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METHODS FOR SELECTING MODELS OF FUNCTIONING OF MULTICOMPONENT INFORMATION AND ENVIRONMENTAL SYSTEMS

МЕТОДИ ВИБОРУ МОДЕЛЕЙ ФУНКЦІОНУВАННЯ БАГАТОСКЛАДОВИХ ІНФОРМАЦІЙНИХ ТА ПРИРОДОТЕХНІЧНИХ СИСТЕМ

The article discusses an approach to assessing the quality of functioning of multicomponent systems and choosing the best options for managing their components. The author emphasizes the importance of choosing effective models for the functioning of modern information and natural-technical systems, which is becoming a key task in the design, analysis, and operation of such systems.

The article investigates the problem of choosing models of functioning of multicomponent information and natural and technical systems. The authors point to the complication of this process due to an incomplete description of the system, limited availability of information and the difficulty of finding a compromise between the quality indicators of the functioning of multicomponent systems. The article notes that the underestimation of alternatives, the difficulty of choosing the optimal solution, and the inefficiency of the system are the causes of these problems. The authors argue that correcting the terms of reference requires significant resources, which increases the cost of designing and operating systems, and note that high-quality models and methods for evaluating and selecting system design options are needed to achieve optimal results. The concept of the moment in time when the operation of each subsystem begins and the conditions that must be met for its optimal functioning are introduced. The authors study the quality assessment using a set of criteria, taking into account various options for complex systems. The authors propose an algorithm for optimal control selection for each component based on the best combinations of its components in multi-component information and natural-technical systems. The article proves a theorem on the choice of options for a complex control system, which demonstrates that this process occurs by eliminating unacceptable types of governing laws and technical implementations. The authors propose a procedure for selecting options for a control system consisting of two stages: screening out unacceptable types of governing laws and their technical implementations. This approach allows to ensure that the system meets the requirements of quality of functioning using the optimal level of resources.

Keywords: *multicomponent systems, complex systems, models, control systems, choice of functioning models.*

У статті розглядається підхід до оцінки якості функціонування багатокомпонентних систем та вибору оптимальних варіантів управління їх компонентами. Наголошується на важливості вибору ефективних моделей для функціонування сучасних інформаційних та природно-технічних систем, що стає ключовим завданням у проєктуванні, аналізі та експлуатації таких систем.

У статті досліджується проблема вибору моделей функціонування багатоскладових інформаційних та природно-технічних систем. Автори вказують на ускладнення цього процесу через неповний опис системи, обмежену доступність інформації та складність пошуку компромісу між показниками якості функціонування багатоскладових систем. В статті зазначається, що недооцінка альтернатив, ускладнення вибору оптимального рішення та неефективність системи стають причинами виникнення цих проблем. Автори стверджують, що корекція технічного завдання вимагає значних ресурсів, що збільшує витрати на проєктування та експлуатацію систем і зазначають, що для досягнення оптимальних результатів необхідні якісні моделі та методи оцінки та вибору варіантів проєктування систем. Введено поняття моменту часу, коли робота кожної підсистеми починається, та умови, які мають бути виконані для її оптимального функціонування. Досліджується оцінка якості за допомогою сукупності критеріїв, враховуючи різні варіанти складних систем. Автори пропонують алгоритм оптимального вибору управління для кожного компоненту на основі найкращих комбінацій його складових в багатоскладових інформаційних та природно-технічних системах. В статті доведено теорему про вибір варіантів складної системи управління, яка демонструє, що цей процес відбувається шляхом відсіювання неприйнятних типів керуючих законів та технічних реалізацій. Авторами запропонована процедура вибору варіантів системи управління, що складається з двох етапів: відсіювання неприйнятних типів керуючих законів та їх технічних реалізацій. Такий підхід дозволяє забезпечити відповідність системи вимогам якості функціонування використовуючи оптимальний рівень ресурсів.

***Ключові слова**: багатоскладові системи, складні системи, моделі, системи управління, вибори моделей функціонування.*

Problem's Formulation

The problem of choosing models for the functioning of multi-component information and environmental systems is complicated by an incomplete description of the system, limited availability of information, and the difficulty of finding a compromise between system indicators. This leads to an underestimation of alternatives, difficulty in choosing the optimal solution, and inefficiency of the system. Correcting the terms of reference requires significant resources, which increases the cost of designing and operating multi-component information and environmental systems. Thus, the process of selecting models for the functioning of complex systems requires careful analysis, consideration of many factors, and a large number of expert opinions to achieve optimal results, which requires high-quality models and methods of evaluation and selection.

