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INFORMATION SYSTEM FUNCTIONING BASED ON MULTIDIMENSIONAL TIME SERIES

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Abstract ***—****The paper addresses the problem of mathematical modeling of complex information systems characterized by a large number of interrelated parameters and heterogeneous information flows. Such systems demonstrate a dynamic behavior over time, which requires the application of methods capable of analyzing temporal dependencies between system parameters. A mathematical model of complex information system functioning based on multivariate time series is proposed. The developed model allows formalizing the processes of system state evolution and capturing relationships between different information streams. In the proposed approach, the system state is represented as a vector time process that includes multiple parameters describing various aspects of the system operation. The mathematical framework of the model describes the dynamics of system state formation and evolution while taking into account external influences and stochastic disturbances. The proposed approach enables a consistent analysis of multidimensional data and allows investigating patterns in the functioning of information systems in dynamic environments. Simulation experiments demonstrate the applicability of the proposed model for analyzing the behavior of complex information systems and evaluating their states based on temporal relationships between system parameters. The obtained results can be applied in the development of methods for processing multidimensional data and designing decision support systems for managing complex information processes.*

Keywords—Data processing, information systems, mathematical model, multivariate time series, system state, temporal dependencies.

I. INTRODUCTION

Modern information systems are characterised by complex structures, a large number of interconnected components, and dynamic processes of data processing and transmission. The functioning of such systems is accompanied by continuous changes in the states of their components, which are determined both by internal information processing processes and by the influence of external factors. In this regard, there is a need for a formalized description of the behaviour of information systems over time, which makes it possible to analyse their states, predict changes in operational characteristics, and support well-grounded management decisions.

The aim of this article is to develop a mathematical model of the functioning of a complex information system based on multidimensional time series. The proposed model enables the formalisation of the temporal evolution of system parameters, takes into account interdependencies between different information flows, and provides a consistent analysis of the system state under conditions of uncertainty and noisy data.

To achieve this aim, the following tasks are addressed in the study: formalisation of heterogeneous data representation in the form of multidimensional time series; constructi of a mathematical model describing the interaction between system parameters; investigation of the temporal dynamics of the information system state; and development of a procedure for integrated assessment of system functioning based on the analysis of temporal dependencies between its parameters.

Each level of the information system performs specific functional tasks related to the generation, transmission, or processing of information flows. At the same time, the efficiency of higher system levels directly depends on the state of lower levels, since it is at these levels that the basic parameters of information processing are formed and data transmission between system components is ensured. Thus, the functioning of an information system can be considered as the result of the interaction of multiple local processes occurring at different levels of its hierarchical structure.

II. Literature Analysis

The study of complex information system functioning and methods for processing multidimensional data has been widely addressed in contemporary scientific research. Particular attention is paid to the development of mathematical models, data analysis methods, and optimisation algorithms that enable the investigation of complex system behaviour in dynamic environments.

In paper [1], the mathematical support of decision support systems is considered, where approaches to the formalisation of information processing processes and the construction of analytical models for complex systems are described. The authors emphasise the necessity of applying formalised mathematical methods for the consistent analysis of multiple parameters characterising the state of information systems.

Papers [2], [15] investigate methods for improving the efficiency of information systems and network structures. In particular, [2] proposes an improved approach to secure routing in software-defined networks, which increases the reliability of data transmission. In article [15], a method for enhancing decision-making efficiency in complex organisational and technical systems is developed, based on analysing the interaction of multiple factors influencing system operation.

An important research direction involves the application of mathematical models for analysing the state of complex systems. In article [4], a methodological approach to the assessment of complex organisational and technical systems is proposed, which involves the use of integrated indicators for evaluating their functioning. Similar problems are considered in [19], where a multicriteria method for evaluating the efficiency of stochastic systems is proposed, enabling the consideration of multiple influencing factors during system analysis.

A significant number of studies are devoted to the application of optimisation methods and bio-inspired algorithms for solving search problems in complex information systems. Papers [3], [16] – [18] consider various approaches to constructing global optimisation algorithms based on behavioural models of natural systems. In particular, [3] proposes a combined bio-inspired search algorithm that integrates several optimisation strategies. In articles [16] and [17], solution search methods based on population-based global optimisation algorithms are developed, which improve the efficiency of analysing complex spatial dependencies. In article [18], an improved solution search method based on the cuckoo search algorithm is presented, demonstrating high efficiency in complex optimisation problems.

