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6 DEVELOPMENT OF A SCIENTIFIC AND METHODOLOGICAL APPARATUS FOR ENSURING THE FUNCTIONAL RELIABILITY OF SPECIAL-PURPOSE INFORMATION SYSTEMS

Oleh Shknai, Illia Dmytriiev, Oleg Sova, Andrii Shyshatskyi, Olesia Zhuk, Bohdan Molodetskyi

ABSTRACT

The object of research is special-purpose information systems (IS). The problem addressed in the study is the improvement of the functional reliability of special-purpose IS. The development of a scientific and methodological apparatus for providing a functional special-purpose IS was carried out. The originality of the research consists of:

– systematic assessment of the state of functional reliability of special-purpose IS using the proposed principles of its provision;

– construction of multidimensional dependencies of the state of functional reliability of the special-purpose IS, which achieves an assessment of the functional reliability of the IS based on an arbitrary number of indicators;

– in the assessment of the functional reliability of special-purpose IS using the joint use of measurement data and fuzzy expert assessments, which solves the problem of dimensionality;

– in the construction of the time dependence of changes in indicators that characterize the state of functional reliability of special-purpose IS, which allows determining the moments of deviation of their values from the nominal ones.

In the assessment of the functional reliability of information services based on the concept of profiles, which achieves the possibility of decentralized influence on the special-purpose IS to increase its functional reliability.

In reducing uncertainty about the state of functional reliability of special-purpose IS, due to the use of an appropriate approach in the method of assessing the functional reliability of information services based on the concept of profiles.

The proposed scientific and methodological apparatus provides an increase in the efficiency of assessing the functional reliability of the IS by an average of 40%, while ensuring high reliability of the obtained results at the level of 92%, which is confirmed by the results of a numerical experiment.

KEYWORDS

Multidimensionality of assessment, complex systems, efficiency, reliability, complex assessment, methodology.

Special-purpose information systems (IS), as a distinct class of complex systems, are becoming increasingly widespread, regardless of their field of use and the tasks they solve [1, 2].

In the conditions of military conflicts of various levels, special-purpose ISs have become widespread to solve a wide range of tasks, such as [1]:

– collecting, processing, and summarizing the information circulating in them;

– storage of various types of data, their archiving, and output;

– solving individual and/or complex calculation tasks for a wide range of users;

– modeling the nature of military conflicts;

– transmission of information between IS elements, etc.

At the same time, considering the specific tasks performed by special-purpose ISs, higher requirements are placed on the hardware and software components compared to ISs that perform the same tasks in the interests of general users.

This is because special-purpose ISs function under a wide range of destabilizing factors, such as:

– the influence of systems and means of radio-electronic countermeasures and cyber warfare;

– fire damage to special-purpose IS elements by various means of damage;

– aggressive influence of climatic and mechanical factors that significantly affect;

– specific methods of using special-purpose IS.

One of the conceptual requirements that significantly distinguishes special-purpose IS is the functional reliability requirements imposed on them.

Taking into account the above, one of the options for increasing the effectiveness of the assessment of the IS state is the development of a scientific and methodological apparatus for ensuring the functional reliability of special-purpose information systems.

The analysis of works [9–74] showed that the common shortcomings of the above-mentioned studies are:

– assessment of the IS functional reliability state is carried out only at a separate level of their functioning, or only at a separate element of the special-purpose IS;

– with a comprehensive approach to assessing the IS functional reliability, as a rule, one or two components of the process of their functioning are considered. This does not allow to fully assess the impact of management decisions on the further functioning of the special-purpose IS;

– the approaches listed above (methods, techniques), provide weak integration into each other (or make it impossible at all), which does not allow them to be combined with each other for a joint assessment of the functioning of the IS state;

– the above approaches for assessing the state of IS functioning use a different mathematical apparatus, which requires appropriate mathematical transformations, which in turn increase computational complexity and reduce the accuracy of assessing the state of IS functional reliability, etc.

The aim of the study is to develop a scientific and methodological apparatus for ensuring their functional reliability. This will make it possible to comprehensively and multidimensionally assess the functional reliability of special-purpose ISs at different levels of their functioning (separate elements of special-purpose ISs) for the development of subsequent management decisions. Also, it will make it possible to develop (improve) the software of modern and promising IS systems by integrating the proposed conceptual foundations into the corresponding software.

To achieve the goal, the following tasks were set:

– to develop a scientific and methodological apparatus for ensuring the functional reliability of special-purpose information systems;

– to evaluate the effectiveness according to the defined criterion of functional reliability of special-purpose IS.

The object of the study is a special-purpose IS. The problem addressed in the study is the improvement of the functional reliability of special-purpose IS. The subject of the study is the process of assessing the functional reliability of special-purpose IS. The hypothesis of the study is the possibility of increasing the functional reliability of special-purpose IS due to the development of a scientific and methodological apparatus for ensuring their functional reliability.

In the course of the study, the following research methods were used:

– a general scientific method of analysis – for decomposing problematic issues of assessing the functional reliability of special-purpose IS when they perform tasks as intended. Also, the general scientific method of analysis is used to determine the advantages and disadvantages of known approaches to assessing the functional reliability of special-purpose IS when they perform tasks as intended;

– general scientific method of synthesis – to substantiate the most appropriate approaches to assessing the functional reliability of special-purpose IS when they perform tasks as intended;

– regression methods – to describe the dynamics of changes in the functional reliability of special-purpose IS. The specified approach was used to determine the regularity of changes in the state of functional reliability of special-purpose IS.

Theory of fuzzy sets – for multidimensional assessment of the functional reliability of special-purpose IS.

The IC of the communication and informatization system of the operational grouping of troops (forces) was adopted as a special-purpose IS for modeling in this study. The operational group of troops (forces) was formed according to the state of martial law (typical state). The mode of operation of the IS system of communication and information systems – defense operation. A computational experiment of the proposed methods was conducted, which is an integral part of the scientific and methodological apparatus in the Microsoft Visual Studio 2022 software environment (USA). The hardware of the research process is AMD Ryzen 5.

6.1 SCIENTIFIC AND METHODOLOGICAL APPARATUS FOR ENSURING FUNCTIONAL RELIABILITY OF SPECIAL-PURPOSE IS

PRINCIPLES AND APPROACHES OF ENSURING THE FUNCTIONAL RELIABILITY OF INFORMATION SYSTEMS

Ensuring the functional reliability of special-purpose IS must be considered from the point of view of managing complex systems. Consideration of the functional reliability of IS as a type of complex system creates a methodological basis for scientifically based adaptation of already known approaches, principles, methods, and models. These approaches have proven themselves well when solving the tasks of managing complex systems in other fields of use, in the field of ensuring the functional reliability of IS.

