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DEVELOPMENT OF A MODEL OF THE INFORMATION AND ANALYTICAL SYSTEM FOR MAKING DECISIONS ON DETECTING FAILURES OF INFORMATION TRANSMISSION CHANNELS

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The object of the research is the channels of information transmission during the control of the information-analytical decision-making system. The development of high technologies and computing capabilities ensures the evolutionary development of smart technologies and socio-cyber-physical systems on the one hand. On the other hand, it forms the integration of targeted (mixed) attacks with the possibility of integration with social engineering methods. In addition, mobile technologies significantly increase the possibilities of data transmission speed. However, this only provides the authentication service, which does not provide a full range of security services. Under such conditions, an urgent task at the decision-making stage is the use of auxiliary systems that ensure the adequacy of decisions and the promptness of their adoption. The proposed mathematical model of the information and analytical system allows to calculate the main technical characteristics of information transmission channels and identify their possible failures. The use of an information and analytical system simplifies the decision-making process, allows to increase the reliability of such decisions due to an increase in the level of automation. Increasing the level of automation in the decision-making process removes subjective factors and the decision depends on the availability of information. Therefore, the reliability of the information transmission channels of the information and analytical system significantly affects the quality of the decisions made. The developed model allows to ensure the required level of reliability of information transmission channels. The obtained results are explained by determining the dependence between the parameters of the information and analytical system and their influence on the quality of information transmission through channels. The results of the study can be used in practice when considering systems with a limited number of states during operation

Keywords: decision adequacy, verification, failure, simulation modeling, information, time matrix, model, Petri net, reliability

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1. Introduction

The decision-making stage involves the use of support systems to ensure the adequacy of decisions and the speed of their adoption. At the same time, the use of an information and analytical system allows not only to simplify the decision-making process, but also to increase the reliability of such decisions by increasing the level of automation. Increasing the level of automation in the decision-making process removes the subjective factor and the decision depends only on the availability of information about the transmission channel [1]. In this case, the subjective opinion of the person who makes the decision may not be taken into account automatically [2]. This use of an information-analytical system when making a decision makes it possible to minimize the influence of external factors and the decision depends only on the availability of information and the adequacy of the algorithms for processing it [3]. This approach provides for strict requirements for the reliability and adequacy of the transmitted (received) information, which is used in decision-making [4]. To monitor failures of information transmission channels, it is necessary to use algorithms and models that, based on certain monitoring parameters, make it possible to determine the serviceability or malfunction of such channels [4].

Thus, timely detection of failures of information transmission channels makes it possible to increase the reliability and validity of the functioning of information systems. At the same time, the urgent task is to justify the use of an information-analytical system for making decisions about the presence of failures of information transmission channels without taking into account subjective factors.

2. Literature review and problem statement

Paper [5] explores solutions and proposes approaches to improve the security of the information transmission channel. This work aims to implement a beamforming method to improve the security of the physical layer in the information transmission channel. However, the proposed results do not allow to determine possible failures of the information transmission channel. In [6], the issues of information loss during transmission through an optical information channel are considered. The developed approach allows to suppress possible interference to increase the reliability of information transmission. At the same time, the proposed results do not consider the process of monitoring the presence of possible failures in information channels. Paper [7] considers an approach to determining security in information transmission based on predicting the influence of external influences. However, this approach does not allow identifying failures that are caused by internal changes in the information transmission channel. In [8], it is proposed to increase the level of reliability of the information transmission channel through artificial intelligence. The proposed approach is based on training artificial intelligence to respond to emergency situations when transmitting information. The disadvantage of the work considered is the difficulty of learning to detect failures caused by changes in the characteristics of the information transmission channel. Two-factor authentication of information transmission channels is considered in paper [9]. This approach makes it possible to increase the reliability of information transmission through the use of an authorization code that is sent through separate channels. This approach requires significant costs for transmitting information due to the use of additional channels with the need for additional processing. It can significantly increase the economic costs of using information transmission channels with a slight increase in reliability. Paper [10] proposes approaches to assessing the reliability of information transmission based on parameters that characterize the state of the channel during transmission and reception. Failure detection is characterized by a change in channel capacity when transmitting and receiving information. A failure will be detected if there is attenuation associated with a change in channel capacitance. However, failure of an information transmission channel is not always associated only with a change in capacity. Also, a change in capacity may indicate the presence of an information leak. However, data leakage is not always associated with a failure of the information transmission channel. Paper [11] considers an approach based on assessing the quality of operation of two equivalent channels (the main and backup, which acts as a model). The disadvantage of this approach is that it is not possible to take into account the occurrence of failures in two channels at once due to their hidden nature of manifestation, caused by a certain time between failures. Paper [12] presents an approach to identifying failures of an information transmission channel based on a probabilistic model using the Monte Carlo method. With this approach, the information transmission channel is characterized by the failure rate and recovery time. The proposed method is effective in detecting obvious failures and does not effectively detect hidden failures. Paper [13] considers an approach to ensuring the reliability of information transmission channels based on determining economic costs. At the same time, issues related to the costs of data loss due to untimely detection of failures in the information transmission channel are not considered. Research [14] studies a reliability management system using block-chain. The disadvantage of this approach is the presence of two-channel information transmission, which does not provide the required level of reliability. Paper [11] considers the issues of changing energy characteristics during data transmission. However, the work does not make recommendations on how changes in energy characteristics affect the detection of possible failures of information transmission channels. Paper [15] examines approaches to ensuring the reliability of information transmission channels using various types of models. In this case, only detection of obvious failures is considered; options for detecting hidden failures of information transmission channels are not taken into account. Paper [16] discusses options for calculating delays in information transmission and their impact on the reliability of information transmission channels. But this work does not allow to formulate an approach to determining hidden failures of information transmission channels.