A separate group of studies focuses on the application of modern metaheuristic optimisation algorithms. Paper [9] presents the chameleon swarm optimisation algorithm, which is an effective tool for solving engineering design problems. In article [13], the application of the grey wolf optimisation algorithm for controlling complex energy systems is considered. Such approaches allow optimal solutions to be identified within complex multidimensional parameter spaces.

Recent studies also actively employ hybrid methods combining different approaches to optimisation and data analysis. In article [12], a hybrid algorithm combining particle filtering and particle swarm optimisation for controlling fuzzy servo systems is proposed. Such approaches improve the efficiency of analysing dynamic systems and enable more accurate modelling of their behaviour.

Papers [6] and [7] examine engineering approaches to the synthesis of control algorithms for mechatronic systems and digital drives. The authors propose methods for tuning motion controllers in systems with nonlinear dynamics, which is essential for ensuring stable operation of complex technical systems.

Problems related to data processing and filtering in modern information systems are studied in [8], where a hybrid approach to data filtering and the use of machine learning methods in content management systems is proposed. In article [14], a method for object detection in satellite imagery based on the firefly algorithm is presented, demonstrating the effectiveness of metaheuristic algorithms in data analysis tasks.

The analysis of the presented studies shows that current research is mainly focused on the development of optimisation algorithms, data processing methods, and approaches for improving the efficiency of complex system operation. At the same time, insufficient attention has been paid to the development of mathematical models for complex information systems that would allow consistent consideration of multidimensional temporal dependencies between system parameters.

Therefore, an important research task is the development of a mathematical model for the functioning of a complex information system based on multidimensional time series, which would allow the formalisation of the temporal dynamics of system parameters and provide a consistent analysis of interdependencies between different information flows.

III. Problem Statement

During the functioning of a complex information system, its states continuously change under the influence of both internal information processing processes and external environmental factors. Such factors may include variations in the intensity of information flows, load fluctuations on individual system nodes, data transmission delays, as well as random disturbances caused by incomplete or noisy information. As a result, the system state becomes dynamic and requires the application of mathematical models capable of describing the temporal evolution of system parameters.

An important characteristic of complex information systems is the presence of a large number of interdependent parameters that determine their current state. A change in one parameter may lead to changes in other system parameters, forming a complex network of functional relationships between system components. Therefore, when modelling the functioning processes of information systems, it is necessary to consider the mutual influence of parameters and the possibility of state propagation between different system elements.

Another characteristic feature of complex information systems is the presence of time delays in information transmission and processing processes. Such delays may arise due to the need for data accumulation, processing, routing, or transmission through communication channels. As a result, a change in the state of one system element may affect other elements not instantaneously but after a certain period of time. This necessitates the consideration of temporal dependencies when constructing mathematical models of information system functioning.

In addition, control processes play an important role in the operation of information systems. Control actions may modify the operating parameters of individual system elements, regulate the intensity of information flows, or redistribute resources among system components. The presence of control mechanisms increases the stability of system operation and ensures its adaptability to changes in external environmental conditions.

IV. Elements of the Methodological Framework

One of the effective approaches to studying the dynamics of complex systems is the use of mathematical models that take into account the multidimensional nature of state parameters and their interdependencies. In many cases, the state of an information system can be represented as a multidimensional time series reflecting the temporal evolution of system parameters. This approach makes it possible to consider delays in information transmission, the influence of interactions between system components, as well as uncertainty and noise in the data.

At the same time, existing approaches to modelling the functioning of information systems often consider only individual aspects of their operation and do not provide a comprehensive representation of the multi-level structure of the system, the interconnections between its elements, and the dynamic variation of parameters over time. This determines the need to develop a mathematical model that enables the formalisation of the functioning process of a complex information system while taking into account multidimensional temporal characteristics.

The generalised form of the mathematical model describing the functioning of a complex information system is expressed as follows:

$$X(t) = F\left(\left\{\sum_{j=1}^{n} \alpha_{ij} x_j(t-\tau_{ij}) + \beta_i u_i(t) + \gamma_i w_i(t)\right\}_{i=1}^{n}\right),$$

where $X(t)$ is the state vector of the information system at time t; $x_j(t-\tau_{ij})$ is the value of j-th system parameter taking into account the time delay τ_{ij}; α_{ij} is the coefficient representing the mutual influence between system parameters; $u_i(t)$ is the control input applied to the i-th component of the system; $w_i(t)$ is the external environmental influence; β_i, γ_i is the weighting coefficients of the corresponding influences; F is the system state transformation operator.