In this section, a system of principles is formed, which forms the basis of the proposed scientific and methodological apparatus for ensuring the functional reliability of special-purpose IS. These principles are necessary for the formation of theoretical developments, a system of views, and the selection of possible ways of informational support for ensuring the functional reliability of special-purpose IS at the stage of preparing them for application.

In accordance with the substantive characteristics and purpose, it is appropriate to classify all the principles applied in the field of ensuring functional reliability into two main groups:

— system-wide principles;

— principles of ensuring functional reliability of special-purpose IS.

System-wide principles for ensuring functional reliability:

1. The principle of systematicity. This principle is basic in the group of system-wide principles, as it reflects the fundamental provisions of the system approach used in the study. The system for ensuring functional reliability is considered simultaneously as a complex subject-centric system, as well as a separate subsystem of the information support system of special-purpose ISs in their preparation for use.

2. The principle of polymorphism. The principle of polymorphism emphasizes the multiplicity of forms of special-purpose IS elements and the variety of connections between them. The implementation of this principle allows describing the same system using different architectural models reflecting different approaches to ensure functional reliability, including scenario analysis as well as the concept of "barrier thinking".

The antipode of the principle of polymorphism is the principle of isomorphism. It assumes the existence of structural and characteristic similarities between ISs of different origins. The essence of this principle converges to the fact that the uniformity of forms of description of IS of different origins, the similarity of structures and properties of system characteristics, determines the possibility of using universal formalized methods of analysis based on the use of symbolic models. In the context of the tasks of ensuring the functional reliability of IS, this principle justifies the use of an architectural approach and system archetypes as tools for determining functional reliability.

3. The principle of diversity. The essence of this principle is to recognize the existence of a set of forms (morphisms) of errors made by subjects in the development of special-purpose IS, as well as defects caused by these errors. A partial manifestation of the diversity principle is multi-criteria, which implies the need to take into account and optimize different criteria. At the same time, the same criterion can be the basis for making decisions, including regarding the continuation or completion of tests of parts of IS for various functional purposes.

4. The principle of decomposition. As part of ensuring the functional reliability of the IS, this principle means the possibility of step-by-step selection of key factors, time, and spatial characteristics of the occurrence of failures, as well as resources and mechanisms aimed at their prevention or elimination.

5. The principle of integration (composition). This principle provides for the possibility of building a set of models that contribute to the choice of rational strategies for achieving the required level of functional reliability of IS.

6. The principle of equivalent ways of achieving the goal. Taking into account the uncertainty inherent in both the state of the special-purpose IS and its individual characteristics at different stages of the life cycle, it is impossible to implement the principle of unity of R. Colman when building models focused on solving the tasks of ensuring functional reliability.

It is assumed that there are many alternative ways to achieve an acceptable level of functional reliability, which are implemented both within the framework of reactive and proactive approaches. The choice of a specific method should be based on the assessment of effectiveness and efficiency in the specific conditions of project implementation.

7. The principle of system readiness. In the context of ensuring functional reliability, this principle consists of the fact that an incident (failure) leads to negative consequences only when a set of conditions necessary for its occurrence occurs simultaneously. This, in turn, can initiate the implementation of the so-called "domino" principle. Therefore, the main principle of failure prevention is to exclude the conditions under which this can happen and become a trigger of a chain reaction of failures.

8. The principle of objectivity. According to this principle, only those that rely on proven knowledge and reliable empirical data should be selected from a set of possible estimates. The a priori uncertainty of the information cannot be compensated by assumptions that have no actual basis, since such a replacement leads to distortion of the results and reduces the reliability of conclusions about the state of the special-purpose IS.

9. The principle of multidimensionality. This principle provides for the functioning of special-purpose IS in several dimensions, such as time, energy, frequency, information, and others. That is why the process of functioning of special-purpose IS should be considered from the standpoint of multidimensionality and reduced to their comprehensive assessment.

Below are approaches to ensuring the functional reliability of special-purpose IS, each of which is based on the principles of creating and operating large and complex systems:

1. The system approach, which acts as a methodological basis of the research, is focused on the analysis of the processes of ensuring the functional reliability of the IS from the standpoint of system-wide principles**.** Within the framework of this approach, it becomes a priority to identify the functional importance of individual subsystems in the formation of the properties of special-purpose IS as a whole, as well as to identify the features of the interaction of special-purpose IS and the external environment.

2. A dynamic approach that involves taking into account changes in the composition and content of IS requirements under the influence of the external environment, including the transformation of end-user needs, as well as changes in the volume and availability of IS resources. Within this approach, the IS is considered as a dynamic object, which state is subject to the influence of both internal and external factors.

3. A structural approach aimed at identifying regularities in the creation of a system for ensuring the functional reliability of IS, which allows establishing the relationship between the structure and its properties.

4. The cybernetic approach, implemented as a methodological framework for research and management, considers the reliability assurance system as a manageable dynamic object. Management efficiency in this context is ensured on the basis of the use of feedback mechanisms, allowing the adjustment of IS behavior on the basis of information on the internal state of the facility and the state of the external environment.

5. A situational approach focused on making project and management decisions under conditions of uncertainty and dynamic changes in the operational situation. The situational approach is based on the analysis of up-to-date information and the use of accumulated experience in the conditions of changes in IS resources.

6. A resource-targeted approach that focuses on the justified and purposeful distribution of resources between activities aimed at ensuring the functional reliability of the IS. It involves setting priorities and developing strategies that ensure the achievement of given targets with the limited resources of the special-purpose IS.

7. An informational approach focused on the creation of complex ISs that implement complex processing of various types of information. Within this methodology, the focus of research is on information flows related to the study of the needs of end users of special-purpose IS.

8. A value-oriented approach focuses on creating a product that meets the needs and expectations of users as much as possible. The main idea of the approach is to take maximum account of the initial stages of creating all the features of using IS to ensure that the functional reliability of IS meets the requirements set by users as much as possible.

9. The reactive approach focuses on the analysis of test results and retrospective data reflecting the experience of IS operation, to identify errors, establish the causes of their occurrence, and patterns in the appearance of failures.

