systems for the purpose of making a choice regarding the architectural solution and the composition of the software is subjectivity, inconsistency of experts' opinions, and the limitation of their judgments. This could lead to unexpected incorrect results.

Further advancement of the proposed method is the construction of specialized databases of experts depending on their specialization and expertise, the development of specialized software for evaluating the projected facility state monitoring system depending on the type of PHF.

7. Conclusions

1. The selection of quality criteria for the designed system that monitors the state of PHF was performed taking into account the most common multi-level model, which is presented by the ISO 9126 standard. This model identifies six main characteristics of software qualities. The main types of indicators by which it is possible to assess the quality of the information environment, IS criteria are safety, credibility, and reliability. In addition, the following criteria were used: efficiency, ease of use, and cost of implementation. The results of our study have confirmed the correctness of such a choice of criteria.

2. The formed group of specialists-experts has a good consensus of opinion, which is confirmed by the results of a preliminary survey of experts and the calculation of the Kendel coefficient, which is equal to 0.981.

3. The calculation of weighting coefficients of the quality criteria for the project solutions to PHF state monitoring system performed by the iterative method was carried out in two iterations. This indicates the rapid convergence of the calculation process and can be used in practice.

4. The best variant of the architectural solution chosen on the basis of the expert method and the composition of the specialized software for the monitoring system was confirmed in practice by the results of implementation. In addition to the new architectural solution, the selected system option also provides for the use of the following software modules as part of the software:

– a module for detecting and correcting multiple transmission errors based on the method proposed in [9];

– the module for predicting changes in the state of the controlled object;

– diagnostic modeling module of the state of the object.

In contrast to traditional solutions, i.e., building a monitoring system that implements parametric control over PHF state, the proposed version of the system provides early detection of the possibility of emergency occurrence on the controlled PHF. This allows the operator to decide on the implementation of compensatory measures to prevent accidents and emergencies. The results of the expert analysis reveal that the area chosen in the dissertation research regarding the development of an architectural solution, methods, and algorithms make it possible to solve the problem of developing effective specialized software for promising regional systems for monitoring the state of PHF.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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