Analysis of recent research and publications

Modern information and environmental systems play a key role in various fields, from science and technology to economics and social aspects. The growing volume of data and complexity of these systems create the need to choose effective models for their operation [1]. Multi-component information and natural systems are complex systems consisting of many interconnected components that can be of different nature (information, technical, biological, etc.). Choosing a model of system functioning is an important task that affects the efficiency of designing, analyzing, and operating these systems. The problem of choosing the most appropriate models arises from the need for accurate predictions, system efficiency, and its ability to adapt to changing conditions [2].

One of the key challenges is the complexity of the system itself and its interaction with the environment. For example, in information systems that process large amounts of data, models with a high degree of adaptability and speed are required [3]. In natural engineering systems, such as ecological or climate systems, models are needed that take into account multidimensional interrelationships and the dynamics of changes over time. Another problem is the availability of various modeling methods, each of which has its own advantages and limitations [4]. To solve these problems, scientists use a variety of methods, including machine learning, simulation modeling, statistical methods, and neural networks. For example, modern information systems often use machine learning algorithms to predict and classify data. In natural engineering systems, simulation modeling allows to take into account complex interactions and dynamics of changes, making forecasting more accurate. In addition, statistical methods allow to take into account the uncertainty and risks associated with the functioning of systems [5]. Choosing models for the functioning of multicomponent information and environmental systems is a complex process that requires consideration of various aspects, such as system complexity, prediction accuracy, and model efficiency.

Modern research offers a variety of model selection methods, including machine learning algorithms, simulation modeling, and statistical approaches. Scientists note that the choice of a model for the functioning of multicomponent information and environmental systems is complicated by a number of factors: complexity — systems may have a large number of components with different characteristics and behaviors, which complicates their modeling; uncertainty — systems may operate under conditions of uncertainty, where not all factors affecting their functioning are known; multidimensionality — systems may have many different characteristics, which makes it difficult to choose a model that would adequately describe them [6—8].

Thus, it is important to continue research in this area to develop more accurate and efficient methods that will optimize the functioning of complex systems in various applications.

Formulation of the study purpose

The purpose of this study is to develop and improve methods for selecting models of functioning of multicomponent information and environmental systems, focusing on the problems that arise at several stages of the abstract design description [9]. Accordingly, the main goal is to solve complex issues of choosing control laws in the subsystems of the system, taking into account their compatibility and importance for achieving the main task of the system's functioning.

Presenting main material

Suppose that t_i is the moment in time when the work of the subsystem of the i-th level begins, where $i = 1,...,n$. The "Output" of the subsystem of the i-th level is the "Input" of the subsystem of the level $i+1$. The subsystem of the i-th level can function during the time $\Delta t = t_{i+k} - t_i$, provided that $i + k \le n$, where n is the number of levels multicomponent systems. An example of a multicomponent system is shown in Fig. 1.

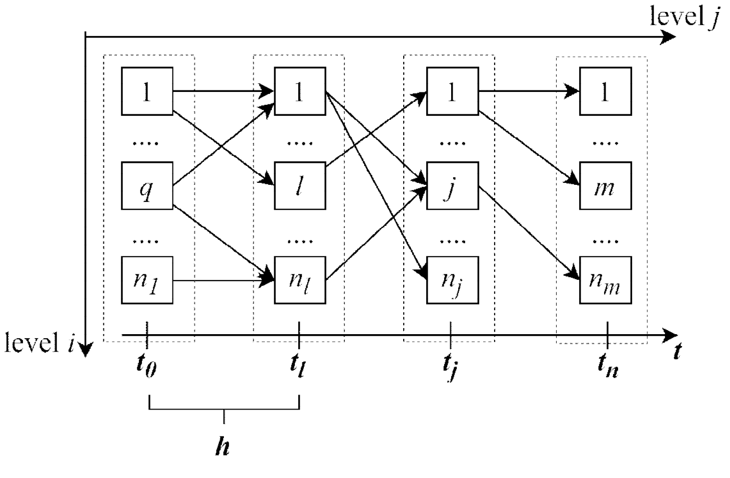

Fig. 1. An example of a multicomponent system

Assessment of the quality of functioning of multicomponent systems is performed using a set of criteria $f = \{f_i(v)\}$, $v \in V$, where $V = \{v_j\}$ — a set of variants of complex multicomponent systems that meet the requirements of functioning (1)—(4):

$$v_{i(l_i,\mu_i)} = \left\{k_j e_{j(q_j)}\right\}, j \in J_{i(l_i)}, q \in Q, \tag{1}$$

accordingly,

$$\left\{v_{i(l_i,\mu_i)}\right\}=\prod_{j}E_j,\, j\in J_{i(l_i)},\tag{2}$$

where k_j is the required number of elements $e_{j(q_j)}\in E_j$ type j; E_j is the set of possible modifications of elements $e_{j(q_j)}\in E_j$; $J_{i(l_i)}$ is the set of types of elements $e_{j(q_j)}\in E_j, q=1,\ldots,\zeta$, required for the implementation of the l_i-th variant in the i-th subsystem.

$$v_j=\left\{u_{1(l_1)},\ldots,u_{i(l_i)},\ldots,u_{n(l_n)}\right\}, i=1,\ldots,n,\tag{3}$$

accordingly,

$$\left\{v_j\right\}=\prod_{i}V_i, i=1,\ldots n,\tag{4}$$

where n is the number of subsystems that start functioning at time t_i.