10. A proactive approach involves identifying both present and future problems related to reliability assurance, the main objective of failure prevention. However, it is necessary to understand that it is impossible to prevent all failures before their occurrence, so it is necessary to maintain a balance between proactive and reactive approaches.

11. The barrier approach focuses on the development of multi-layered, echeloned protection systems against aggressive external influences. None of the individual barriers provides full protection against the negative effects caused by the potential hazard. However, integration into a single system of barriers allows to increase in the level of protection due to the manifestation of a systemic effect. The conceptual basis of the "barrier thinking approach" (barrier thinking) is the philosophy of "defense-in-depth" [20].

Let's consider *the main criteria for ensuring the functional reliability of special-purpose IS*:

1. Connectivity. Special-purpose ISs include sets of different types of agents, the interaction between which forms connections of different strengths, which determine the level of correspondence and mutual influence between agents.

2. Autonomy. Agents function without centralized management, having a certain autonomy within the established rules adopted for special-purpose IS. The high autonomy of the agents implies a higher complexity of the system.

3. Emergence. The behavior of special-purpose IS is formed from local interactions of self-organizing agents that lead to the emergence of global structures. These structures, in turn, begin to influence the behavior of the agents themselves in the form of negative (weakening) or positive (reinforcing) feedback.

4. Unbalance. The special-purpose IS functions in conditions of constant external and internal disturbances. Such changes can lead to fluctuations associated with a cyclic transition from one equilibrium state to another, with the strength of the bonds between the elements affecting the stability of the special-purpose IS. Understanding the strength of connections between special-purpose IS elements allows to identify "bottlenecks" and manage the behavior of special-purpose IS in the future.

5. Nonlinearity. The final behavior of a special-purpose IS is not a simple sum of the behavior of individual components (agents). Minor disturbances can cause large-scale consequences — manifestation "butterfly effect". The emergence of autocatalytic processes is often caused by minor and sometimes random events.

6. Self-organization. Special-purpose IS can independently rearrange structure and behavior in response to changes, restoring stability and preventing degradation. Such adaptability can generate collective decisions and new forms of functioning — manifestations of "emergent mind".

7. Evolution. If to consider the external environment of a special-purpose IS as a set of all systems interacting with it, it becomes clear that complex systems are open: they not only adapt to environmental conditions, but also actively transform them. Such interaction has, as a rule, an irreversible nature — decisions made in conditions of self-organization cannot be reproduced again, since the initial conditions are already lost. In other words, developing in parallel and asynchronously, complex systems and their environments affect each other; that is, they co-evolve.

The given criteria, principles, and approaches to ensuring the functional reliability of special-purpose IS are components of the methodology for ensuring the functional reliability of special-purpose IS at the stage of preparation for application.

METHODOLOGY FOR ENSURING THE FUNCTIONAL RELIABILITY OF SPECIAL-PURPOSE ISS AT THE STAGE OF PLANNING THEIR APPLICATION

The conceptual framework of this study relies on the following system of views:

1. Ensuring the functional reliability of the special-purpose IS as part of the intelligent decision support systems of network-centric management of distributed complex systems belongs to the class of management tasks in the conditions of dynamic fuzzy management goals.

2. ISs are a type of complex subject-centric system. This fact confirms the possibility of scientifically based adaptation of known approaches to the model description of failures that occur when managing complex systems of various nature in the field of ensuring the functional reliability of special-purpose IS. A model description of problematic situations is the basis for informational support for making rational decisions regarding their settlement.

3. A critical factor in functional reliability is the failure of IS elements. Sources of failures are destructive factors that affect special-purpose IS, as well as technical failures of software and hardware.

4. The basis for ensuring functional reliability is the complex use of information obtained from various sources: the subsystem of technical analysis of IS, the results of processing retrospective data on the experience of using special-purpose IS in similar conditions.

5. Functional reliability is determined by the number of failures that occurred at different stages of the life cycle, starting with the awareness of the presence of a problematic situation, for the settlement

of which the IS use is necessary. Moments of failure and moments of their occurrence are distributed in space and time.

As part of the methodology for ensuring the functional reliability of special-purpose ISs at the planning stage of their application, the following is proposed in this study:

– the method of constructing multidimensional dependencies based on the joint use of measurement data and fuzzy expert evaluations;

– the method of assessing the functional reliability of information services based on the concept of profiles;

– the method of multidimensional assessment of the functional reliability of special-purpose IS.

A METHOD OF CONSTRUCTING MULTIDIMENSIONAL DEPENDENCIES BASED ON THE JOINT USE OF MEASUREMENT DATA AND FUZZY EXPERT EVALUATIONS

The use of information on the causes and places of occurrence of failures in special-purpose IS is currently gaining particular importance due to the high cost associated with insufficient functional reliability of the IS [2, 10].

One of the aspects of the conceptual foundations of ensuring the functional reliability of special-purpose IS is highlighted as follows:

– the basis of ensuring functional reliability is the complex use of information obtained from various sources: structural analysis of the architectures of systems for ensuring functional reliability and the internal structure of the IS, the results of processing retrospective data (including metric characteristics) related to the manifestation of failures of various nature, expert evaluations of subjects involved in the creation and application of special-purpose IS, forms the basis of the systematic approach of ensuring functional reliability at the application stage.

The classical approach to solving this task is based on the use of empirical (regression) data characterizing the relationship between the parameters of the conditions and processes of the implementation of IS creation projects and the parameters characterizing the properties of the obtained IS. Traditional approaches to the construction of regression dependencies [7] assume the presence of a table of values of independent and dependent random variables that are jointly observed.

Regression dependencies are one of the main tools for constructing empirical descriptive models of inertialess objects.

To date, the theoretical apparatus for building regression models has been developed, on the basis of which software-implemented tools have been developed. At the same time, a special place in the tasks of regression analysis is occupied by linear models. This is because they create the basis of studying the main properties of objects under conditions of a small number of measurement data, which is characteristic when studying the experience of using special-purpose IS due to the uniqueness of this process [4, 12, 13].

The information basis for the construction of regression dependencies is a table of jointly observed values of independent and dependent random variables. When solving practical tasks, one has to face a situation where the formation of such tables meets a number of difficulties. Under such conditions, the lack of measurement data has to be compensated by expert evaluations of various kinds: as expected values; in the form of an interval of possible values; in the form of a collection of expected values, an interval of possible values of a random variable, as well as personal (subjective) opinions of experts.

Due to these circumstances, it is of interest to develop a method of converting measurement data and fuzzy expert estimates, given in various forms to the form of a table of jointly observed values, which is the basis for the construction of multidimensional regression dependencies.

