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THEMATIC ISSUE

Models and Methods for Checking the Attainability of Goals and Feasibility of Plans in Large-Scale Systems Using the Example of Goals and Plans for Elimination of the Consequences of Flood

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Abstract—Models and methods have been developed to verify the achievability of goals and the feasibility of plans implemented when managing large-scale systems in their development. An algorithm for analyzing the achievability of a set of goals and plans implemented when managing these systems is proposed and justified. Statements and hypotheses that make it possible to machine-check the feasibility of plans have been generated. A model example is given that confirms the possibility of checking the feasibility of plans for eliminating the consequences of a flood using the developed models and methods. In managing large-scale systems development, it is advisable to use control loops that check the achievability of set goals and the feasibility of plans over a selected time interval. In the absence of this verification, the chosen trajectory of development of a large-scale system at specific points in time may turn out to be unrealizable, which will lead to disruption of the work being carried out, as well as to significant costs of the human, financial, technical and other types of resources for the implementation of obviously impracticable plans.

Keywords: autonomous goal setting, achievability of goals, feasibility of structurally complex plans, system dynamics

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1. INTRODUCTION

Considerable attention is paid to the study of models and methods for forming and testing the achievability of set goals when managing complex human-machine, social, economic, and biological systems. Currently, checking the achievability of a set of goals carried out when planning, designing, and managing large-scale systems needs to be formalized more and is carried out mainly using the intuition and experience of decision-makers. Characteristics of targets at various levels of the hierarchy, as well as indicators of their implementation, can change significantly over time intervals for achieving goals, which complicates the activities of decision-makers in designing and managing large-scale systems and planning the results of their activities. Issues of formalizing the goal-setting procedure were discussed in the works of domestic and foreign researchers [1, p. 5]. The results obtained in this area of research, however, have not yet led to the creation of a holistic set of models and methods that make it possible to verify the achievability of the goals of large-scale systems. The lack of these developments, as well as specialized mathematical and information software designed to verify the achievability of the goals of large-scale systems, as well as plans for their creation and development, understood as a series of actions combined sequentially to achieve a goal with possible deadlines, causes difficulties in the development and management of human-machine, economic, social objects [2, p. 252].

The article is devoted to developing of new tasks, models, and methods for checking the achievability of goals and the feasibility of plans in large-scale systems.

2. MAIN AREAS OF RESEARCH

We develop the following models and methods for testing the achievability of goals and the feasibility of plans in large-scale systems:

1. To develop a methodological basis for creating an intelligent system that allows anyone to predict, identify, and prevent events that lead to the impracticability of action plans based on the mathematical apparatus of system dynamics, probabilistic safety analysis, and the theory of Bayesian networks [3, p. 168].

2. To formulate and justify a general approach to checking the feasibility of structurally complex plans, which involves analyzing feasibility using the apparatus of Boolean functions, Bayesian networks, and knowledge representation models of intelligent systems, as well as using the system dynamic approach and system dynamics equations [4, p. 21].

3. To develop models and methods for an intelligent decision support system designed to analyze the feasibility of structurally complex action plans using logical probabilistic models, Bayesian networks, a system dynamic approach, the mathematical apparatus of probabilistic safety analysis, and the theory of deep neural networks.

4. Develop methods that allow anyone to present the plan being tested in the form of a hierarchical cause-and-effect model and generate indicators of its feasibility.

5. To create models and methods for checking quickly the achievability of goals and the feasibility of plans using the apparatus of dynamic graphs and knowledge representation models, characterized by the ability to analyze plans over long time intervals in dynamics, which will allow timely changes to plans for large-scale systems when their impracticability occurs.

6. To develop problem statements, models, and methods to test the feasibility of a structurally complex action plan using a system dynamic approach. The action plan is presented as a cause-and-effect network of events. The modeled variables are indicators characterizing the implementation of individual plan activities. The arcs are the cause-and-effect relationships that exist between these indicators. A system of differential equations is written, and the initial conditions corresponding to the desired values of the indicated indicators are determined. A verifiable structurally complex plan is feasible if the generated system of equations under the selected initial conditions has the solution in a given range.

7. To propose and justify methods for conducting computational experiments that characterize the possibilities of using the developed mathematical software when testing the feasibility of a structurally complex action plan for domestic energy development.

8. To create and test a problem-oriented intelligent decision support system that implements the main results of this research.

3. FORMULATION OF THE PROBLEM

The formulation of the problem of checking the feasibility of plans for the functioning of industrial enterprises and organizations in a substantive and formal form is given in [5–8]. In those papers, this statement is extended to the goals of large-scale systems and plans for their implementation.

It has the following formulation: models and methods for checking the achievability of goals and the feasibility of plans used in large-scale systems at various time intervals during their creation and operation; identify possible reasons that impede the solution of this problem and suggest ways to eliminate them. Solving this problem will make it possible to create a methodological basis for the development of intelligent goal-setting systems, the use of which in managing large-scale complexes will significantly increase the efficiency of their functioning. Some approaches to managing development plans and programs are shown in [9–12].