Thus, the analysis of publications [5–16] showed that possible methods (techniques) for identifying hidden failures of information transmission channels when monitoring an information-analytical decision-making system are not sufficiently taken into account. Basically, identifying failures of information transmission channels is associated with parameters that characterize obvious failures. This does not take into account possible hidden failures of information transmission channels, which may be associated with degradation of channel elements or loss of parameters due to long-term (or harsh) operation. Therefore, this study is aimed at solving the problem of developing a model of an information-analytical system for making decisions about the presence of failures of information transmission channels.

3. The aim and objectives of the study

The aim of this study is to develop a model of an information-analytical decision-making system for the presence of failures of information transmission channels. This model is based on determining the relationship between the parameters of the information and analytical system and their impact on the quality of information transmission by channels. The developed model allows to ensure the required level of reliability of information transmission channels.

To achieve the aim of the study, it is necessary to solve the following objectives:

– build a graph of a model of an information and analytical system;

– develop a mathematical model of an information and analytical system;

– carry out verification of the proposed model.

4. Materials and methods of research

The object of the study is the process of identifying failures of information transmission channels when monitoring an information and analytical decision-making system.

The research hypothesis was as follows. The condition for the start of the event, the appearance of a failure of the information transmission channel, is preceded by a change in its internal parameters (for example, aging of elements, leakage of capacitors, change in internal resistance, etc.) and the influence of external factors (humidity, overloads, poor-quality power supply, etc.). The sequence of events in a Petri net is reflected by the firing of transitions, and the fulfillment of any condition is associated with the appearance of a label in the place corresponding to this condition. This means that if in a simulated network of functioning of an information-analytical system the tag is in a certain place, for example, monitoring for the presence of failures before use, then in a real system self-monitoring of the system occurs. Label transitions in the model of functioning of the information-analytical system from one place to another characterize the order of operations when monitoring the presence of failures of the information transmission channel. Conventions on transition firing rules are a way of expressing the concept of cause-and-effect relationships between conditions and events in a modulated system. Only after the preconditions are met can response events occur. After an event has taken place, the postconditions of some other events are realized, and so on. In this case, the root causes will disappear, for example, the event – the beginning of restoring the functionality of information transmission channels depends on the results of monitoring for the presence of failures and does not depend on the event – the beginning of monitoring for the presence of failures before using the system [17, 18]. Therefore, to achieve the aim of the study, the theory of Petri nets is used.

To test the adequacy and performance of the proposed mathematical model of the information-analytical system and conduct simulation experiments, the HPSim software tool was used [19].

During the simulation, the developed model was described in the HPSim software environment and launched for execution. The HPSim software tool allows for verification of the network model. Verification is carried out by checking the network model for limitations, security, persistence and completeness of the network [19].

The following limitations and assumptions were introduced during the study. A finite number of possible states during the functioning of the information and analytical system was used. The number of states for the simulated system corresponds to its real functioning process. The limitation is that the number of model states at a certain stage may not be complete. The number of operating states depends on the complexity of the system, its tasks, and the conditions of its use. The assumption of the study is a finite number of possible states of functioning of the information and analytical system, which are considered in the work.

The input data for this study are:

– the final number of possible states during the operation of the information-analytical system under consideration is 14 (states were considered during the development of the model);

– the conditions for the transition of an information and analytical system from one state to another during operation are limited to 7 (determined during the development of the model);

– an information-analytical system during operation can only be in one state (for example, transmitting information, monitoring the presence of failures, waiting for information, etc.). The transition to another state depends on the presence of a command for further functioning;

– the state of functioning of the information-analytical system for transmitting information requires preliminary monitoring of the presence of failures in the information transmission channels and their elimination (if any);

– the presence of limiting states of the functioning of the information-analytical system: waiting for restoration or repair (in the presence of failures of information transmission channels) and replacement (in case of economically unprofitable repairs).