An approach to the construction of multidimensional regression dependencies is proposed in the case when the output data corresponding to different components of vectors of independent and dependent variables are presented either in the form of measurement results or in the form of various expert evaluations.

The classical approach to the construction of regression dependencies can be matched with the scheme

$$A^{(0)} : \left\{\vec{x},\vec{y}\right\}_1^N \rightarrow \vec{y} = \varphi_0\left(\vec{x},\vec{\theta}\right), \tag{6.1}$$

where $\left\{\vec{x},\vec{y}\right\}_1^N$ – a set of jointly observed values of the components of independent vectors $\vec{x}$ and dependent $\vec{y}$ magnitudes;

$\varphi_0\left(\vec{x},\vec{\theta}\right)$ – functional dependence given in parametric form;

N – number of pairs of values $\vec{x}$ and $\vec{y}$.

When solving practical tasks, due to the complexity of organizing the collection of initial data, formation $\left\{\vec{x},\vec{y}\right\}_1^N$ serious difficulties arise.

Work [19] describes an approach to the construction of one-dimensional non-parametric strict functional dependencies based on solving the inverse problem of constructing the distribution law of a random argument function.

The scheme for solving the reverse problem has the form

$$A^{(1)} : \left\{F\left(x\right),F\left(y\right)\right\} \rightarrow y = \varphi_1\left(x\right), \tag{6.2}$$

where $F(x)$, $F(y)$ – estimates of one-dimensional laws of distribution of independent and dependent random variables, determined based on sample data processing

$$A^{(2)} : \left\{x\right\}_1^N \rightarrow x = F\left(x\right), A^{(2)} : \left\{y\right\}_1^M \rightarrow y = F\left(y\right). \tag{6.3}$$

A feature of scheme (6.2) is that the properties of the sample data $\left\{x\right\}_1^N$, $\left\{y\right\}_1^M$ (scope, accuracy of registration) can be different. A limitation of scheme (6.2) is the need to justify the very fact of the presence of strict dependencies, for example, based on the physical content of the task.

Expert estimates are presented as estimates of the expected value of a random variable $M[z]$ (in other words, estimates of mathematical expectation) and/or the interval of possible values of a random variable Z (The following options for presenting intervals are possible: $z \in \left[a_z, b_z\right]; z \in \left[a_z, \infty\right)$).

The works [2, 4, 7] consider the following separate tasks of constructing estimates of the laws of distribution of random variables based on expert estimates:

If only the limits of the interval of possible values of a random variable are known, i.e $z \in [a_z, b_z]$, that's it

$$A^{(3)} : [a_z, b_z] \rightarrow F^{(3)}(z). \tag{6.4}$$

In this case, the optimal assessment $F^{(3)}(z)$ there is a uniform distribution law, if mathematical expectations are known $M[z]$, and the interval of possible values of a random variable is presented in the form $[a_z, \infty)$, then the construction of the assessment is reduced to solving the task

$$A^{(4)} : \{M[z], [a_z, \infty)\} \rightarrow F^{(4)}(z). \tag{6.5}$$

Optimal assessment $F^{(4)}(z)$ in this case, there is an indicative distribution law

$$F^{(4)}(z) = 1 - e^{-\lambda z}. \tag{6.6}$$

The parameter of the distribution law is determined by the ratio

$$\lambda = \left(M[z] - a_z\right)^{-1}.$$

If known $M[z]$ and the limits of the interval $[a_z, b_z]$, then the assessment of the distribution law is a result of solving the task

$$A^{(5)} : \{M[z], [a_z, b_z]\} \rightarrow F^{(5)}(z). \tag{6.7}$$

The assessment shall be presented as

$$F^{(5)}(z) = \int_{a_z}^{z} e^{\mu_0 + \mu_1 \tau} d\tau, \tag{6.8}$$

and the parameters of the model μ0, μ1 are a result of solving a system of equations

$$\begin{cases} \int_{a_z}^{b_z} e^{\mu_0 + \mu_1 \tau} d\tau = 1 \\ \int_{a_z}^{b_z} \tau e^{\mu_0 + \mu_1 \tau} d\tau = M[z] \end{cases}. \tag{6.9}$$

In a separate case, if it is additionally known that $F^{(5)}(a_z) = 0$, $F^{(5)}(b_z) = 1$, $F^{(5)}(z)$ is a triangular distribution.

The transformation of expert estimates into the form of laws of distribution of continuous random variables allows expanding scheme (6.2) in the case of the construction of one-dimensional non-parametric regression dependencies based on the joint use of measurement data and expert estimates.

At the same time, the methods of constructing strict functional dependencies based on solving the inverse problem of constructing the law of distribution of the function of a random argument, including those based on the joint use of measurement data and expert evaluations, are focused on the study of one-dimensional dependencies and are not adapted to the study of the behavior of multidimensional systems.

Next, an approach is described that allows the adaptation of the construction methods of strict one-dimensional functional dependencies to investigate the behavior of multivariate objects.

Static models used to describe multivariate inertialess multiconnected objects include multivariate regression dependencies

$$y_j = \varphi_j\left(x_{j1},\ldots,x_{jk_j}\right),\ j = \overline{1;N}, \tag{6.10}$$

where y_j – vector component value Y dependent variable;

x_{jk_j}, $j = \overline{1;N}$ – components of the vector of independent variables;

$\varphi_j(\bullet)$ – relationship-establishing dependency (parametric or non-parametric) j-th components of the vector of the dependent variable on the values of the components of the vector of the independent variable.

Construction of the ratio of the type (6.10) depending on the form of representation of the components of the vector of the independent variable x_{jk_j} and the dependent variable y_j (measuring data, or expert evaluations) boils down to using one of the transformations (6.4), (6.6), (6.8) to construct one-dimensional laws of distribution of random variables, followed by an assessment of strict non-parametric functional dependencies taking into account (6.2).

The presence of one-dimensional functional dependencies $y_j = f_{ij}\left(x_j\right)$ allows to reduce the formation of a table of jointly observed values of independent and dependent variables to the sequential implementation of the following steps.