The state of an information system is formed under the influence of internal relationships between its parameters, control signals, and external environmental factors. Taking into account time delays makes it possible to describe the inertia of information processing and data transmission processes within the system.

For a more detailed description of the functioning processes of the information system, let us introduce the set of components that form its structure. Suppose that the system consists of a set of data processing nodes, data transmission channels, and information flows between them.

Then, the structure of the information system can be represented as: $\mathcal{S} = \{N, C, L, \Lambda\}$, where $N = \{n_1, n_2, ..., n_k\}$ is the set of information system nodes; $C = \{c_1, c_2, ..., c_k\}$ is the set of data transmission channels; $L = \{l_1, l_2, ..., l_k\}$ is the set of system functioning levels; Λ is the matrix of information flows between the system nodes.

Taking into account the introduced parameters, the state of the information system at time t can be represented as a function that depends on the parameters of nodes, transmission channels, and the structure of information flows: $X(t)=\Psi(N(t), C(t), \Lambda(t), U(t))$, where $N(t)$ is the state of the system nodes at time t; $C(t)$ is the state of the data transmission channels; $\Lambda(t)$ is the matrix of information flows; $U(t)$ is the set of control influences.

Since an information system has a hierarchical structure, it is appropriate to represent it as a set of levels, each characterised by its own operational parameters. Let the system consist of *L* levels. Then, the state of the level of the system can be represented as:

$$X^{(l)}(t)=\left\{x_1^{(l)}(t), x_2^{(l)}(t), \ldots, x_{n_l}^{(l)}(t)\right\},$$

where $l=1,2,\ldots,L$ is the level index of the system: n_l is the number of parameters characterising the state of the corresponding level. The interaction between the levels of the information system is determined by the inter-level transformation operator: $X^{(l+1)}(t)=\Theta_l\left(X^{(l)}(t), P_l(t)\right)$, where Θ_l is the operator describing the transition between system levels; $P_l(t)$ is a set of parameters of the operating environment level.

Considering that a complex information system has a spatially distributed structure, its topology can be described as a directed graph whose vertices correspond to system nodes and whose edges represent data transmission channels between them. Formally, such a structure can be represented by an adjacency matrix:

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1k} \\ a_{21} & a_{22} & \cdots & a_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ a_{k1} & a_{k2} & \cdots & a_{kk} \end{bmatrix}.$$

The state of information flows between system nodes can be represented as a matrix of data transfer intensities, where $\lambda_{ij}(t)$ is the intensity of information transfer between system nodes:

$$\Lambda(t)=\begin{bmatrix} \lambda_{11}(t) & \lambda_{12}(t) & \cdots & \lambda_{1k}(t) \\ \lambda_{21}(t) & \lambda_{22}(t) & \cdots & \lambda_{2k}(t) \\ \vdots & \vdots & \ddots & \vdots \\ \lambda_{k1}(t) & \lambda_{k2}(t) & \cdots & \lambda_{kk}(t) \end{bmatrix}.$$

The dynamics of changes in the states of information system nodes can be described by a system of equations that takes into account the influence of neighbouring nodes and information flows:

$$x_i(t+1)=x_i(t)+\sum_{j=1}^{k} a_{ij}\lambda_{ij}(t)-\sum_{j=1}^{k} a_{ji}\lambda_{ji}(t)+u_i(t),$$

where $x_i(t)$ is the node status; $u_i(t)$ is the managerial influence.

To describe the relationship between system parameters, let us introduce a matrix of interaction coefficients:

$$B=\begin{bmatrix} \beta_{11} & \beta_{12} & \cdots & \beta_{1n} \\ \beta_{21} & \beta_{22} & \cdots & \beta_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \beta_{n1} & \beta_{n2} & \cdots & \beta_{nn} \end{bmatrix}.$$

Then, the general dynamic model of the information system can be represented as follows:

$$X(t+1)=AX(t)+BU(t)+MW(t),$$

where *A* is the system structure matrix; *B* is the control matrix; *M* is the matrix of external factors.

To evaluate the effectiveness of the information system, we introduce a vector of quality indicators with *P*, *R* weight matrices:

$$J=\int_0^T (X^T(t)PX(t)+U^T(t)RU(t))dt.$$

Optimal system performance is achieved by minimising functionality: $U^*(t)=\arg\min_{U(t)} J$.

