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THE RESEARCH OF LEVELS OF DESCRIPTION
OF MODERN CRITICAL APPLICATION SYSTEMS

Ю. Бабич, М. Бабич, А. Павлишко, А. Мамедова. **Дослідження рівнів опису сучасних систем критичного застосування.** На сучасному етапі економічного та технічного розвитку, однією з найбільш важливих проблем є підтримка надійності та відмовостійкості систем критичного застосування, які використовуються в управлінні атомними електростанціями, повітряними, залізничними та автотранспортними перевезеннями, технологічними агрегатами в металургії, нафтогазовій промисловості та ін.. Загальну тенденцію розвитку систем критичного застосування характеризують такі фактори: зростання ступеня складності об'єктів управління, розширення складу та рівня складності розв'язуваних функціональних завдань, скорочення часу на прийняття рішення, зростання ціни помилок та ймовірності виникнення масштабних аварійно-небезпечних ситуацій. Основними причинами ескалації виникнення аварійно-небезпечних ситуацій – є відмови в системах критичного застосування. В публікації розглядається поняття системи критичного застосування, досліджується питання рівнів опису систем критичного застосування, розглядається питання взаємозалежних підсистем на основі концепції потенціалу та інформаційних технологій підтримки надійності та відмовостійкості систем критичного застосування. Для таких систем (системи електроживлення та енергопостачання, водопостачання та водовідведення і т.ін.), актуальною проблемою є забезпечення об'єктивності, достовірності та адекватності прогнозування і попередження аварійно-небезпечних і можливих каскадних ефектів, що можуть призвести до техногенних аварій і катастроф. Це може суттєво вплинути на функціонування, стійкість і живучість систем критичного застосування, еколого-техногенну безпеку прилеглих територій і безпеку життєдіяльності населення України. У разі ураження системи критичного застосування, які можуть бути раптовими та інтенсивними, це призведе до надзвичайної ситуації техногенного характеру.
Ключові слова: система критичного застосування, рівень опису системи, взаємозалежні системи, потенціал системи

Yu. Babych, M. Babych, A. Pavlyshko, A. Mamedova. **The research of levels of description of modern critical application systems.** At the current stage of economic and technical development, one of the most important problems is maintaining the reliability and fault tolerance of critical application systems used in the management of nuclear power plants, air, rail and road transport, technological units in metallurgy, the oil and gas industry, etc. The general trend of the development of critical application systems is characterized by the following factors: an increase in the degree of complexity of control objects, an expansion of the composition and level of complexity of solved functional tasks, a reduction in decision-making time, an increase in the cost of errors and the probability of large-scale emergency situations. The main reasons for the escalation of dangerous situations are failures in critical application systems. The publication examines the concept of a critical application system, examines the question of levels of description of critical application systems, examines the issue of interdependent subsystems based on the concept of potential and information technologies supporting the reliability and fault tolerance of critical application systems. For such systems (power supply and energy supply systems, water supply and drainage, etc.), an urgent problem is to ensure the objectivity, reliability and adequacy of forecasting and prevention of dangerous and possible cascading effects that can lead to man-made accidents and catastrophes. This can significantly affect the functioning, stability and survivability of systems of critical application, the ecological and technogenic safety of the surrounding territories, and the safety of life of the population of Ukraine. In the event of damage to the system of critical application, which can be sudden and intense, it will lead to an emergency situation of a man-made nature.
Keywords: critical application system, system description level, interdependent systems, system potential

Introduction

Today, one of the important problems of critical application systems functioning in Ukraine is their safety. At the same time, an important issue is the interaction between critical application systems, such as energy, environmental, and production systems, since minor errors in their operation can lead to serious consequences and human casualties [1]. Therefore, research on the issue of reliability and fault tolerance of such systems is relevant.