The total indicator of the l-th subsystem of the i-th level will be as follows:

$$f_i\left(v\right)=\sum_{i=1}^{n}f_i\left(v_{j(l_j,\mu_j)}\right),\ i=1,\ldots,n,\ j\in J_{i(l_i)}.\tag{5}$$

The option restriction function for the selection of multicomponent systems has the form:

$$\begin{aligned}&g_p\left(v\right)\leq g_p^{*}, p=1,\ldots,q, q\in Q;\\&g_p\left(v\right)\geq g_p^{*}, p=1,\ldots,q, q\in Q.\end{aligned}\tag{6}$$

Lemma: A complex control system for multicomponent systems that aims to achieve optimal system performance is determined by the optimal control strategies in its individual components $f_i\left(v\right)$.

Proof: Each component $f_i\left(v\right)$ is characterized by its own control method, among which the best control option is the best combination of its components, which collectively implement this control law. In accordance,

$$\max_{j}f_i\left(v_j\right)\equiv\sum_{j=1}^{m}\max_{l_j}f_i\left(v_{j(l_j,\mu_j)}\right)\equiv\sum_{j=1}^{m}\max_{l_j}\left(\sum_{p\in J_{j(l_j)}}k_p\left(\max_{q_p}\left(f_i\left(e_{p(q_p)}\right)\right)\right)\right);\tag{7}$$

$$\min_{j}f_i\left(v_j\right)\equiv\sum_{j=1}^{m}\min_{l_j}f_i\left(v_{j(l_j,\mu_j)}\right)\equiv\sum_{j=1}^{m}\min_{l_j}\left(\sum_{p\in J_{j(l_j)}}k_p\left(\min_{q_p}\left(f_i\left(e_{p(q_p)}\right)\right)\right)\right),\tag{8}$$

where parameter $k_p=k_p^h$ is the specified step of the parameter values.

Theorem: System of constraints (9):

$$\begin{aligned}&f_i\left(v\right)\geq f_i^{*}\left(k_0\right), i\in I_1, I_1\subseteq I;\\&f_i\left(v\right)\leq f_i^{*}\left(k_0\right), i\in I_2, I_2\subseteq I,\end{aligned}\tag{9}$$

is compatible with the value of the parameter $k_0=k_0^h$ at the h-th step only if the following conditions are met:

1. Each optimal variant for any of the criteria $f_i\left(v\right)$ must lie within the permissible values that meet the requirements:

$$f_i^{*}\left(k_0\right)=\begin{cases}f_i^0-\dfrac{k_0}{\rho_i}\left(f_i^0-f_{i(\min)}\right), i\in I_1, I_1\subseteq I;\\[2mm] f_i^0+\dfrac{k_0}{\rho_i}\left(f_{i(\max)}-f_i^0\right), i\in I_2, I_2\subseteq I,\end{cases}\tag{10}$$

where ρ_i is the vector of preferences $\rho_i\in P$; P is a set of parameter vectors.

2. There is at least one optimal variant of the subsystem $u_{j(l_j)} \in U_j, j = 1,...,m,$ for which the condition is fulfilled:

$$\begin{aligned} f_i\left(u_{j(l_j,\mu_j)}\right) \geq \overline{f}_i^* \,|_{k_0=k_o^h}, i \in I_1, I_1 \subseteq I; \\ f_i\left(u_{j(l_j,\mu_j)}\right) \leq \overline{f}_i^* \,|_{k_0=k_o^h}, i \in I_2, I_2 \subseteq I, \end{aligned} \tag{11}$$

where $\overline{f}_i^* \,|_{k_0=k_o^h} = f_i^*\left(k_0^h\right) - f_i^u$, in accordance,

$$f_i^u = \begin{cases} \sum\limits_{p \neq j} \max\limits_{l_p}\left(f_i\left(u_{p(l_p)}\right)\right), i \in I_1, I_1 \subseteq I; \\ \sum\limits_{p \neq j} \min\limits_{l_p}\left(f_i\left(u_{p(l_p)}\right)\right), i \in I_2, I_2 \subseteq I, \end{cases}$$