To account for data noise, the actual system parameters can be represented as follows: $\tilde{X}(t)=X(t)+\varepsilon(t)$, where $\varepsilon(t)$ is the random noise.

The final state of the information system, taking into account external factors and data noise, is determined by the ratio:

$$\tilde{X}(t+1)=A\tilde{X}(t)+BU(t)+\Gamma W(t)+\varepsilon(t).$$

V. Prospective Issues of the Theory and Practice of AMS Design

To verify the proposed mathematical model, simulation modelling of the state dynamics of a complex information system was performed in discrete time. The system dynamics are described by a state transition equation that takes into account control inputs, external factors, and measurement noise.

The comparison was carried out for several scenarios differing in the noise level and the type of control applied, in order to evaluate the stability and controllability of the system based on both integral and stepwise characteristics.

Figure 1 illustrates the variation of the norm of the state vector $P\tilde{X}(t)P$ over time for different scenarios.

The state norm is used as a generalised measure of system load: its increase indicates the accumulation of imbalances within the system, whereas its decrease reflects system stabilisation under the influence of control actions or favourable operating conditions.

Figure 2 presents the stepwise quality measure $q(t) = \tilde{X}^T(t)P\tilde{X}(t) + U^T(t)RU(t)$ and its cumulative value in the form of a discrete analogue of the integral performance criterion *J*. Lower values of *J* correspond to a more efficient system operating mode.

Figure 3 shows a comparison of the state components (or their subset) over time for different scenarios.

This makes it possible to visually assess which variables are most sensitive to noise and control actions, as well as how quickly the system recovers after disturbances.

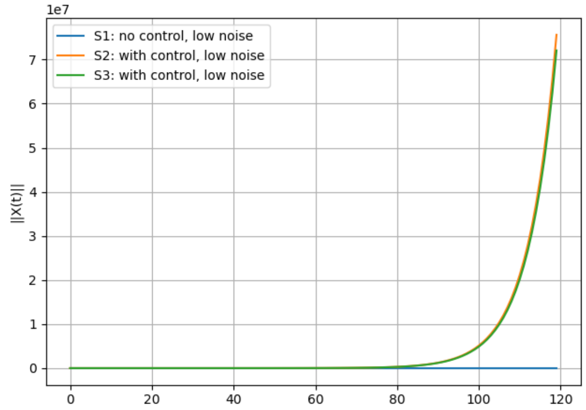

Fig. 1. Comparison of system dynamics

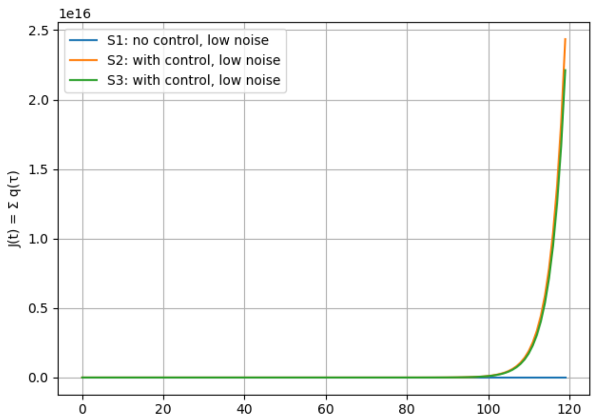

Fig. 2. Comparison of the integral performance criterion (discrete analogue)

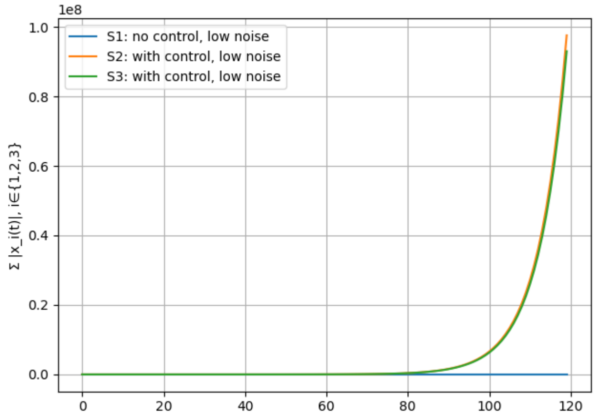

Fig. 3. Comparison of sensitive state components

For ease of interpretation of the modelling results and to reduce the load of tabular data, the results of the scenario comparison are presented in the form of a diagram. For the main indicators (maximum and average state norm, integral criterion, average value of the local quality indicator), normalization was performed relative to the base scenario S1, which allows comparing parameters of different dimensions on a single scale. The stabilization time is presented separately, as it characterizes the dynamic property of the system and has a different scale.