Literature review and problem statement

Recently, in Ukraine, there has been a steady trend towards an increase in the number of critical cases associated with the destabilization of the critical application system. The analysis of modern scientific publications on this topic showed the existence of problems of ensuring the reliability and fault tolerance of critical application systems. The main ones are consideration of the system of critical application as a whole, and not of its individual component levels, support of effective use for the purpose of not each structural level, but the system as a whole [2, 3]. The general trend of the development of critical application systems is characterized by the following factors: an increase in the degree

of complexity of control objects, an expansion of the composition and level of complexity of solved functional tasks, a reduction in decision-making time, an increase in the cost of errors and the probability of large-scale emergency situations.

According to most experts in this field, currently there is no universally accepted model for assessing possible threats to a critical application system, but there are only specific solutions for specific situations [3].

Research objectives and tasks

A critical application system is a complex, multi-level system that requires a systemic approach to its research, as well as a detailed study of each level of its description and the formation of a decision support system for the operator who makes decisions in a specific critical situation. Therefore, the following tasks are addressed in the research:

– determination of levels of critical application system description;

– description of critical application systems from a functional, morphological, and informational point of view.

Materials and methods of research

Functional level of describing a critical application system. At the top hierarchical level of describing a critical application system, it can be divided based on qualitative properties of interaction with other similar systems [4] into the following types:

1. Passive functioning, which results in preparing material, energy, or informational material for other critical application systems;

2. Serving higher hierarchical level critical application systems;

3. Opposition in an environment containing other critical application systems with antagonistic interests and target settings.

4. Existence, the sense of which is purposeful activity related to absorbing other critical application systems.

5. Existence aimed at transforming other critical application systems.

The quality of a critical application system's functioning in mathematical models is described by an efficiency model, according to which an assessment of the quality of its work as a whole is carried out [5].

Morphological level of describing a critical application system. This level contains a description of the system structure, while the depth of the description is a parameter. The morphological description itself can have a hierarchical form. At the bottom hierarchical level, the elements are described, inside which the morphological description does not penetrate.

Elementary level of describing a critical application system. Details structural properties that are used in infrastructural minimal structural units. For example, homogeneous, heterogeneous, information-structured elements, etc.

The level of structural properties describes the critical application system. This level determines the nature and stability of relationships between elements and is divided into:

– stable deterministic structures;

– stable probabilistic structures;

– chaotic structures;

– stable structures;

– unstable structures.

Composition level. This level defines the way elements of the critical application system are combined into infrastructure subsystems [5]. Among the subsystems described at the compositional level, the following should be highlighted: effector, receptor, and reflexive.

Effector subsystems are capable of transforming influences and actively impacting other subsystems.

Receptor subsystems carry out transformations of external influences at energy, informational, and actual levels.

Reflexive subsystems have the ability to generate influences. The completeness of the compositional level description is supplemented by an indication of the existence of undefined subsystems with weakly expressed properties [6].

The multi-level description of the critical application system during problem-solving requires the construction of a unified concept oriented towards the creation of unified procedures for analyzing critical application systems. The main problem associated with further development of scientific knowledge in the given field is the need for in-depth processing of issues related to the formalization

of the critical application system. This is because the development of decision support information technologies for the synthesis and management of critical application systems should be based on the peculiarities of the organization of such systems. This contradiction can be resolved through the development of an appropriate mathematical apparatus, on the basis of which, in the future, it will be possible to develop special issues that reduce to the level of engineering solutions [7].

The decision-making processes in critical systems are associated with the need to maintain a balance in real-time between different subsystems that have conflicting target functions. Therefore, increased demands are placed on the performance of the critical system's structure, the purposefulness of its functioning, and the rational interaction of its elements. The main problem associated with the development of scientific knowledge in this field is the lack of effective information technologies for planning the work of different levels of the system, the analysis of which allows forming the potential of the critical application system's work as a whole.