4. GENERAL APPROACH TO THE SOLUTION

Imagine the plan being tested as the tree containing conjunctive and disjunctive vertices. The possibility of such a transformation follows from its hierarchical structure (conjunctive vertices) and the conditions for implementing individual activities $M_i \in \{M_1, \dots, M_n\}$. Each vertex of the graph G lets us match the variable g_i, $i = \overline{1, n}$, which takes the value 1 when the event is performed M_i and the value is 0 if it is not executed. The developed solution method is based on the following statements.

Statement 1. *At the moment in time $t_0 \in [t_h, t_k]$, plan $P(\vec{x}, \vec{u}) \in \{P(\vec{x}, \vec{u})\}$ is impossible if the output is at least one chain of conjunctive and/or disjunctive vertices connecting any terminal vertex connecting any terminal vertex of the tree G with its root vertex, so the relation is valid $g_i = 0$.*

The description of this statement follows from the fact that if at least one plan event that is part of the conjunctive chain is not completed, then the entire plan will not be completed since otherwise, the vertex corresponding to this event must be excluded from the graph as not affecting the execution plan. This statement is a necessary condition for satisfiability $P(\vec{x}, \vec{u}) \in \{P(\vec{x}, \vec{u})\}$, asserting that for the plan to be feasible, each activity must be completed $M_j \in \{M_1, \dots, M_n\}$, without which the corresponding event $M_j \in \{M_1, \dots, M_n\}$ is impossible.

Statement 2. *Let us assume that at the moment of time $t_0 \in [t_h, t_k]$ there are unfulfilled activities $M_j \in \{M_1, \dots, M_n\}$, included in tree chain composition G, connecting the root vertex to the terminal ones. Then, the plan $P(\vec{x}, \vec{u}) \in \{P(\vec{x}, \vec{u})\}$ will not be feasible at a given time if there is at least one tree section G, with the output of a conjunctive-disjunctive chain $g_i = 0$.*

In the design and management of large-scale systems, a goal or a plan developed to achieve it is considered achieved if the requirements of the above statements are met. The problem with using this approach to checking the feasibility of goals is that the boundaries of the numerical range are determined by the decision maker, usually based on experience and intuition based on opportunistic considerations using largely incomplete and subjective ideas about the system, time-varying cause-and-effect relationships, existing between individual indicators, with insufficient consideration of the influence of environmental disturbances, etc. All this leads to the fact that plan $P(\vec{x}, \vec{u}) \in \{P(\vec{x}, \vec{u})\}$ may not be feasible at specific points in time, the occurrence of which is complicated to predict in advance.

The hypothesis forms a sufficient condition for checking the plan when using a system of indicators. It allows anyone to present the main stages of checking the achievability of goals and the feasibility of plans in the diagram (Fig. 1).