Action 1. Independent ones are generated q-th $\left(q = \overline{1;Q}\right)$ the value of random variables $\xi_j^{(q)}$, which correspond to the estimates of distribution laws $\hat{F}\left(x_j\right)$ based on random number sensors by inverse transformation method [11]

$$\xi_j^{(q)} = \hat{F}^{-1}\left(x_j\right),\ i = \overline{1;M} \tag{6.11}$$

Action 2. By values $\xi_j^{(q)}$, using constructed one-dimensional parametric dependencies $f_{ij}\left(x_j\right)$ calculated values y_j according to the rules

$$y_i^q = \sum\nolimits_i f_{ij}\left(\xi_j^{(q)}\right). \tag{6.12}$$

Action 3. Meaning $\left\{\xi_j^{(q)}, y_i^{(q)}\right\}$ entered as a row in the table of values.

In the future, the formed table is processed by known methods of multidimensional regression analysis.

Thus, a method of constructing multivariate regression dependencies is proposed, which allows for representing the IS in the form of a multi-connected object by a set of one-dimensional non-parametric regression dependencies. The basis of the method is the transformation of the original data, which are initially presented in different forms, to the form of the law of distribution of a continuous random variable. The method allows for investigating the behavior of multi-connected objects in the case where some components are metric characteristics, and some are represented by expert evaluations.

A distinctive feature of the proposed approach is that a multi-connected object is described by a collection of one-dimensional strict nonparametric regression dependencies. A limitation of the approach is the need for a priori logical justification of the existence of a relationship between independent and dependent variables.

A METHOD OF ASSESSING THE FUNCTIONAL RELIABILITY OF INFORMATION SERVICES BASED ON THE CONCEPT OF PROFILES

Functional reliability is determined by the ability of the IS to provide the user with complete information in a timely manner [11, 20].

When implementing network-centric management and creating a single information and management space, it is advisable to consider information services rather than functions.

One of the factors that should be taken into account when building a profile of information services is the consideration of the set of IS operation modes (full-time, the cause of non-full-time; non-full-time). In addition, different information needs of service consumers arise in different modes, which causes them to change their assessments of the properties of the same services in different modes.

The profile of an information service means a complete set of alternatives (for example, a set of alternative categories of users, functions, etc.), for each of which occurrence is probable.

Formally, the profile is a tree, each edge of which is matched by a weight characteristic that characterizes the probability of crossing it.

Since it is assumed that the transition of one and only one of the edges from each vertex takes place necessarily, and which is not known in advance, each of the nodes is assigned the correspondence of formula (6.13)

$$\sum_{j} P_{i,j}^{(l)} = 1, \tag{6.13}$$

where l – layer number;

i – node number in the layer;

j – the number of edges coming out of i-th nodes.

Building a service profile allows to quantify the degree of coverage of tasks by special-purpose IS information services. Yes, for i-th the task of the task layer, the degree of coverage is determined by the following formula

$$SS_i^{(S)} = \frac{{}^2S_i^{(R)}}{{}^2S_i^{(R)} + {}^2S_i^{(PR)}}, \tag{6.14}$$

where ${}^2S_i^{(R)}$ – the number of implemented information services;
${}^2S_i^{(PR)}$ – the number of information services expected to be implemented.

In a similar way, it is possible to evaluate all modes of operation. One of the most important characteristics that must be taken into account when allocating resources, in particular temporary ones, to the development of new information services and the improvement of existing ones, is the degree of coverage of tasks by information services.

Different variants of service profiles can be matched with a system model of the form

$$<E, Pr, Rel>, \tag{6.15}$$

where *E* – the set of possible events (simple paths in the graph);

Pr – the set of probability values (implicit profiles) corresponding to each of the events (implicit profile is defined as the product of the weights of the arcs entering the simple path);

Rel – the set of reliability assessments of information services.

When constructing formal models, there is a need to convert subjective user estimates to quantitative estimates.

To evaluate reliability characteristics based on subjective user evaluations, it is proposed to use an approach based on the membership function of the linguistic scale.

The linguistic scale in terms of which users belonging to the same *m*-th target group evaluate the reliability of the information service has the form: {*low; medium; high*}.

To everyone *l*-th the value of the linguistic scale is matched by the membership function μ*l*, defined on the interval $\mu_l \in [0;1]$. Provisions of maximum membership *l*-th the value of a linguistic scale is defined as its reference value *rl* on axis *y*.

Each user expresses its opinion about the reliability of the information service and its degree of confidence in it.

It is postulated that the evaluations provided by users reflect their true independent opinion about the information service in the special-purpose IS.

The main issue of the task of quantifying expert evaluations is the selection of membership functions. Proposed solution: membership functions of a triangular type with the same boundaries that coincide with the boundaries of the axis $y \in [0;1]$.

The cumulative reliability score based on subjective user scores is determined based on the ratio

$$D^{(m)} = \frac{\sum_{k=1}^{N_m} \mu_k^{(l)} * r_l^{(k)}}{\sum_{k=1}^{N_m} \mu_k^{(l)}}, \tag{6.16}$$

where N_m – the number of users belonging to *m*-th target group;

$r_l^{(k)}$ – the reference value corresponding to l-th the value of the linguistic scale determined k-th user;

$\mu_k^{(l)}$ – the degree of confidence k-th user in the assessment given.

The main uncertainties complicating practical use (6.17) are:

– approaches to choosing values r_l;

– approaches to choosing the form of the membership function μ_l;

– approaches to defining boundaries $\left\{r_l^{(up)}, r_l^{(down)}\right\}$.

To eliminate the specified uncertainties, it is proposed to use the following approach. The basis of the definition r_l to take into account the share of users owned m-th target group and selected l-th the value of the linguistic scale. Under such an approach as r_1 the value is $\frac{n_1^{(m)}}{N_m}$, where $n_1^{(m)}$ – number of users m-th target groups that have selected the value of the linguistic scale "low".

As r_2 the value is: $r_2 = \frac{n_1^{(m)}}{N_m} + \frac{n_2^{(m)}}{2N_m}$, where $n_2^{(m)}$ – the number of users of the target group who selected the value of the linguistic scale "average".

Meaning r_3 determined by the ratio: $r_3 = \frac{n_1^{(m)}}{N_m} + \frac{n_2^{(m)}}{N_m}$. Magnitude r_2 is the middle of the sub-interval between values r_1 and r_3.

Regarding the uncertainties related to the choice of the form of the membership function, as well as the lower and upper bounds $\left\{r_l^{(up)}, r_l^{(down)}\right\}$, the following should be noted.