5. Development of a model of an information and analytical system

5. 1. Design of a graph for a model of an information and analytical system

In Petri nets, the condition for performing a certain operation is the place of the network, and the event that involves performing such an operation is a transition. The condition for the start of the event, which consists in identifying failures before using the information-analytical decision-making system, is the presence of a command to determine the reliability of the information transmission channel. For clarity, let's represent the structure of the functioning model of the information-analytical system by a Petri net graph that models the interaction of the system and operations for monitoring the presence of failures of the information transmission channel (Fig. 1).

Therefore, in the developed model of the information-analytical system, the control equipment is reflected in the form of places, and events – in the form of transitions. In the theory of Petri nets, a set of places is denoted by $P=\left\{p_i,\ i=\overline{1,n}\right\}$, and a set of transitions is denoted by $T=\left\{t_j,\ j=\overline{1,m}\right\}$. For temporary networks, a variable Z is usually introduced – the delay time of the network token in the corresponding place [16]. However, the indicated notations are accepted for the probabilities of random events and time parameters. Therefore, in this study, the following notations are used to describe the proposed Petri net: D – place, G – transition, T – matrix of time delays of the network token in model places.

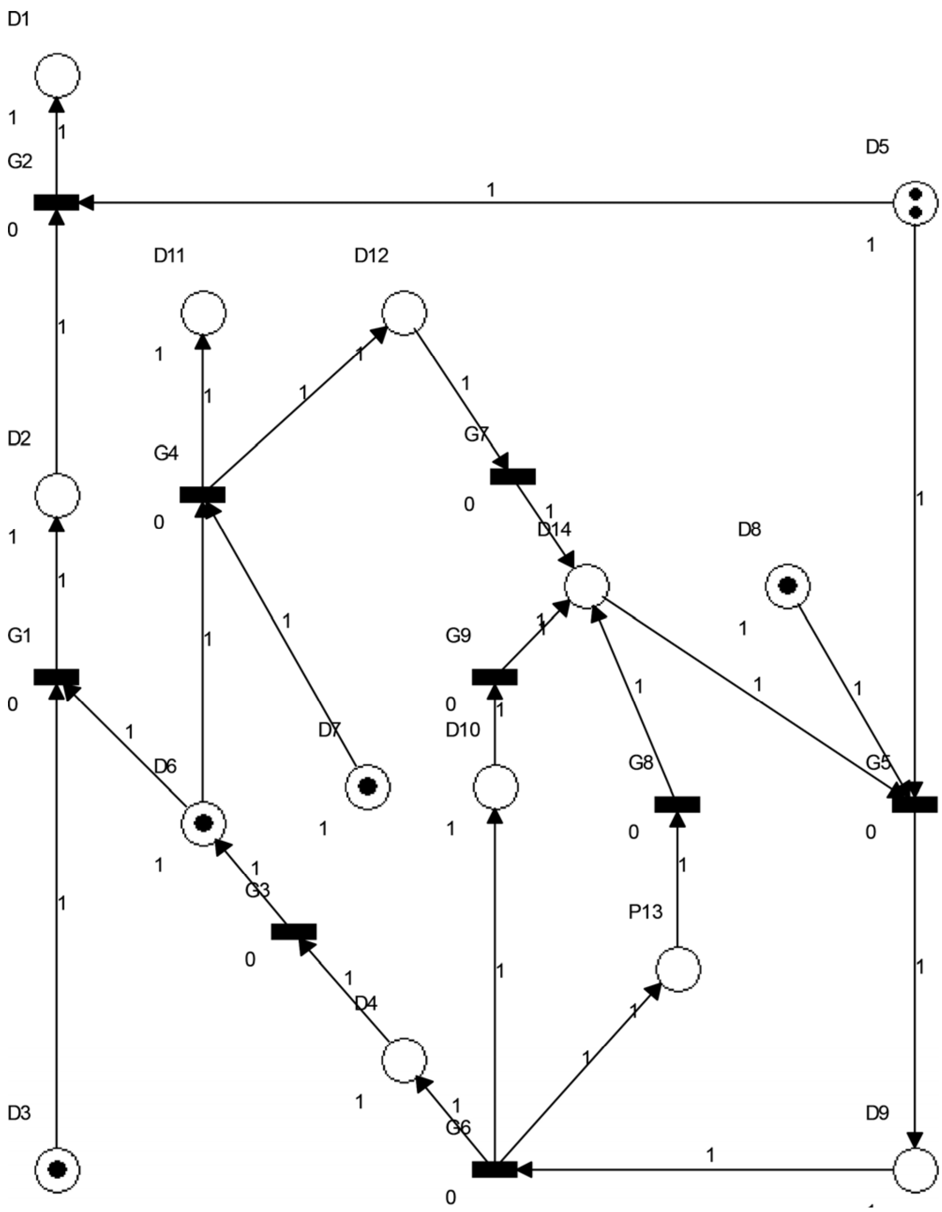

Fig. 1. Model structure in the form of a Petri net

Transitions g_1 and g_5 have the same physical meaning as transitions g_1 and g_5. These transitions are duplicated for the convenience of depicting individual places on the graph. Fig. 1 shows that the proposed Petri net is characterized by two states that have no output (limit states). This is explained by the peculiarity of the functioning of the information-analytical decision-making system as an object operating in the presence of failures in the transmission of information.