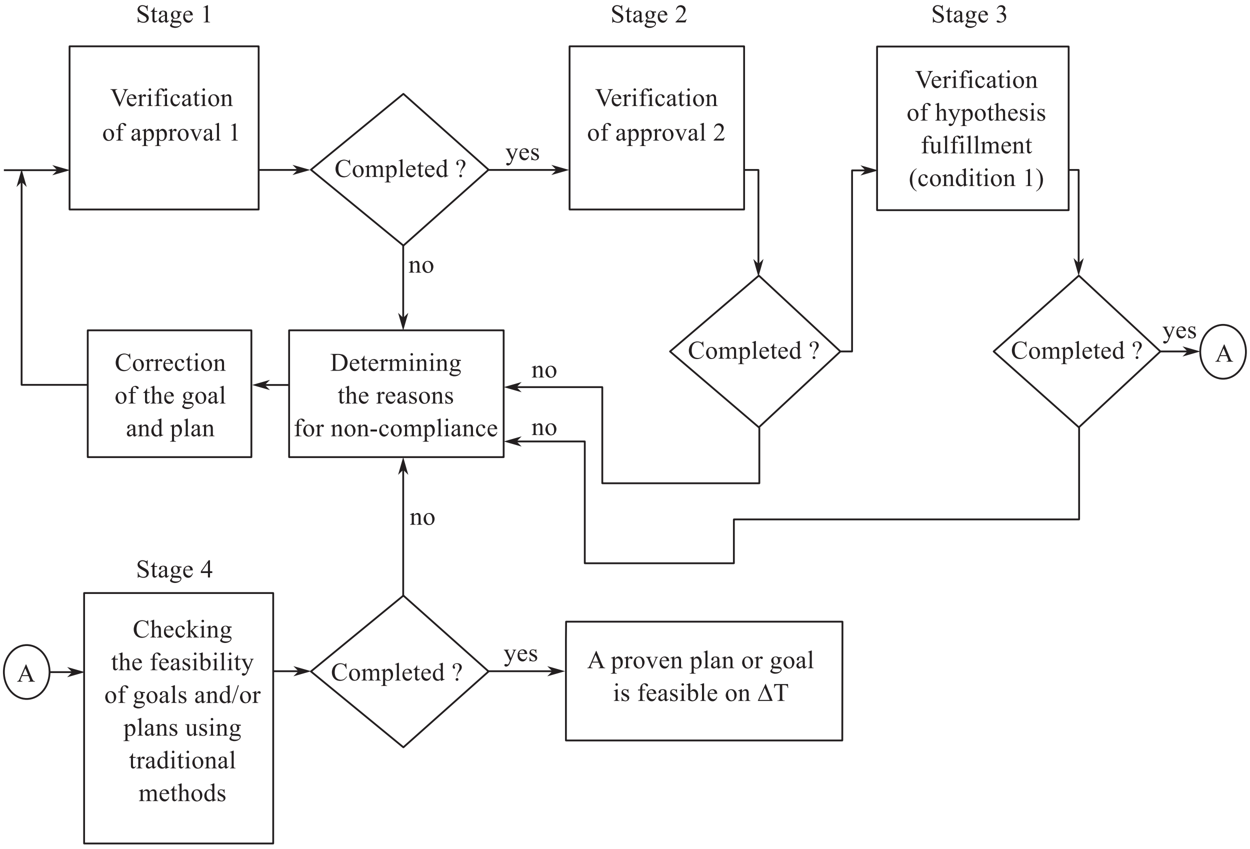

Fig. 1. Main stages of checking the achievability of goals and feasibility of plans.

Proposition 1. *Plan $P(\vec{x}, \vec{u}) \in \{P(\vec{x}, \vec{u})\}$ will be achieved within a given time interval ΔT, if a system of indicators of its achievability is known $l_1, \ldots, l_m$, for which the following is performed:*

$$\exists t_i \in \Delta T : \min l_i \leqslant l_i \leqslant \max l_i, \quad i = 1, \ldots, m, \tag{1}$$

where $\min l_i$, $\max l_i$ *are the lower and upper limits of indicator changes* l_i*;* m *is a known constant.*

Decision makers widely use this hypothesis when checking the achievability of goals at various levels of the management hierarchy of large-scale systems. This circumstance confirms the possibility of its use in the development of a computer system for verifying the achievability of goals and the feasibility of plans.

In the first stage, the fulfillment of statement (1) is checked; if in the conjunctive chains connecting the terminal vertices with the terminal one, at least one event has not been completed, then the goal or plan is impossible and requires correction. In the second stage, the requirements for goals are checked and plans, excluding the possibility of approving a plan that is not feasible due to an unfavorable combination of events (Statement 1). In the third stage of verification, it is determined whether all indicator values $t_0 \in [t_h, t_k]$ are within the acceptable range for all periods all $l_1(t_0), \ldots, l_m(t_0)$. When checking this condition, the apparatus of system dynamics is used since the indicators are influenced by a large number of linear and nonlinear feedbacks, as well as time-varying environmental disturbances. In the fourth stage, mathematical tools are used to check plans' achievability and goals' feasibility.

5. FEASIBILITY CHECKING ALGORITHM OF THE ACTION PLAN

Algorithm 1.

1. The beginning of the algorithm.

2. Set the vertex u^* on the graph $G^*(U,E)$, having zero half-degree of approach. This vertex corresponds to the vertices M_1 or Z_1, characterizing the implementation of the action plan or the achievement of the general goal, respectively.

3. Set all vertices $u_{m_0}, u_{k_0}, \ldots, u_{l_0} \in U$ on the graph $G^*(U,E)$ with incidental u^*. Add the first condition into the emerging product model F: Plan M or goal Z_1 will be carried out when carrying out activities or goals corresponding to the vertices $u_{m_0}, u_{k_0}, \ldots, u_{l_0}$.

4. Continue step 2 until the vertices reach $G^*(U,E)$ with zero half-degree of outcome. Thus, build the production model F ultimately.

5. Match the production system with a logical function $f(u_{1k}, \ldots, u_{vk})$, which takes the value 0 if the plan has not been completed, or 1 otherwise.

6. Construct a digital discrete device circuit DU, to determine the values $f(u_{1k}, \ldots, u_{vk})$, and the function indicators $f_{ind}(C, C_1)$, which characterize the degree of implementation of the action plan or achievement of the general goal.

7. Submit at the entrance DU binary signals characterizing the fulfillment or non-fulfillment of individual activities of the plan under review or the goals of the analyzed target structure. At $f_{ind}(C, C_1) = 1$ the plan is feasible or the goal is achievable; if $f_{ind}(C, C_1) = 0$, then it is necessary to correct them.

8. Moving along the branches of propagation of zero signals of the device DU, determine the reasons for the plan's impracticability or the goal's unattainability and report them to the decision maker.

9. Determine whether the conditions for using the Kolmogorov–Chapman equations are met to calculate the probability of failure to complete the action plan or the unattainability of the goal. If not, then go to step 10.

10. Determine the minimum sections L_i, $i = 1, \ldots, m$, characterizing failure to implement a plan or achieve a goal due to a combination of unfavorable circumstances. Each of the minimum sections characterizes one of the combinations of relatively unimportant events, which in their totality lead to the goal's unattainability and the plan's impracticability.

11. Solving the system of linear homogeneous Kolmogorov–Chapman equations for each minimal section, determine the probability of an unfavorable combination of circumstances occurring P_i, $i = 1, \ldots, m$.

12. If $P_i \geqslant \varepsilon$, $i = 1, \ldots, m$, then issue a message about the high probability of unattainability of the goal and impracticability of the plan due to an unfavorable combination of event L_i, $i = 1, \ldots, m$, issue recommendations to the decision maker, change the goal or plan being checked and proceed to step 7.