If the value r_1 corresponds to the maximum value of the linguistic scale "low", then to the left r_1 the degree of satisfaction cannot increase, i.e μ_1 at $y \in \left[0; r_1\right]$ takes the value 1. Right-hand than a point r_1 the expert's confidence in the selected assessment drops. Given that any information about the rate of value reduction μ_1 as possible to move away from the right of the point r_1 absent, following the principle of entropy maximization [5], it is appropriate to consider this rate constant.

In the absence of information imposing restrictions on the scope of the definition μ_1, as such an area, it is advisable to take the entire interval $y \in [r_1; 1]$.

Consequently, the developed approach allows obtaining metric estimates of the reliability of information services taking into account the combined use of both measurement data and subjective user estimates.

It should be noted that the proposed approach to the quantification of expert evaluations is largely formalized, which allows it to be implemented as a tool in the software of modern special-purpose IS.

THE METHOD OF MULTIDIMENSIONAL ASSESSMENT OF THE FUNCTIONAL RELIABILITY OF SPECIAL-PURPOSE IS

Let them be known: a set of solutions $D = \left\{d_j\right\}, \left(j = \overline{1,m}\right)$, which corresponds to the result of the multidimensional assessment of the functional reliability of the special-purpose IS y; a set of input indicators $X = \left\{x_i\right\}, \left(i = \overline{1,n}\right)$; ranges of quantitative change of each input indicator characterizing the functional reliability of the special-purpose IS $x_i \in \left[\underline{x_i}, \overline{x_i}\right], i = \overline{1,n}$; membership functions that allow to present indicators $x_i, i = \overline{1,n}$ in the form of fuzzy sets knowledge matrix, which can be graphically displayed in the form of **Fig. 6.1**.

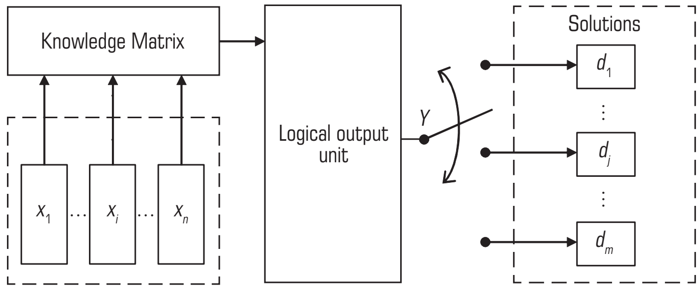

Fig. 6.1 Graphical interpretation of the process of holding a multidimensional assessment of the IS functional assessment

From the analysis of the functioning of the special-purpose IS and indicators for assessing the functional reliability of the special-purpose IS in different operating conditions, the directions of assessment are determined: the similarity of the indicators of the functional reliability of the special-purpose IS, and their changes during the performance of the special-purpose IS tasks.

Let's describe the process of multidimensional assessment of the functional reliability of special-purpose IS

$$D(k) = f\begin{bmatrix} Y_1(k-1), Y_2(k-1), \dots, Y_n(k-1), Q(k-1), R(k-1), \\ Z_1(k-1), \dots, Z_n(k-1) \end{bmatrix}, \tag{6.17}$$

where $Y_1(k-1)$ – a vector characterizing the functional reliability of a special-purpose IS based on the first indicator of the assessment on *k*-1 simulation steps;

$Y_2(k-1)$ – a vector characterizing the functional reliability of the special-purpose IS according to the second indicator on *k*-1 simulation steps;

$Y_n(k-1)$ – a vector characterizing the functional reliability of special-purpose IS by *n*-th assessment indicator on *k*-1 simulation steps;

$Q(k-1)$ – a vector characterizing the time-frequency indicators of the functioning of the subsystem for assessing the functional reliability of special-purpose IS;

$R(k-1)$ – a vector characterizing the information indicators of the functioning of the subsystem for assessing the functional reliability of special-purpose IS;

$Z_1(k-1),\ldots,Z_n(k-1)$ – vectors characterizing modes of operation of special-purpose IS.

For indicators that have a quantitative dimension, the range of change is divided into four quanta. This will provide the ability to transform a continuous universal set $U=\left[\underline{u},\overline{u}\right]$ into a discrete five-element set [2]

$$U=\left\{u_1,u_2,\ldots,u_5\right\}, \tag{6.18}$$

where $u_1=\underline{u}$, $u_2=\underline{u}+\Delta_1$, $u_3=u_2+\Delta_2$, $u_4=u_3+\Delta_3$, $u_5=\overline{u}$, and $\Delta_1+\Delta_2+\Delta_3+\Delta_4=\overline{u}-\underline{u}$, $\overline{u}\left(\underline{u}\right)$ – the upper (lower) limit of the indicator change range. Then all matrices of even comparisons have dimension. The choice of four quanta is determined by the possibility of approximating nonlinear curves at five points [3, 19].

Each of the introduced terms is a fuzzy set given by the corresponding membership function. In the general case, input variables x_1, x_2, …, x_n may be given by a number, a linguistic term, or by the thermometer principle [1, 16].

A multidimensional assessment of the functional reliability of special-purpose IS using expert information is carried out using fuzzy logical equations [4], which are a knowledge matrix and a system of logical statements. These equations make it possible to calculate the values of the membership functions of various identification results at fixed values of the input indicators.

Let $\mu^{\alpha_i^{jp}}(x_i)$ – indicator membership function $x_i\in\left[\underline{x},\overline{x}\right]$ fuzzy term α_i^{jp}, $i=\overline{1,n}$, $j=\overline{1,m}$, $p=\overline{1,l_i}$; $\mu^{d_j}\left(x_1,x_2,\ \ldots,x_n\right)$ – the function of belonging to the vector of input variables $X=\left(x_1,x_2,\ \ldots,x_n\right)$ and the value of the initial assessment $y=d_j$, $j=\overline{1,m}$.

The relationship between these functions is determined by a fuzzy knowledge base and can be represented as the following logical equations

$$\begin{aligned}
&\mu^{d_j}\left(x_1,x_2,\ \ldots,x_n\right)=\mu^{a_1^{j1}}\left(x_1\right)\wedge\mu^{a_2^{j1}}\left(x_2\right)\wedge\ldots\wedge\mu^{a_n^{j1}}\left(x_n\right)\vee\\
&\vee\mu^{a_1^{j2}}\left(x_1\right)\wedge\mu^{a_2^{j2}}\left(x_2\right)\wedge\ldots\wedge\mu^{a_n^{j2}}\left(x_n\right)\ldots\\
&\ldots\mu^{a_1^{jl_j}}\left(x_1\right)\wedge\mu^{a_2^{jl_j}}\left(x_2\right)\wedge\ldots\wedge\mu^{a_n^{jl_j}}\left(x_n\right),\ j=\overline{1,m}.
\end{aligned} \tag{6.19}$$

The equations are obtained from a fuzzy knowledge base by replacing variables (linguistic terms) with their membership functions, and operations I and OR – with operations $\wedge$ and $\vee$.