Figure 4 comparison of complex information system performance indicators for modelling scenarios: relative metric values (normalised to S1 = 100%); stabilisation time for each scenario.

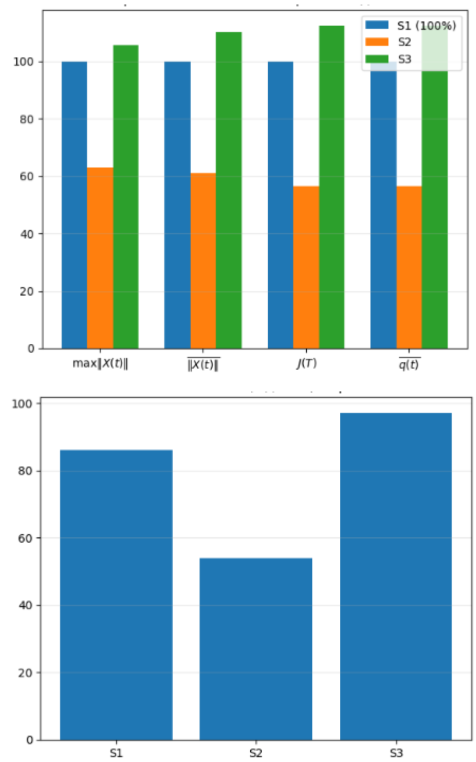

Fig. 4. Comparison of indicators and stabilisation time for scenarios

The results shown in the diagram indicate that scenario S2 (control applied under a low noise level) demonstrates the most favourable operating mode of the system. In comparison with the baseline scenario S1, a simultaneous decrease in both the peak values of the state norm and its average value is observed, which indicates a reduction in parameter deviations over time. Such behaviour is typical for dynamic models with effective control: the system responds more rapidly to disturbances and transitions to a regime characterised by lower state energy.

The integral performance criterion in scenario S2 is also significantly reduced relative to S1. Since this criterion reflects the accumulated effect of costs over the entire simulation interval, its decrease indicates that the system operates in a more efficient regime throughout the whole time period rather than exhibiting only local improvements at individual time steps.

Scenario S3 (control present but with an increased noise level) requires separate analysis. The diagram shows that an increase in the noise component leads to higher peak values of the state norm as well as an increase in its average level. This means that random disturbances and measurement noise not only produce short-term fluctuations but also maintain the system in a regime of increased variability throughout the entire simulation interval. Accordingly, the integral performance criterion increases, which provides quantitative confirmation of the degradation in efficiency caused by the deterioration of data quality.

The stabilisation time is consistent with these observations. For scenario S2, a reduction in stabilisation time is observed, which can be interpreted as a faster transition of the system into a quasi-stationary regime due to the control mechanism. In contrast, for scenario S3 the stabilisation time increases, since noise sustains fluctuations and prevents the system from reacting quickly even in the presence of control actions. Overall, these results confirm that control is an effective mechanism for reducing integral costs and accelerating stabilisation; however, its effectiveness strongly depends on the noise level and the reliability of observed data.

VI. CONCLUSIONS

This article proposes a mathematical model for the functioning of a complex information system based on representing its state in the form of a multidimensional time series. The proposed approach makes it possible to formalise the temporal evolution of system parameters and to take into account the interdependencies between system elements.

The developed mathematical model incorporates the influence of control inputs, external factors, and random disturbances, which enables the description of information system dynamics under conditions of uncertainty. The use of a matrix representation of system parameters allows the structure of interactions between system components to be formalised and provides the possibility for analysing system stability.

The performed simulation modelling confirmed the feasibility of the proposed approach and demonstrated the possibility of applying the mathematical model to analyse the dynamics of information system states and to evaluate the efficiency of their functioning.

The obtained results can be used in the development of methods for forecasting the states of information systems, as well as for the design of decision support systems in tasks related to the management of complex information processes.