13. Select an indicator system I_i, $i = 1, \ldots, h$, which characterizes the feasibility of the plan being tested or the achievability of the goal. Identify relevant relationships between indicators, which can be linear or nonlinear. Determine environmental disturbances affecting the indicators.

14. Determine the limit values of indicators I_i^*, $i = 1, \ldots, h$, the achievement of which means the feasibility of the plan being verified or the feasibility of the set goal.

15. Create a system of nonlinear differential equations in the normal Cauchy form, characterizing the change in the system of indicators over time, considering their mutual influence and the impact of environmental disturbances.

16. Solve a system of equations using one of the numerical methods under given initial conditions. If the solutions obtained go beyond the area limited I_i^*, $i = 1, \ldots, h$, then issue a message to the decision maker, recommend actions to eliminate the discrepancy, and proceed to step 10.

17. Message the decision maker that the check did not reveal the goal's unattainability or the plan's impracticability.

18. End of the algorithm.

6. GOAL ACHIEVABILITY CHECKING AND THE ACTION PLAN FEASIBILITY

Let us consider the features of implementing individual stages of checking the achievability of goals and the feasibility of plans for a large-scale system using a plan to eliminate the consequences of floods and floods [13–16]. The problem statement has the following formulation:

Task 1. Develop formal models and algorithms that allow, on a time interval $t \in [t_0; t_N]$ determine whether goal attainability indicators are missing $X_i(t, a(t), p(t))$, $i = 1, \ldots, n$ beyond specified limits: $X_i(t, a(t), p(t)) \geqslant X_i^{\min}$, $i = 1, \ldots, n$. If this condition is not satisfied for at least one indicator, then the plan is considered unfeasible due to the inability to achieve the required value of this indicator.

The indicator values are determined by solving a system of nonlinear differential equations $\frac{dX_i(t,p(t),a(t))}{dt} = f(t, a(t), X_1(t, p(t)), \ldots, X_n(t, p(t)))$, $i = 1, \ldots, n$ at $t > 0$, $0 < X_i(t, a(t), p(t)) \leqslant M_{\max}^{X_i}$, $i = 1, \ldots, n$, where X_i^* are recommended values for characteristics of flood consequences, $X_i(t, a(t), p(t))$, $i = 1, \ldots, n$ are characteristics of the consequences of flooding, affecting the amount of damage, γ_i are the weight coefficient of the characteristic, $a(t)$ is the vector of environmental parameters.

6.1. Mathematical Model

The following system of first-order nonlinear differential equations describes the mathematical model.

$$\frac{dX_i(t, a(t), p(t))}{dt} = f_i^+(F_1, \ldots, F_m) - f_i^-(F_1, \ldots, F_m), \quad i = 1, \ldots, n, \tag{2}$$

where f_i^+, f_i^-, $i = 1, \ldots, n$ – rates, continuous or piecewise continuous functions that determine the positive and negative rate of change in the value of a system variable $X_i(t, a(t), p(t))$, $i = 1, \ldots, n$. Functions f_i^+, f_i^-, $i = 1, \ldots, n$ are functions of factors F_j, $j = 1, \ldots, m$, wherein F_j may be system variables or environmental parameters.

The directed cause-and-effect graph shows the relationships between model variables (Fig. 2).

The functions on the right side of (3) have the form

$$f_i^{+/-}(F_1, \ldots, F_n) = \sum_{l=1}^{n} k_{i,l}^{+/-} \prod_{j=1}^{n} f_{i,l}^{F_j}(F_j),$$

where coefficients $k_{i,l}^{+/-}$, $i = 1, \ldots, 12$ are determined at the stage of adapting the model to the object of study. Let us also assume that the coefficients $k_{i,l} = 0$, $l = 1, \ldots, m-1$, $k_{i,l} \neq 0$, $l = m$, $k_{i,l} = 0$, $l = m+1, \ldots, n$. Then this expression will take the form $f_i^{+/-}(F_1, \ldots, F_n) = k_i^{+/-} \prod\limits_{j=1}^{n} f_i^{F_j}(F_j)$.