After a successful self-monitoring operation, the information-analytical system transmits information (place d_1), after which it is put into an idle state (waiting for further arrival of new information). If it is impossible to carry out repairs by personnel (place d_4), the information and analytical system is also taken out of operation and sent for routine maintenance (repairs) by specialized service centers. If it is impossible to eliminate the identified failures, the information and analytical decision-making system is taken out of service (decommissioned) [17]. Therefore, the model of functioning of an information-analytical decision-making system is characterized by two marginal states.

5. 2. Development of a mathematical model of an information and analytical system

Taking into account the developed graph (Fig. 1), a mathematical model of the functioning of the information and analytical decision-making system is proposed in the form [17]:

$$S=\{D,\ G,\ F,\ M_0,\ T\}, \qquad (1)$$

where $D=\{d_i,\ i=\overline{1,14}\}$ – set of Petri net places;

$G=\{g_j,\ j=\overline{1,9}\}$ – set of Petri net transitions;

$F=F(Q,\ R)$ – Petri net incident function;

$M_0=M(d_6)=\{00000100000000\}$ – initial network marking vector;

$T:D\to t_i=R^+$ network token delay time in places (t_i – token delay in the i-th place; R^+ – set of positive real numbers).

Taking into account the peculiarities of operation and monitoring of the parameters of the information-analytical system, which characterize the presence of failures of channels for transmitting information, channels, places d_i, $i=\overline{1,14}$, and transitions g_i, $j=\overline{1,9}$, have the following designations:

d_1 – the information and analytical system is operational and allows to transmit information with the required indicators of reliability and reliability;

d_2 – conducting self-monitoring of the information and analytical system (before use);

d_3 – the emergence of information that needs to be transmitted through the channels of the information and analytical system;

d_4 – it is necessary to repair the faulty information and analytical system

d_5 – after monitoring the information and analytical system, the result was "proper";

d_6 – the information and analytical system is operational and ready to transmit information;

d_7 – the appearance of a task (fault detection or scheduled monitoring) to monitor the parameters of the information and analytical system, which characterizes checking for failures of information transmission channels;

d_8 – after testing, the result was "faulty";

d_9 – the information and analytical system, based on the results of the control, is determined to be faulty and cannot be used to transmit information;

d_{10} – carrying out adjustment work on the parameters of the information and analytical system to return it to serviceable condition;

d_{11} – the information and analytical system, based on the results of the control, is determined to be serviceable and is allowed to transmit information;

d_{12} – carrying out preparatory operations to monitor the presence of failures in information transmission channels;

d_{13} – replacement of faulty components of the information and analytical system (paths, blocks, elements);

d_{14} – monitoring the presence of failures in information transmission channels;

g_1 – start of self-monitoring of the information and analytical system (before use);

g_2 – end of self-monitoring of the information and analytical system;

g_3 – transfer of a working information and analytical system after self-monitoring to the stage of information transfer;

g_4 – start of preparation for monitoring the presence of failures of the information transmission channel;

g_5 – end of the operation of monitoring the presence of failures of the information transmission channel;

g_6 – start of adjustment work of the information and analytical system;

g_7 – completion of preparation for monitoring the presence of failures of the information transmission channel;

g_8 – completion of replacement of faulty components of the information and analytical system (paths, blocks, elements);

g_9 – completion of adjustment work on parameters of the information and analytical system that are outside the tolerance limits.

The incidence function is specified by the matrices of input and output incidents, respectively:

$$Q(g_1)=\{d_3,\ d_6\};\ \ R(g_1)=\{d_2\};$$

$$Q(g_2)=\{d_2,\ d_5\};\ \ R(g_2)=\{d_1\};$$

$$Q(g_3)=\{d_4\};\ \ R(g_3)=\{d_6\};$$

$$Q(g_4)=\{d_6,\ d_7\};\ \ R(g_4)=\{d_{11},d_{12}\};$$

$$Q(g_5)=\{d_5,\ d_8,\ d_{14}\};\ \ R(g_5)=\{d_9\}; \qquad (2)$$

$$Q(g_6)=\{d_9\};\ \ R(g_6)=\{d_4,\ d_{10},\ d_{13}\};$$

$$Q(g_7)=\{d_{12}\};\ \ R(g_7)=\{d_{14}\};$$

$$Q(g_8)=\{d_{13}\};\ \ R(g_8)=\{d_{14}\};$$

$$Q(g_9)=\{d_{10}\};\ \ R(g_9)=\{d_{14}\}.$$

The input incident $Q(g_i)=\{d_i, d_j\}$ shows that for the transition g_i to be fired, places d_i, d_j must be executed, that is, the presence of a network token in them. For example, the entry $Q(g_1)=\{d_3, d_6\}$ shows that to begin self-control (transition g_1), a token must be present in places d_3 (a task has been received to transmit information) and d_6 (the information-analytical system is ready to transmit information). The input incident $R(g_i)=\{d_i, d_j\}$ shows that after the transition g_i is fired, place d_i is executed, that is, the network token will move to it. For example, the entry $R(g_9)=\{d_{14}\}$ shows that after the end of regulation (transition g_i), place d_{14} is executed, that is, monitoring the parameters of the information-analytical system for the presence of failures of the information transmission channel.

The vector of the initial marking of the network M_0 (the presence of a unit token in the corresponding column) shows in what place the token is located before the start of its operation (for this model, the initial state is that the information and analytical system is operational and ready to transmit information, the token is in place d_6).

The set of positive real numbers R^+ of the matrix T characterizes the time the simulated system is in the corresponding state (place).

Place delays have the following meanings:

$$T=\left\{0,\ \tau_{pk},\ 0,\ \tau_{nv},\ 0,\ T_n,\ 0,\ 0,\ 0,\ \tau_v,\ 0,\ 0\ ,\tau_{z_i},\ \tau_n\right\}, \qquad (3)$$

where τ_{pk}, τ_{nv}, T_n, τ_v, τ_{z_i}, τ_n are the time parameters of using the information and analytical system.

Some delay values in the matrix are zero. This is explained by the fact that fulfilling the conditions in places does not require any time overhead, so in them the token delay is zero. At place d_{12}, the token delay time is zero, since it is included in the control duration.

To resolve the conflict at transition g_6 (after moving to the place, it is necessary to determine the type of routine maintenance – the direction of movement of the token), a defining place has been introduced – r_n. If r_n=0, then the token moves from place d_9 to place d_4. If r_n=1, then the token moves to place d_{10}; if r_n=2, the token moves to place d_{13}.

Places d_5, d_8 use the reliability characteristics of the information transmission channels of the information and analytical system for the result of monitoring the presence of failures. The presence of a token in one of the two considered places characterizes the serviceability (malfunction) of the information and analytical system and determines the options (opportunities) for its further use.

5. 3. Verification of the proposed model

Petri net modeling is simulation modeling. Therefore, to verify the proposed model of the information-analytical system, it was checked for limitations, security, persistence and completeness of the network.

The property of limitation is associated with the limited capacity of real conditions for the implementation of events.

From the definition of the rules for firing network transitions, it follows that in order to implement an event modeled by a certain transition, it is sufficient that each of its input places contains a certain finite number of tokens equal to the multiplicity of the arc connecting it with the transition. However, when the network operates, some of its places can accumulate an unlimited number of tokens. The network limited property shows that the number of tokens in network places is limited and does not exceed a specified value.

One of the most important properties of a Petri net that models a real device is security. For example, the same information and analytical system cannot simultaneously be used to transmit information and be subject to regulation (restoration). Simultaneous transmission of information and monitoring of the presence of failures of the information transmission channel is also not allowed. Using the example of the given network, it can be seen that if tokens mistakenly appear simultaneously in places d_3 and d_7, only one transition will be fired – g_2 or g_4, since performing, for example, transition g_2 will lead to the loss of the token in place d_6 and transition g_4 will be impossible.

The network persistence property indicates that tokens are never created or destroyed. This characterizes the fact that the network places that model the states of a real object are executed in the strictest sequence and the model has a clear completion after the cycle is completed. For example, after performing preparatory operations to monitor the presence of failures, the information transmission channel, the system moves to the parameter monitoring stage, i. e., the token from place d_{12} moves to place d_{14}.

The completeness property of a network comes down to the fact that from the initial marking it is possible to achieve the required state of the model.

Let's analyze the modeled information and analytical system for adequacy. There are two known analysis methods for Petri nets [3, 16, 18]:

– a method based on solving matrix equations;

– a method based on constructing a reach tree.

The matrix method appeared relatively recently and has not yet been fully studied; due to existing shortcomings, it is rarely used. Two difficulties of the matrix method of Petri net analysis have been identified:

– the matrix obtained from the matrices Q and R (2) does not fully reflect the structure of the Petri net;

– there is no information about the sequence of the transition fire vector.