By the potential of the critical application system, we mean the maximum efficiency of its functioning, which can only be ensured in the best organization of the system and the most favorable nature of the interaction between its levels [8]. The measure of potential achieved at a certain stage of managing the critical application system may be, for example, the relative volume of gross product:

$$P_g = \frac{\sum_i h_i^g w_i^g}{\max_{t \in [0;T]} \sum_i h_i^t w_i^t} + t_0 \, ,$$

where i is the subsystem number, T is the time of degradation of the critical application system, h_i^t is the cost of one unit of product produced by the i-th subsystem, at time t, w_i^t is the volume of the product synthesized by the i-th subsystem at time t, and t_0 is the start time of the countdown. Here and below, the superscript indicates the moment in time.

It should be noted that to synthesize a product with the volume of w_i^t, it is necessary to comply with the constraint (1):

$$\forall q \in \{1, 2, \ldots, z\} : (\tilde{d}_{i,q}^t \geq d_{i,q}^t), \tag{1}$$

where z is the number of types of resources; $d_{i,q}^t$ is the amount of q-th type resource allocated to the i-th subsystem at time t; $d_{i,q}^t$ is the amount of resource required to synthesize w_i^t. Resources are considered to be processor power, memory, level of professional readiness of the system operator, raw materials for production, etc. Since resources are diverse, they do not compensate for each other.

The value of P_g depends on the purposefulness of functioning and mutual coordination of all subsystems in the critical application system, rational interaction of its elements, and the effectiveness of the system structure as a whole. There are interdependent (Fig. 1) and independent, balanced and unbalanced subsystems.

Two subsystems are considered interdependent if the product produced by subsystem i is a resource for synthesizing the product of subsystem j (and vice versa). An example of interdependent subsystems is the interaction of the production and energy subsystems. Electricity is necessary for producing goods, and it is paid for with the funds received from these goods [9, 10]. In case of a shortage of electricity, production capacities are in idle mode, and due to the violation of the requirements of interdependent production control of the product, the potential of the critical application system will not be achieved at all.

The task of ensuring balance in interdependent critical application systems can be formulated based on already formulated principles [10]. There are k subsystems that produce different types of products with a volume of $w_{i,r}$, where $i, j = 1, \ldots, k \cdot n$ – the subsystem number, $r = 1, \ldots, k \cdot n$ – the subsystem number, $r = 1, \ldots, n$ – the type of synthesized product. Since the critical application system is interdependent, to synthesize a product by a certain subsystem, the constraint (1.1) must be satisfied, that
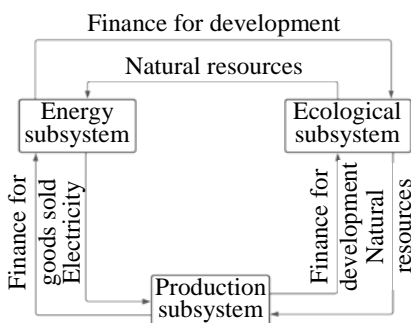

Fig. 1. Interdependence of critical application system

is, for any $\forall_{i,j=1,\ldots,k\cdot n}$ known expenses $c_{j,rp}$ are related to the processing of one unit of product of the r-th type (resource used in the production of the p-th type product) by the j-th subsystem.

As a rule, in independent critical application systems, there are subsystems that produce an unused product [10]. Thus, for interdependent critical application systems, the equality (2) is valid, which takes into account the absence of processes for synthesizing an unused product:

$$\forall r = 1,\ldots,n: \sum_i \sum_j w_{ij,r}, \tag{2}$$

where $w_{ij,r}$ is the volume of the product of the r-th type supplied from the i-th subsystem to the j-th subsystem.

It should be noted that the synthesized product is not only the subject of export but also ensures the functioning and evolutionary development of the entire system [10].