Let's briefly write the system (6.20) as follows

$$\mu^{d_j}\left(x_i\right)=\mathop{\vee}_{p=1}^{l_j}\left[\mathop{\wedge}_{i=1}^{n}\mu^{\alpha_i^{jp}}\left(x_i\right)\right],\ j=\overline{1,m}. \tag{6.20}$$

Fuzzy logical equations are an analogue of Zadeh's introduced procedure of fuzzy logical inference [4, 5], which is carried out using the operation "fuzzy (min-max) composition", in which operations $\wedge$ and $\vee$ min and max operations correspond.

6.2 EVALUATION OF THE EFFECTIVENESS OF THE FUNCTIONAL RELIABILITY OF THE SPECIAL-PURPOSE IS ACCORDING TO THE DEFINED CRITERION

To determine the effectiveness of the scientific and methodological apparatus for ensuring the functional reliability of special-purpose information systems, modeling of the specified provisions was carried out when solving the task of assessing the state of functional reliability of the special-purpose IS of the group of troops (forces) under the initial conditions.

Separate parts of the computational experiment, using the proposed scientific and methodological apparatus, are given in **Tables 6.1** and **6.2**. The general computational experiment is laid out on 126 sheets; in this section, only its separate part is presented.

Table 6.1 Results of calculations of the functional reliability of special-purpose IS using membership functions

№ rules	Results of calculations of decision membership functions according to the rules											
	1	2	3	4	5	6	7	8	9	10	11	12
1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.00065	0.043	0.042	0.037	0.064	0.03	0.0068	0.0061	0.0087	0.045	0.066	0.045
2	0.06	0.0387	0.1148	0	0.1265	0.1534	0.1487	0.0112	0.0765	0.1381	0.166	0.1612
3	0.063	0.0443	0.05	0.0259	0.0122	0.0576	0.0341	0.067	0.0466	0.052	0.064	0.044
4	0.088	0.074	0.153	0.068	0.004	0.1	0.0018	0.169	0.0052	0.053	0.046	0.163
5	0.174	0.0147	0.083	0.083	0.076	0.002	0.102	0.083	0.162	0.116	0.09	0.105
6	0.028	0.057	0.019	0.036	0.047	0.038	0.025	0.028	0.0029	0.005	0.036	0.063
7	0.061	0.067	0.056	0.045	0.012	0.014	0.0007	0.012	0.022	0.056	0.069	0.00216
8	0.197	0.219	0.211	0.232	0.197	0.203	0.057	0.07	0.119	0.13	0.138	0.0054
9	0	0.122	0.124	0.157	0.243	0.003	0.262	0.208	0	0.165	0.084	0.151
10	0.146	0.079	0.142	0.076	0.005	0.121	0.107	0.121	0.114	0.091	0.049	0.139
11	0.165	0.139	0.065	0.044	0.07	0.1	0.083	0.163	0.061	0.165	0.133	0.086
12	0.026	0.039	0.001	0.006	0.043	0.021	0.036	0.013	0.014	0.034	0.02	0.03
13	0.035	0.006	0.037	0.04	0.021	0.038	0.004	0.0005	0.033	0.017	0.021	0.017
14	0.0054	0.003	0.033	0.021	0.007	0.028	0.029	0.0076	0.05	0.033	0.017	0.038
15	0.049	0.009	0.012	0.021	0.033	0.03	0.044	0.023	0.024	0.034	0.018	0.041
16	0.03	0.042	0.027	0.019	0.014	0.047	0.029	0.011	0.036	0.023	0.05	0.033
17	0.021	0.0005	0.031	0.028	0.032	0.047	0.031	0.02	0.024	0.012	0.02	0.032
18	0.03	0.008	0.016	0.044	0.02	0.036	0.016	0.048	0.05	0.014	0.035	0.0086

Continuation of Table 6.1

1	2	3	4	5	6	7	8	9	10	11	12	13
19	0.026	0.039	0.038	0.014	0.003	0.002	0.031	0.011	0.031	0.0076	0.034	0.013
20	0.007	0.046	0.049	0.033	0.015	0.007	0.049	0.023	0.05	0.016	0.03	0.034
21	0.042	0.026	0.026	0.025	0.037	0.029	0.027	0.021	0.015	0.01	0.041	0.00758
22	0.126	0.027	0.017	0.315	0.033	0.096	0.206	0.305	0.093	0.146	0.116	0.00332
23	0.391	0.462	0.616	0.443	0.077	0.231	0.0064	0.077	0.616	0.109	0.237	0.61
24	0.132	0.005	0.04	0.002	0.035	0.139	0.063	0.0088	0.112	0.118	0.109	0.037
25	0.14	0.125	0.044	0.139	0.13	0.074	0.107	0.125	0.1	0.054	0.021	0.158
26	0.041	0.047	0.02	0.026	0.008	0.016	0.025	0.019	0.043	0.031	0.04	0.049
27	0.022	0.014	0.041	0.037	0.034	0.046	0.013	0.027	0.022	0.011	0.042	0.012
28	0.038	0.008	0.015	0.011	0.018	0	0.017	0.033	0.018	0.042	0.043	0.023
29	0.037	0	0.039	0.015	0.035	0.004	0.021	0.017	0.039	0.031	0.004	0.05
30	0.007	0.028	0.011	0.031	0.012	0.048	0.021	0.026	0.032	0.036	0.033	0.026
31	0.032	0.011	0.007	0.018	0.033	0.036	0.04	0.011	0.038	0.024	0.018	0.045
32	0.041	0.02	0.05	0.027	0.008	0.017	0.05	0.024	0.031	0.045	0.034	0.022
33	0.022	0.019	0.039	0.049	0.043	0.000	0.045	0.029	0.0025	0.016	0.013	0.037
34	0.042	0.048	0.011	0.02	0.013	0.042	0.006	0.0035	0.014	0.0056	0.049	0.049
35	0.05	0.032	0.032	0.037	0.027	0.014	0.005	0.046	0.038	0.02	0.037	0.039
36	0.081	0.044	0.049	0.102	0.016	0.146	0.053	0.114	0.133	0.054	0.054	0.086
37	0.139	0.153	0.025	0.172	0.014	0.142	0.025	0.114	0.063	0.04	0.091	0.135
38	0.019	0.044	0.012	0.004	0.03	0.047	0.008	0.024	0.05	0.033	0.008	0.0015
39	0.023	0.034	0.041	0.003	0.015	0.015	0.05	0.048	0.018	0.036	0.035	0.027
40	0.034	0.063	0.056	0.023	0.085	0.045	0.025	0.0073	0.012	0.113	0.078	0.036
41	0.045	0.016	0.023	0.027	0.032	0.006	0.027	0.011	0.036	0.045	0.038	0.041
42	0.018	0.013	0.019	0.038	0.05	0.021	0.023	0.03	0.028	0.024	0.015	0.045
43	0.0005	0.031	0.033	0.028	0.047	0.023	0.0005	0.035	0.0066	0.034	0.044	0.031
Defense operation	0.166	0.151	0.177	0.011	0.146	0.162	0.152	0.173	0.164	0.147	0.161	0.168