REFERENCES

[1] S. O. Kashkevich, (Ed.) Decision support systems: mathematical support, p. 202, 2025, Kharkiv: TECHNOLOGY CENTER PC. https://doi.org/10.15587/978-617-8360-13-9

[2] H. A. Pliekhova, S. M. Neronov, M. V. Kostikova, & S. O. Kashkevich, "Improvement of the secure routing model in software-defined networks," *Bionics of Intelligence (Kharkiv National University of Radio Electronics)*, (1), 50–57, 2024. https://doi.org/10.30837/bi.2024.1(100).07

[3] K. A. Tamer, O. Sova, O. Shaposhnikova, V. Yashchenok, I. Stanovska, S. Shostak, O. Rudenko, S. Petruk, O. Matsyi, & S. Kashkevich, "Development of a solution search method using a combined bio-inspired algorithm," *Eastern-European Journal of Enterprise Technologies*, 1(4/127), 6–13, 2024. https://doi.org/10.15587/1729-4061.2024.298205.

[4] B. A. Mohammed, I. Stanovska, S. Kashkevich, A. Lebedynskyi, Y. Vakulenko, N. Protas, O. Klyuchak, O. Lastivka, A. Semeniuk, and O. Kivshar, "Development of a methodological approach for assessing the condition of complex organizational and technical systems," *Eastern-European Journal of Enterprise Technologies*, 2 (3 (134)), 47–53, 2025. https://doi.org/10.15587/1729-4061.2025.326468.

[5] V. Koval, O. Nechyporuk, A. Shyshatskyi, et al., "Development of a method of complex analysis and multidimensional forecasting of the state of intelligence objects," *Eastern-european Journal of*

Enterprise Technologies, pp. 31–41, 2023. https://doi.org/10.15587/1729-4061.2023.276168.

[6] O. Tachinina, O. Lysenko, S. Ponomarenko, S. Chumachenko, and V. Kutiepov, "Engineering Methodology for the Synthesis of Control Algorithms for Digital Electric Drives of Mechatronic Devices of Flying Search Robots," *Lecture Notes in Networks and Systems Open source preview*, 2024, 996 LNNS, 427–439.

[7] O. Lysenko, O. Tachinina, I. Alekseeva, Y. Tymofelev, "Engineering Method for Adjusting Electric Drive Regulators of Manipulator Motion Units With Significant Nonlinearities," *ICST-2025: Information Control Systems & Technologies, September 24-26*, 2025, Odesa, Ukraine, Ceur Workshop ProceedingsOpen source preview, 2025, 81–93.

[8] O. Poliarus, S. Krepych, & I. Spivak, "Hybrid approach for data filtering and machine learning inside content management system," *Advanced Information Systems*, 7(4), 70–74, 2023. https://doi.org/10.20998/2522-9052.2023.4. 14–32.

[9] M. S. Braik, "Chameleon swarm algorithm: a bio-inspired optimizer for solving engineering design problems," *Expert Systems with Applications*, vol. 174, 114685, 2021. https://doi.org/10.1016/j.eswa.2021.114685.

[10] S. Kashkevich, I. Dmytriiev, I. Shevchenko, O. Lytvynenko, L. Shabanova-Kushnarenko, and N. Apenko, *Scientific-method apparatus for improving the efficiency of information processing using artificial intelligence*, Information and control systems: modelling and optimizations: collective monograph. Kharkiv: TECHNOLOGY CENTER PC, 2024, pp. 137–167. https://doi.org/10.15587/978-617-8360-04-7.ch5.

[11] B. A. Mohammed, I. Stanovska, S. Kashkevich, A. Lebedynskyi, Y. Vakulenko, N. Protas, O. Klyuchak, O. Lastivka, A. Semeniuk, and O. Kivshar, "Development of a methodological approach for assessing the condition of complex organizational and technical systems," *Eastern-European Journal of Enterprise Technologies*, 2 (3 (134)), 47–53, 2025. https://doi.org/10.15587/1729-4061.2025.326468.

[12] C. Pozna, R. -E. Precup, E. Horváth and E. M. Petriu, "Hybrid Particle Filter–Particle Swarm Optimization Algorithm and Application to Fuzzy Controlled Servo Systems," *IEEE Transactions on Fuzzy Systems*, vol. 30, no. 10, pp. 4286–4297, Oct. 2022. https://doi.org/10.1109/TFUZZ.2022.3146986.

[13] N. Paliwal, L. Srivastava, and M. Pandit, Application of grey wolf optimization algorithm for load frequency control in multi-source single area power system," *Evolutionary Intelligence*, vol. 15, pp. 563–584, 2022. https://doi.org/10.1007/s12065-020-00530-5.