Expression (3) takes into account that the volume of the product of type r consumed by subsystem j is the sum of the quantities $z_{j,r}$ and $e_{j,r}$ in the absence of the restriction $i \neq j$:

$$(\forall i,j = 1,\ldots,k\cdot n) \wedge (r,p = 1,\ldots,n): \sum_i w_{ij,r} = z_{j,r} + e_{j,r}, \tag{3}$$

where $\sum_i w_{ij,r}$ is the volume of the product of type r supplied to subsystem j; $z_{j,r} = \sum_p m_{j,rp} \sum_k w_{jk,p}$ is the volume of internal consumption of the product of type r in the functioning of subsystem j; $e_{j,r}$ is the volume of internal consumption of the product of type r for the evolutionary development of subsystem j; $m_{j,rp}$ is the volume of product of type r (resource) required by subsystem j for the synthesis of one unit of product of type p.

The balance relationship (3) takes into account the functional features of the critical application system and its ability to develop.

The processing cost of product of type r into product p is equal to:

$$S_{rp} = \sum_i \sum_j c_{ij,rp} w_{ij,r},$$

where $c_{ij,rp}$ is the cost associated with processing one unit of product of type r (obtained from subsystem i and used by subsystem j in the production of product of type p) by subsystem j.

To ensure the potential of the critical application system, it is necessary to form control influences according to the constraints listed above [11], aimed at maintaining balance in the interdependent system.

The model of interdependent management of critical application systems (Fig. 2) for the given parameters of the functioning of such systems as a whole and the constraint systems:

$$\begin{cases} \sum_i w_{ij,r}^{t_k} = \sum_p m_{j,rp}^{t_k} \sum_k w_{jk,p}^{t_k} + e_{j,r}^{t_k}; \\ \sum_i \sum_j \sum_r c_{ij,rp}^{t_k} w_{ij,r}^{t_k} \leq \sum_i h_i^{t_k} w_{i*}^{t_k}; \\ \forall i,j = 1,\ldots,k; \forall r,p = 1,\ldots,n; \\ w_{ij,r}^{t_k} \geq 0. \end{cases} \tag{4}$$
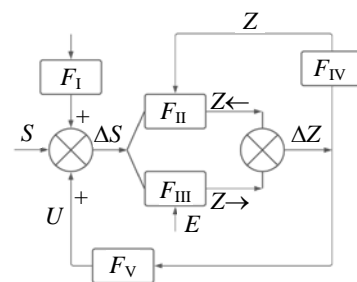

Fig. 2. Diagram of interdependent control of critical application system

for $\forall i,j = 1,\ldots,k$; $\forall r,p = 1,\ldots,n$; $t_k \in t_k [0; T]$ performs a search for the control $u^{t_k} \in U$ of the oriented critical application system, where $C = \{c_{ij,rp}^{t_k}\}$, $\underset{Z}{\leftarrow} = \{w_{*i}^{t_k}\}$, $\underset{Z}{\rightarrow} = \{w_{i*}^{t_k}\}$, $Z = \{w_{ij,r}^{t_k}\}$, $E = \{e_{j,r}^{t_k}\}$.

The operators $F_I - F_V$ describe the characteristic features of subsystems, for example, F_{III} takes into account the efficiency of the product costs of the r-th type on the evolutionary development of the j-th subsystem.

Thus, the synthesis of the control that manages $u^{t_k} \in U$, requires finding $w_{ij,r}^{t_k}$, that satisfies (4).

To effectively solve this nonlinear programming problem, it is necessary to develop specialized information technologies [12] that are capable of overcoming the deficit of a priori information based on an adaptive approach to search for functional planning models with asymptotic minimization of losses and clustering of the factor space of information situations in real-time.

Analysis and research of different levels of description of a critical application system will help the operator in planning the system's work and provide the necessary data for decision-making focused on the potential of the critical application system.

Research results

The levels of description of the critical application system proposed in this study specify production decisions at each level, provide the operator with specific data in the event of an emergency, and assist in making the correct decision aimed at maximizing the performance of the critical application system while considering its potential.

Conclusion

The research on levels of description of critical application systems has provided operators with the ability to obtain information at each level and make final decisions with consideration of the potential of a specific system and possible risks and threats. This will allow the development of a model for evaluating possible threats, risks, and cascading effects, enabling timely management decisions to prevent emergencies.

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