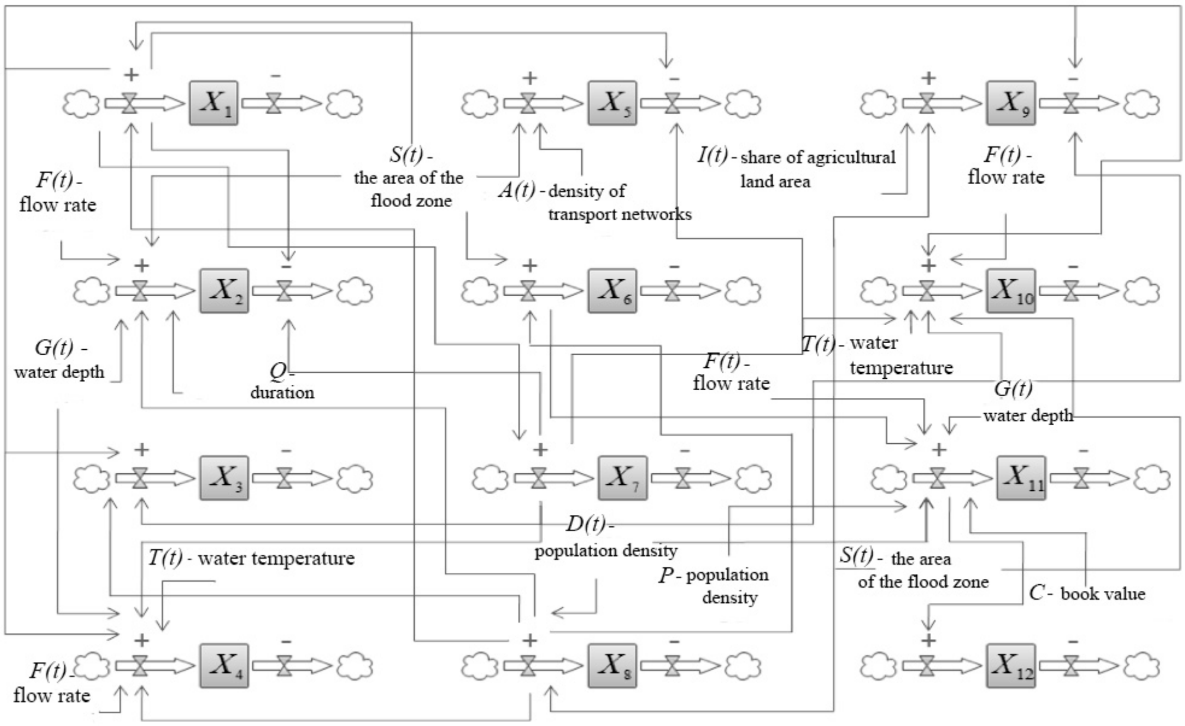

Fig. 2. Cause-and-effect relationships between model variables.

The developed mathematical model will have a general form based on the analysis of the graph of cause-and-effect relationships:

$$\begin{cases}
\dfrac{dX_1(t)}{dt} = k_1^+ f_1^S(S(t)) f_1^{X_8}(X_8(t)), \\
\dfrac{dX_2(t)}{dt} = k_2^+ F(t)G(t)t f_2^S(S(t)) f_2^{X_8}(X_8(t)) - k_2^- f_2^{X_1}(X_1(t)) f_2^{X_7}(X_7(t)), \\
\dfrac{dX_3(t)}{dt} = k_3^+ f_3^{X_8}(X_8(t)) f_3^{X_1}(X_1(t)) f_3^{X_7}(X_7(t)), \\
\dfrac{dX_4(t)}{dt} = k_4^+ F(t)G(t)T(t) f_4^{X_8}(X_8(t)) f_4^{X_7}(X_7(t)) f_4^{X_1}(X_1(t)), X_1(t)), \\
\dfrac{dX_5(t)}{dt} = k_5^+ A(t) f_5^S(S(t)) - k_5^- f_5^{X_1}(X_1(t)) f_5^{X_7}(X_7(t)), \\
\dfrac{dX_6(t)}{dt} = k_6^+ f_6^S(S(t)) f_6^{X_8}(X_8(t)), \\
\dfrac{dX_7(t)}{dt} = k_7^+ f_7^{X_1}(X_1(t)), \\
\dfrac{dX_8(t)}{dt} = k_8^+ D(t) f_8^S(S(t)) - k_8^- f_8^{X_4}(X_4), \\
\dfrac{dX_9(t)}{dt} = k_9^+ I(t) f_9^S(S(t)) - k_9^- f_9^{X_1}(X_1(t)) f_9^{X_7}(X_7(t)), \\
\dfrac{dX_{10}(t)}{dt} = k_{10}^+ F(t)G(t)T(t) f_{10}^S(S(t)) f_{10}^{X_1}(X_1(t)) f_{10}^{X_7}(X_7(t)), \\
\dfrac{dX_{11}(t)}{dt} = k_{11}^+ PCF(t)G(t)D(t) f_{11}^S(S(t)) f_{11}^{X_6}(X_6(t)), \\
\dfrac{dX_{12}(t)}{dt} = k_{12}^+ f_{12}^{X_{11}}(X_{11}(t)),
\end{cases} \tag{3}$$

where $f_j^{X_i}$ – functional dependence of the system variable on $X_j(t)$ from X_i, and f_j^S – dependence of the X_j from $S(t)$, $i, j = 1, \ldots, 12$. If such dependencies are unknown, they can be determined based on statistical data by experts or software developers.