[14] H. Khudov, I. Khizhnyak, S. Glukhov, N. Shamrai, & V. Pavlii, "The method for objects detection on satellite imagery based on the firefly algorithm," *Advanced Information Systems*, vol. 8, no. 1, pp. 5–11, 2024. https://doi.org/10.20998/2522-9052.2024.1.01.

[15] S. R. Owaid, Y. Zhuravskyi, O. Lytvynenko, A. Veretnov, D. Sokolovskyi, G. Plekhova, V. Hrinkov, T. Pluhina, S. Neronov, & O. Dovbenko, "Development of a method of increasing the efficiency of decision-making in organizational and technical systems," *Eastern-European Journal of Enterprise Technologies*, vol. 1, no.4 (127), pp. 14–22, 2024. https://doi.org/10.15587/1729-4061.2024.298568.

[16] V. Tyurin, R. Bieliakov, E. Odarushchenko, V. Yashchenok, O. Shaposhnikova, A. Lyashenko, O. Stanovskyi, B. Melnyk, S. Sus, & M. Dvorskyi, "Development of a solution search method using an improved locust swarm algorithm," *Eastern-European Journal of Enterprise Technologies*, vol. 5, no. 4 (125), pp. 25–33, 2023. https://doi.org/10.15587/1729-4061.2023.287316.

[17] S. Yakymiak, Y. Vdovytskyi, Y. Artabaiev, L. Degtyareva, Y. Vakulenko, S. Nevhad, V. Andronov, R. Lazuta, P. Shapoval, & Y. Artamonov, "Development of the solution search method using the population algorithm of global search optimization," *Eastern-European Journal of Enterprise Technologies*, vol. 3, no. 4 (123), pp. 39–46, 2023. https://doi.org/10.15587/1729-4061.2023.281007.

[18] B. A. Mohammed, O. Zhuk, R. Vozniak, I. Borysov, V. Petrozhalko, I. Davydov, O. Borysov, O. Yefymenko, N. Protas, & S. Kashkevich, "Improvement of the solution search method based on the cuckoo algorithm," *Eastern-European Journal of Enterprise Technologies*, vol. 2, no. 4 (122), pp. 23–30, 2023. https://doi.org/10.15587/1729-4061.2023.277608.

[19] L. Raskin, L. Sukhomlyn, D. Sokolov, & V. Vlasenko, "Multi-criteria evaluation of the multifactor stochastic systems effectiveness," *Advanced Information Systems*, vol. 7, no. 2, pp. 63–67, 2023. https://doi.org/10.20998/2522-9052.2023.2.09.

[20] S. Arora and S. Singh, "Butterfly optimization algorithm: a novel approach for global optimization," *Soft Computing*, vol. 3, pp. 715–734, 2019. https://doi.org/10.1007/s00500-018-3102-4.

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О. П. Нечипорук, С. В. Подельський. Математична модель функціонування складної інформаційної системи на основі багатовимірних часових рядів
У статті розглянуто задачу математичного моделювання функціонування складних інформаційних систем, що характеризуються наявністю великої кількості взаємопов'язаних параметрів та різнотипних інформаційних потоків. Особливістю таких систем є динамічний характер зміни їх стану у часі, що обумовлює необхідність використання методів аналізу часових залежностей між параметрами системи. Запропоновано математичну модель функціонування складної інформаційної системи на основі багатовимірних часових рядів, яка дозволяє формалізувати процеси зміни параметрів системи та враховувати взаємозв'язки між окремими інформаційними потоками. У моделі стан системи описується у вигляді векторного часового процесу, що включає множину параметрів, які характеризують різні аспекти функціонування інформаційної системи. На основі запропонованого підходу побудовано математичний апарат, що описує процеси формування та зміни стану системи, а також враховує вплив зовнішніх факторів та випадкових збурень. Запропонована модель дозволяє здійснювати узгоджений аналіз багатовимірних даних та досліджувати закономірності функціонування інформаційних систем у динамічному середовищі. Проведене імітаційне моделювання підтверджує можливість використання запропонованої моделі для аналізу процесів функціонування складних інформаційних систем та оцінювання їх стану на основі часових залежностей між параметрами системи. Отримані результати можуть бути використані під час розроблення методів обробки багатовимірних даних та побудови систем підтримки прийняття рішень у задачах управління інформаційними процесами.
Ключові слова: багатовимірні часові ряди, інформаційні системи, математична модель, обробка даних, стан системи, часові залежності.

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