Table 6.2 Comparative results of the process of assessing the functional reliability of the special-purpose IS of the state of the grouping of troops (forces)

Evaluation limits	With use scientific and methodological apparatus	Without use scientific and methodological apparatus
Promptness of the process of assessing the functional reliability of the special-purpose IS of the group of troops (forces)		
Better case	59–502 s	82–801.3 s
Worse case	255.1–2501.5 s	402.8–4007 s
The reliability of the obtained solutions for assessing the functional reliability of the special-purpose IS of the group of troops (forces)		
Better case	0.94–1.0	0.76–0.82
Worse case	0.9–1.0	0.66–0.77

From the analysis of **Table 6.2**, it can be concluded that the proposed scientific and methodological apparatus provides an increase in efficiency by an average of 40%, while ensuring high reliability of the obtained results at the level of 92%.

6.3 DISCUSSION OF THE RESULTS OF THE DEVELOPMENT OF A SCIENTIFIC AND METHODOLOGICAL APPARATUS FOR ENSURING THE FUNCTIONAL RELIABILITY OF SPECIAL-PURPOSE IS

The advantages of the proposed scientific and methodological apparatus for ensuring functional reliability are as follows:

– to systematically conduct a multi-level assessment of the state of functional reliability of special-purpose IS using the proposed principles of its provision. This will make it possible to comprehensively assess the functional reliability of the special-purpose IS, both as a separate element of it and as a whole, in comparison with works [2, 5];

– to consider from different sides the problem of ensuring the functional reliability of special-purpose IS, with the help of the proposed methodology, which expands the system of views on its provision, compared to works [4, 7];

– to build multidimensional dependencies of the state of functional reliability of special-purpose IS (expressions (6.1)–(6.12)), which will allow to evaluate the functional reliability of IS based on an arbitrary number of indicators, compared to works [9, 13];

– to assess the functional reliability of special-purpose ISs by sharing measurement data and fuzzy expert evaluations (expressions (6.1)–(6.12)), which will solve the dimension problem, compared to works [8, 12];

– to build a time dependence of the change in indicators that characterize the state of functional reliability of special-purpose IS (expressions (6.1)–(6.12)), which allows for determining the moments of deviation of their values from the nominal, in comparison with works [11, 14];

– to evaluate the functional reliability of information services based on the concept of profiles (expressions (6.13)–(6.16)), which achieves the possibility of decentralized influence on special-purpose IS to increase its functional reliability, compared to works [12, 16];

– reduce uncertainty about the state of functional reliability of special-purpose IS, by using an appropriate approach in the method of assessing the functional reliability of information services based on the concept of profiles, compared to works [10, 14];

– to conduct a comprehensive and multidimensional assessment of the state of functional reliability of the special-purpose IS due to the use of the method of multidimensional assessment of the functional reliability of the special-purpose IS (expressions (6.17)–(6.20)), compared to works [9, 17].

The disadvantage of the proposed scientific and methodological apparatus should include the need to coordinate the opinions of experts about the state of functional reliability of special-purpose IS.

The proposed scientific and methodological apparatus allows:

– conduct modeling of the process of assessing the functional reliability of special-purpose IS;

– determine effective measures to increase the efficiency of assessing the state of functional reliability of special-purpose IS;

– comprehensively assess the functional reliability of special-purpose IS.

The limitations of the study are the need to take into account the delay time for collecting and proving information from special-purpose IS sensors (sensors).

The proposed scientific and methodological apparatus should be used as software for automated troop control systems of the "Dzvin-AS", "Oreanda-PS" type, as well as integrated information systems of the "Delta" type.

CONCLUSIONS

The study proposes a scientific and methodological apparatus for ensuring the functional reliability of special-purpose information systems. The novelty of the proposed scientific and methodological apparatus consists in:

– systematic assessment of the state of functional reliability of special-purpose IS using the proposed principles of its provision. This will make it possible to comprehensively assess the functional reliability of the special-purpose IS, both as a separate element of it and as a whole;

– an extended consideration on various sides of the problem of ensuring the functional reliability of the special-purpose IS, with the help of the proposed methodology, which expands the system of views on its provision;

– construction of multidimensional dependencies of the state of functional reliability of the special-purpose IS, which achieves an assessment of the functional reliability of the IS based on an arbitrary number of indicators;

– the assessment of the functional reliability of special-purpose IS using the joint use of measurement data and fuzzy expert assessments, which solves the problem of dimensionality;

– the construction of the time dependence of changes in indicators that characterize the state of functional reliability of special-purpose IS, which allows determining the moments of deviation of their values from the nominal ones;

– the assessment of the functional reliability of information services based on the concept of profiles, which achieves the possibility of decentralized influence on the special-purpose IS to increase its functional reliability;

– reducing uncertainty about the state of functional reliability of special-purpose IS, due to the use of an appropriate approach in the method of assessing the functional reliability of information services based on the concept of profiles;

– conducting a comprehensive and multidimensional assessment of the state of functional reliability of a special-purpose IS, due to the use of the method of multidimensional assessment of the functional reliability of a special-purpose IS.

The proposed scientific and methodological apparatus provides an increase in the efficiency of assessing the IS functional reliability by an average of 40%, while ensuring high reliability of the obtained results at the level of 92%, which is confirmed by the results of a numerical experiment.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

USE OF ARTIFICIAL INTELLIGENCE

The authors confirm that they did not use artificial intelligence technologies in creating the submitted work.

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