The mathematical model will take the following form, taking into account the polynomials of auxiliary dependencies:

$$\begin{cases}
\dfrac{dX_1(t)}{dt} = \dfrac{1}{X_1^{\max}}(k_1^+(0.001S^3(t) - 0.04S^2(t) + 0.6S(t) - 2.1)\\
\times(54X_8^4(t) - 137X_8^3(t) + 103.4X_8^2(t) - 20.7X_8(t) + 1.2)),\\
\dfrac{dX_2(t)}{dt} = \dfrac{1}{X_2^{\max}}(kt(-0.02S^3(t) + 0.64S^2(t) - 6.4S(t) + 21)\\
\times(-14.5X_8^2(t) + 22.5X_8(t) - 3.3) - k_2^-(0.57X_1^2(t) + 0.276X_1(t) + 0.05)\\
\times(-3.3X_7^2(t) + 5.6X_7(t) - 0.13)),\\
\dfrac{dX_3(t)}{dt} = \dfrac{1}{X_3^{\max}}(k_3^+(3.28X_8^2(t) - 23.31X_8(t) + 12.3)\\
\times(-1.26X_1^2(t) + 10.1X_1(t) - 17.8)(-0.33X_7^2 + 2.2X_7 - 0.26)),\\
\dfrac{dX_4(t)}{dt} = \dfrac{1}{X_4^{\max}}(k_4^+F(t)G(t)T(t)(-1.3X_8^4(t) + 1.92X_8^3(t) - 0.95X_8^2(t)\\
+0.3X_8(t) + 0.7)(-0.42X_7^4(t) - 7.19X_7^3(t) + 19.34X_7^2(t) - 15.1X_7(t) + 4.435)\\
\times(X_1^3(t) - X_1^2(t) + 1.5X_1(t) + 0.02)),\\
\dfrac{dX_5(t)}{dt} = \dfrac{1}{X_5^{\max}}(k_5^+A(t)(0.01S^2(t) - 0.1S(t) + 0.5) - k_5^-(0.217X_1^2(t)\\
-0.505X_1(t) + 0.3(-0.304X_7^2(t) + 1.1X_7(t) + 0.26)),\\
\dfrac{dX_6(t)}{dt} = \dfrac{1}{X_6^{\max}}(k_6^+(0.002S^2(t) + 0.056S(t) + 0.48)(-0.05X_8^3(t)\\
+0.9X_8^2(t) - 0.02X_8(t) + 0.23)),\\
\dfrac{dX_7(t)}{dt} = \dfrac{1}{X_7^{\max}}(k_7^+(3.5X_1^3(t) - 5.3X_1^2(t) + 3.27X_1(t) + 0.0003)),\\
\dfrac{dX_8(t)}{dt} = \dfrac{1}{X_8^{\max}}(k_8^+D(t)(0.18S^3(t) - 0.06S^2(t) + 0.77S(t) - 1.77)\\
-k_8^-(2.17X_4^2(t) - 0.0024X_4(t) + 0.16)),\\
\dfrac{dX_9(t)}{dt} = \dfrac{1}{X_9^{\max}}(k_9^+I(t)(0.002S^2(t) + 0.07S(t) + 0.5) - k_9^-(0.43X_1^3(t) - 2.3X_1^2(t)\\
+3.2X_1(t) - 0.07)(1.15X_7^3(t) - 1.78X_7^2(t) + 0.93X_7(t) - 0.024)),\\
\dfrac{dX_{10}(t)}{dt} = \dfrac{1}{X_{10}^{\max}}(k_{10}^+F(t)G(t)T(t)(-0.0007S^4(t) + 0.03S^3(t) - 0.46S^2(t)\\
+2S(t) - 0.4)(0.25X_1^3(t) - 1.24X_1^2(t) + 2.04X_1(t) - 0.049)\\
\times(10.9X_7^3(t) - 26.57X_7^2(t) + 16.7X_7(t) - 0.515)),\\
\dfrac{dX_{11}(t)}{dt} = \dfrac{1}{X_{11}^{\max}}(k_{11}^+PCF(t)G(t)D(t)(-0.0005S^3(t) + 0.02S^2(t) - 0.01S(t) + 0.4)\\
\times(-3.5X_6^3(t) + 7.8X_6^2(t) - 2.7X_6(t) + 0.25)),\\
\dfrac{dX_{12}(t)}{dt} = \dfrac{1}{X_{12}^{\max}}(k_{12}^+(-45.3X_{11}^4(t) + 111.95X_{11}^3(t) - 84.07X_{11}^2(t) + 20.04)),
\end{cases} \tag{4}$$

where $t_0 = 1,\ X_i(t_0) = X_{i0},\ i = 1, \ldots, 12.$

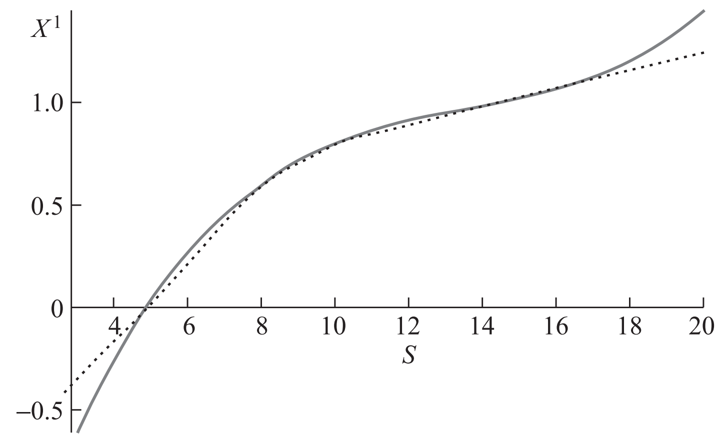

Fig. 3. Graphs of piecewise linear function and polynomial for f_1^S.