Therefore, a method based on constructing a reach tree was used. A reach tree is a set of possible places of a Petri net and reflects the possible states of the modeled system. Marking, for example $M\{0\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\}$, shows that at this step of the model the network token is in place d_4, that is, it is necessary to restore the faulty system. Zeros in the marking indicate the absence of a token in the corresponding place.

A distinctive feature of the proposed model of an information-analytical system from a similar model given in [3] is a clear distinction between the concepts of reliability and validity of information transmission channels. In the proposed model of an information-analytical system, the influence of the reliability of the information transmission channel on the efficiency of using the information-analytical system is determined for the first time.

During use, the reliability characteristics of information transmission channels change randomly over time, which leads to possible failures. Moreover, obvious failures can often be determined visually, for example, loss of full or partial operability of equipment. In this case, hidden failures are detected only after inspection, since this type of failure is caused by the characteristics of the information and analytical system exceeding the established acceptable limits, which cannot be visually determined. Hidden failures of the information and analytical system occur much more often than obvious ones, while the process of change (drift) of characteristics occurs continuously and regardless of whether the system is in use or in standby mode. Therefore, the model of the information-analytical system takes into account the influence of a hidden failure of the information-analytical system (states d_5, d_8) on the result of monitoring the parameters for identifying failures of the information transmission channel. This makes it possible to increase the reliability of decision-making about the suitability of the information-analytical decision-making system for transmitting information.

To test the performance of the proposed mathematical model of the information-analytical system and conduct simulation experiments, it was implemented in the HPSim software tool. The choice of the software tool was due to the fact that today it is one of the most popular applications for working with Petri nets. The HPSim software tool is freely distributed and is successfully used in modeling processes in complex systems. The program tabs and icons are standard for Windows programs.

A Petri net is executed by firing transitions. The transition can be started only if at least one token is present in all input places. One token is subtracted from each input place and one is added to each output place. Only one transition can fire at a time, which solves the problem of conflicts (when one place is associated with several transitions ready to be executed).

The program window that appears starting HPSim is shown in Fig. 2.

Fig. 3 shows the intermediate state of the Petri net of the developed mathematical model. The location of the tokens in the places corresponds to the formed system of states of the individual elements of the information-analytical system, and the highlighted transitions indicate those fired in the last cycle of the simulation.

From the analysis of Fig. 3 it can be seen that the proposed model was tested for correctness and the possibility of performing the stage of functioning of the information and analytical system - the system is operational and ready for transmitting information through channels. Thus, an information and analytical system is capable of transmitting information without loss when:

– option 1:

1) the appearance of information that needs to be transmitted through the channels of the information and analytical system (place d_3);

2) after monitoring the information and analytical system, the result was "proper" (place d_5);

3) the information and analytical system is operational and ready to transmit information (place d_6);

– option 2:

1) monitoring the presence of failures in information transmission channels (place d_{14});

2) carrying out adjustment work on the parameters of the information and analytical system to return it to serviceable condition (place d_{10});

3) based on the results of the control, the information and analytical system is determined to be serviceable and is allowed to transmit information (place d_{11}).