3. There is a set of elements of the implementation of a complex system $E_{p(j,l_j)}\left(k_o^h\right), p \in J_{j(l_j)},$ for which the following conditions are satisfied:

$$\begin{aligned} f_i\left(e_{p(q_p)}\right) \geq \breve{f}_i^* \,|_{k_0=k_o^h}, i \in I_1, I_1 \subseteq I; \\ f_i\left(e_{p(q_p)}\right) \leq \breve{f}_i^* \,|_{k_0=k_o^h}, i \in I_2, I_2 \subseteq I, \end{aligned} \tag{12}$$

where $\breve{f}_i^* \,|_{k_0=k_o^h} = \dfrac{f_i^* \,|_{k_0=k_0^h} - f_i^e}{k_p}$, in accordance,

$$f_i^e = \begin{cases} \sum\limits_{\substack{q \in J_{j(l_j)}, \\ q \neq p}} k_p \cdot \max\limits_{l_q}\left(f_i\left(e_{q(l_q)}\right)\right), i \in I_1, I_1 \subseteq I; \\ \sum\limits_{\substack{q \in J_{j(l_j)}, \\ q \neq p}} k_p \cdot \min\limits_{l_q}\left(f_i\left(e_{q(l_q)}\right)\right), i \in I_2, I_2 \subseteq I \end{cases}.$$

Proof: assume that $v_{j(l_j,\mu_j)} \setminus v_j^*\left(k_0^h\right)$, where $v_j^*\left(k_0^h\right)$ is an acceptable variant of the optimal multi-component system, is included in the subset of valid options $V^{\sup} = \left\{\tilde{v}_{1(l_1,\mu_1)},...,\tilde{v}_{i(l_i,\mu_i)},...,\tilde{v}_{n(l_n,\mu_n)}\right\}$, provided: $V_q^{\sup} \subseteq V_q^*\left(k_0^h\right), \forall q = 1,...,n, q \neq j.$

Since the assumption is made that $V_q^{\sup}$ is a subset of admissible variants of the optimal mult-component system, $f_i\left(v^{\sup}\right) \geq f_i^*\left(k_0^h\right), i \in I_1, I_1 \subseteq I,$ we obtain:

$$f_i\left(v_{j(l_j,\mu_j)}\right) \geq f_i^*\left(k_0^h\right) - \sum_{q \neq j} f_i\left(\tilde{v}_{q(l_q,\mu_q)}\right) = f_i^*\left(k_0^h\right) - f_i\left(\tilde{v} \setminus U_j\right) \geq f_i\left(k_0^h\right) - f_i\left(v \setminus U_j\right), i \in I_1, I_1 \subseteq I,$$

accordingly, $v_{j(l_j,\mu_j)} \notin U_j^*\left(k_0^h\right)$. The theorem is proved. ■

Based on the above and condition (9), we can assume that the procedure for selecting options for a multicomponent system consists of two main stages:

1. the types of governing laws are screened out in subsystems where elements with the optimal value of the criterion are used f_i, which do not allow creating alternatives for the entire system that would satisfy conditions (9). If the control law in the subsystem, based on the elements with the optimal value of the criterion f_i, does not provide an opportunity to build an alternative for the entire system that would meet the conditions (9), then its implementation on the elements with the worst values of the crite-

rion is also impossible. Screening of such types of governing laws takes place during the verification of the fulfillment of conditions (11) for the criterion f_i, which allows to form a limited morphological set of types of governing laws in the considered system for which these conditions are fulfilled [10].

2. for each type of control law included in the morphological set of control laws, variants of technical implementation for which inequalities (12) are not fulfilled are screened out. This makes it possible to form reduced morphological sets of technical implementation elements for each type of control law that satisfies inequalities (12) according to the criterion f_i.

Thus, the selection of variants of a complex control system [11] is carried out by sifting out both the types of governing laws in the subsystems and the variants of elements of different types that implement this governing law, adding it to the system clearly violates condition (9) [12].

Conclusions

The article considers the problem of managing multicomponent systems using optimal control options in individual components of the system. The concept of the moment when the subsystem starts operating and the assessment of the quality of functioning of multicomponent systems through criteria are defined. It is noted that the best control option for each component is determined by the best combination of its components. The process of selecting control system options consists of two stages: screening out types of governing laws and technical implementation options that do not meet the requirements. It is proved that the selection of optimal control system options is carried out by eliminating inappropriate types of governing laws and technical implementation options. This procedure is aimed at ensuring that the system functions in accordance with the requirements and achieves the optimal result. This approach allows to effectively manage complex systems and ensure their stability and reliability under various operating conditions.

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