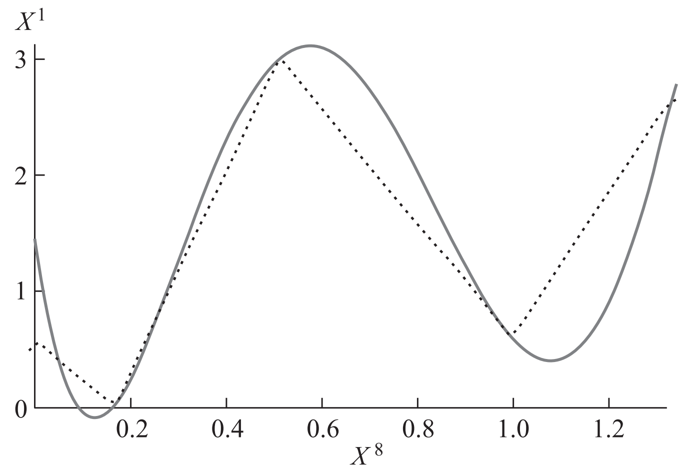

Fig. 4. Graphs of piecewise linear function and polynomial for $f_1^{X^8}$.

The system of differential equations (4) is a Cauchy problem; it can be solved by one of the numerical methods. The simulated characteristics of the system were normalized relative to the maximum values for the convenience of presenting the obtained results.

In particular, auxiliary dependencies $f_j^{X_i}$ and f_j^S take the following form for the case of the flood in the Primorsky region in 2001.

On Figs. 3 and 4 the constructed polynomials are presented $f_1^S = 0.001S^3(t) - 0.04S^2(t) + 0.6S(t) - 2.1$ and $f_1^{X_8} = 54X_8^4(t) - 137X_8^3(t) + 103.4X_8^2(t) - 20.7X_8(t) + 1.9$ for functional dependencies f_1^S and $f_1^{X^8}$.

The developed mathematical models make it possible to solve problem (1), as shown in the description of the model example.

7. MODEL EXAMPLE

Let us check the constructed model to check the plan's feasibility for eliminating the consequences of floods and floods.

The plan has been developed to reduce losses from their occurrence in various regions of Russia, the upper level of which is shown in Fig. 5.

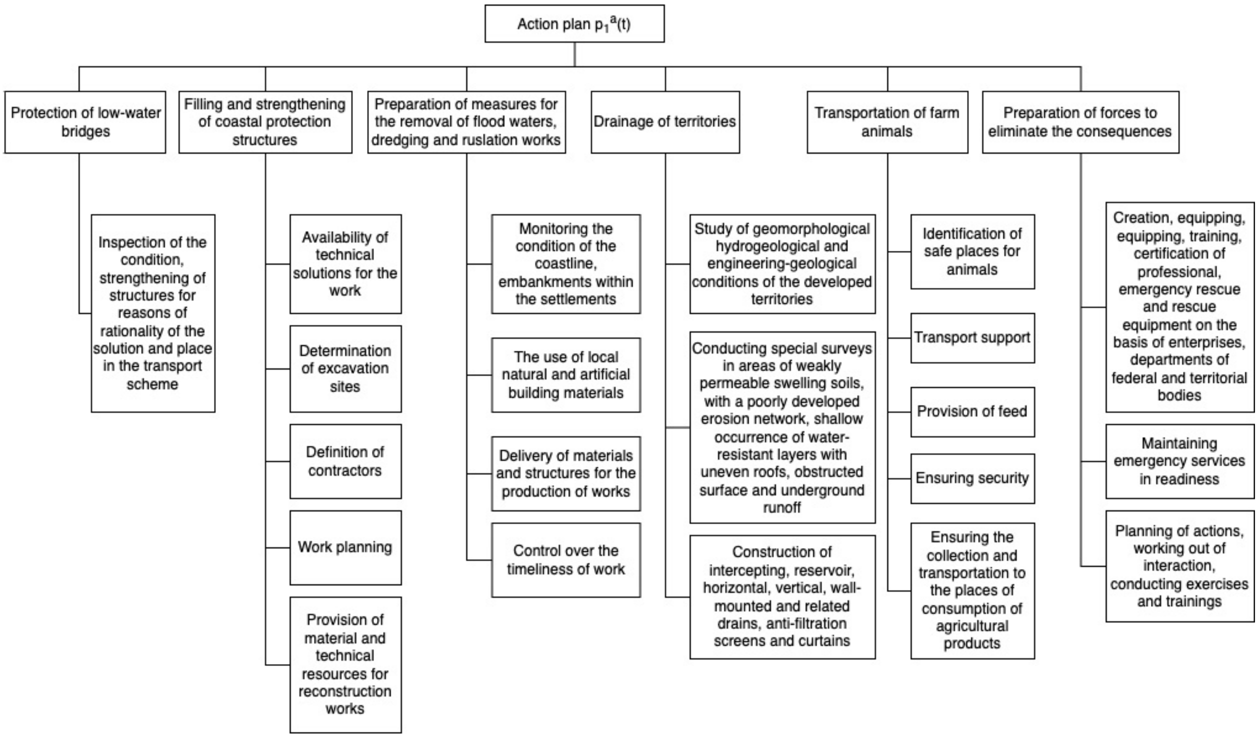

Fig. 5. Flood consequences liquidation plan.