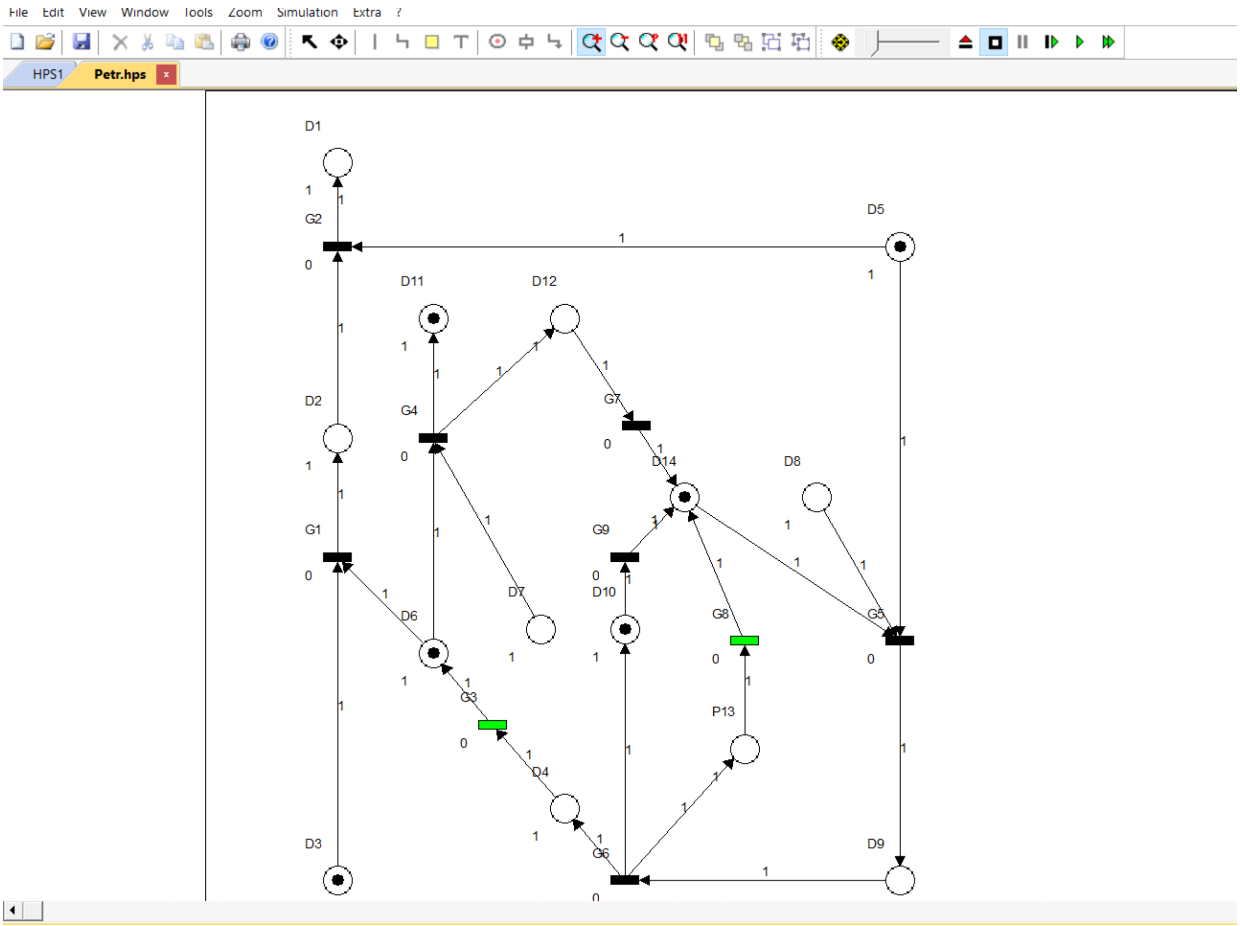

Fig. 2. Window of the HPSim simulation tool

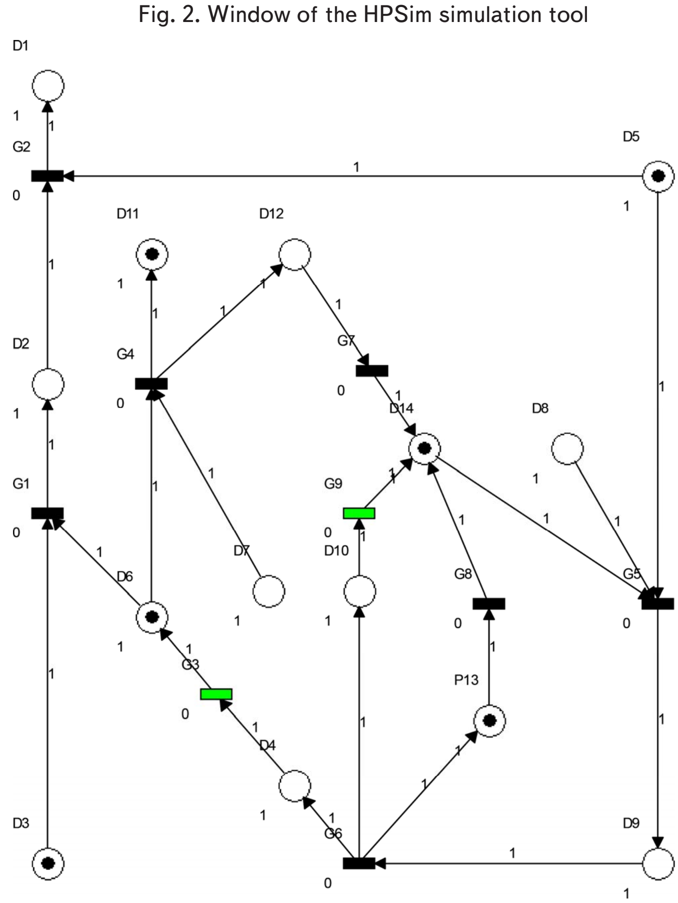

Fig. 3. Intermediate state of the Petri net during the modeling process

Thus, the intermediate state of the model (Fig. 3) shows the possibility of fulfilling places d_3, d_5, d_6, d_{10}, d_{11}, d_{14}, which corresponds (does not contradict) the real functioning of the information and analytical system.