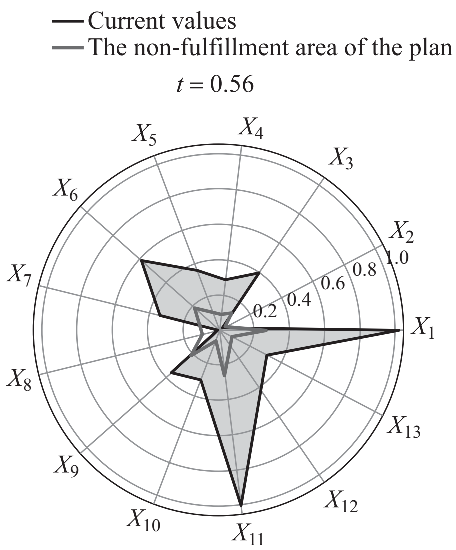

Fig. 6. Feasibility of the action plan at various points in computer time.

To achieve greater clarity, we assume that the plan feasibility check is carried out over a computer time interval $[0; 1]$, normalized values of model variables were selected as indicators of feasibility $X_i(t),\ i = 1, \dots, 13$. Results of solving a system of equations under initial conditions $X_i(t_0) = 0.5;\ i = 1, \dots, 13$ are shown in Fig. 6. They show that the action plan turns out to be impracticable at the moment of computer time $t = 0.56$. For the rest of the interval, the tested plan is feasible. The minimum values of the indicators at which the plan will be feasible are shown in Fig. 6 in gray lines, and the current values of the indicators are shown in black lines.

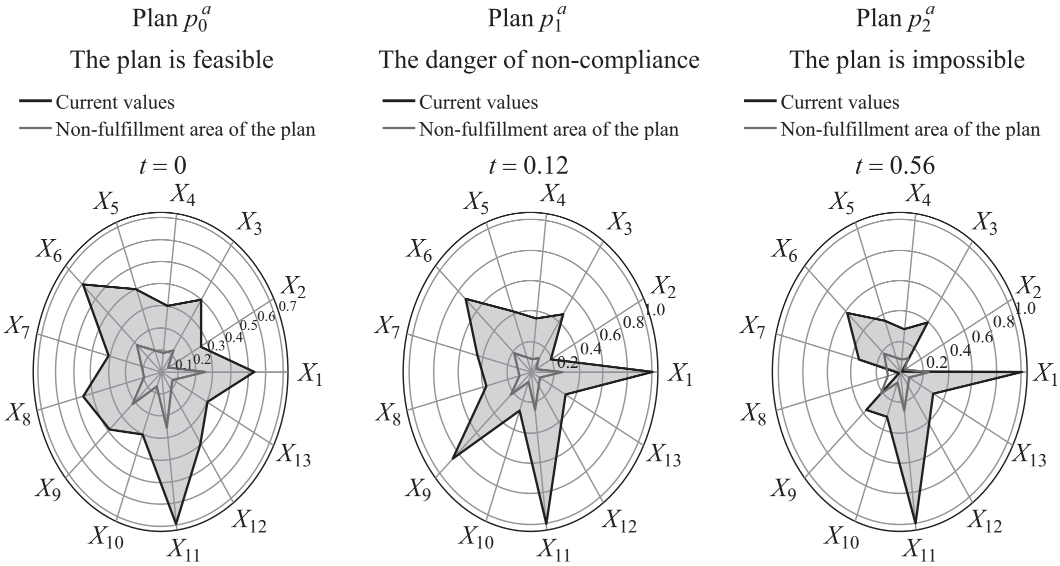

Fig. 7. Checking the feasibility of flood mitigation plans.

Figure 7 shows the results of a feasibility test of three alternative flood response plans. The first indicates the points in time when these plans are feasible, the second when there is a risk of failure, and the third when they are not feasible.

The feasibility of various flood mitigation plans shows it is necessary to check for the feasibility of the plan that implements the most preferred management strategy when solving problems of managing large-scale systems. Solving control problems for large-scale systems shows that the plan implementing the most preferred control strategy must be checked for feasibility. This plan must be feasible at any point in the time interval under consideration. Suppose the plan is not feasible, at least at one point. In that case, preference should be given to a control strategy whose implementation plan will be feasible over the entire control time interval.

8. CONCLUSIONS

Models and methods for checking the achievability of goals and the feasibility of plans implemented when managing large-scale systems in their development are considered. An algorithm for analyzing the achievability of a set of goals and plans implemented when managing these systems is proposed and justified. Statements and hypotheses that make it possible to machine-check the feasibility of plans have been generated.

A model example is given that confirms the possibility of checking the feasibility of plans for eliminating the consequences of a flood using the developed models and methods. In managing large-scale systems development, it is advisable to use control loops that check the achievability of set goals and the feasibility of plans over a selected time interval. In the absence of this verification, the chosen trajectory of development of a large-scale system at specific points in time may turn out to be unrealizable, which will lead to disruption of the work being carried out, as well as to significant costs of the human, financial, technical and other types of resources for the implementation of obviously impracticable plans.

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