6. Discussion of the results of simulation modeling of the developed model of information and analytical decision-making system

The study proposes a model of an information-analytical system for detecting failures of information transmission channels. The results of the simulation (Fig. 3) of the developed model in the form of a graph (Fig. 1), mathematical (formulas (1)–(3)) and software (Fig. 2) descriptions confirmed its successful verification.

From the analysis of Fig. 3 shows that the proposed model has two transitions (two rectangles are highlighted in green), which can occur simultaneously. In this case, the remaining transitions (rectangles highlighted in black) and places (black circles) do not occur simultaneously, and the movement of the token (black dot) depends on the execution of the developed mathematical model (1), matrices of input and output incidents (2) and the delay time in places (3). The simultaneous appearance of two places g_3 and g_8 (highlighted in green) is explained by the modeling conditions. The stages of functioning of the information and analytical system involve a transition from place g_8 to place g_3. This is explained by the fact that after the completion of the replacement of faulty components of the information-analytical system (paths, blocks, elements) (place g_8), it is subject to self-control and is allowed to transmit information (place g_3).

When modeling in the HPSim software tool, black symbols mean the absence of conflict situations in the model when examining it for limitations, safety, persistence and completeness of the network. Thus, the simulation results (Fig. 3) of the developed model confirm its correspondence between the mathematical (formulas (1) – (3)), graphic (Fig. 1) and software (Fig. 3) description (verification).

The features of the proposed model in comparison with the known ones are as follows. The development of methods for identifying failures of information transmission channels is based on the use of the following mathematical (analytical) apparatus:

– state space models (for example, Markov models);

– graphs (dependencies) of events, Bayesian networks;

– models of stochastic game theory, stochastic programming.

Such an apparatus presupposes sequential actions, ordered sampling paths or situations that are static in time. This implies many simultaneous streams of events.

From the many existing approaches to modeling, an approach focused on the use of Petri nets was chosen. Petri nets overcome some of the shortcomings of other methods. They allow the modeling of parallel, simultaneous streams of events (for example, information transfer and control of transmission channel failures), allow statistical analysis (including Bayesian) through stochastic extensions, and can also be used as a tool for managing and modeling dynamic scenarios.

The developed model makes it possible to identify possible hidden failures of information transmission channels, which may be associated with degradation of channel elements or loss of parameters due to long-term (or harsh) operation. Such features of the proposed model are a significant advantage, since known similar models and methods are aimed at detecting obvious failures.

The limitations of this study include the finite number of possible states during the functioning of the information and analytical system. At the same time, the proposed number of states for the system under consideration reflects its real process of functioning, although it may not be complete.

The disadvantage of this study is the lack of consideration of the probability of the mark being in the corresponding place. Therefore, the developed model does not take into account, for example, random factors (such as a hacker attack, a sharp change in the characteristics of the power supply, etc.) during the operation of the information and analytical system.

The development of this study may be as follows.

Formalization. Continued improvement of the formalism of modeling the information-analytical decision-making system to identify not only failures of information transmission channels, but also the implementation of cyber attacks on the corresponding elements of the system. Increasing the level of formalization opens up the possibility of automatically generating Petri net models for any other scenario using fault trees and attacks, as well as a significant complication of the scenarios used.

Education. Implementation and extension of machine learning methods to larger models of data transmission channel failures and cyber attacks on target computer systems. Such models are formed as a result of the synthesis of models from several components. The study shows the use of Petri nets as a promising tool for analyzing and assessing the reliability and security of information transmission channels. In the future, it is planned to increase the system performance by training data using a learning algorithm and developing a methodology for automatically creating protection trees against failures and attacks for Petri net models.

Integration. Improving software integration of simulation tools, increasing the visibility of modeling results and simplifying the use of tools through a web interface. Implementation of the transition to an object-oriented Petri net modeling environment.

7. Conclusions

1. A graph of the information-analytical system model has been constructed, implemented in the form of a Petri net. The proposed network is characterized by two states that have no output (limit states), which is explained by the peculiarity of the functioning of the information-analytical decision-making system as an object operating under conditions of failures in the transmission of information.

2. A mathematical model of the information-analytical system has been developed, which is a formal description of the model graph in the form of a Petri net. A set of places is defined, reflecting the possible states of the information-analytical system, a set of transitions, reflecting the conditions for transition to the corresponding states, the initial state of the network is specified, and time delays are determined that characterize the dynamics of the functioning of the information-analytical system.

3. The verification of the proposed model of the information-analytical system has been carried out. The model has

been verified using such characteristics of network models as limitedness, safety, integrity and completeness. The simulation results of the developed model of the information-analytical system confirm its correspondence between the mathematical, graphic and program description. The developed model has been tested for verification.

Conflict of interest

The authors declare that there are no conflicts of interest regarding this study, including financial, personal, authorship or other nature, which could influence the research and its results presented in this article.

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Data Availability

The manuscript has no associated data.

Use of artificial intelligence

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

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