

Operational Control of Marine Catastrophes Based on Competitive Computing Technologies

V.A. Bondarev, Yu.I. Nechaev & P.Yu. Kovalishin
Kaliningrad State Technical University, Kaliningrad, Russian Federation

ABSTRACT: The paper considers the structure and functional elements of the emergency computing center that carries out operational control of sea catastrophes of vessels of the fishing fleet based on the integration of intelligent systems of new generations and high-performance computing within the problem-oriented dynamic environment of the virtual testing area. The real time operation of the computer center is provided by the system integration of information, algorithmic and software support based on dynamic measurement data and a structured knowledge base. The focus is on providing decision support in complex dynamic environments using modern catastrophe theory.

1 INTEGRATED EMERGENCY CONTROL ENVIRONMENT

The purpose of the experimental studies conducted during development of the emergency computing center (ECC) is connected with the study of the characteristics of the vessel's interaction with the external environment in emergency situations (Fig. 1) based on the on-board intelligent system (IS) of the new generation operating in the emergency computing mode (Urgent Computing). - UC [1] - [17]. The integrated environment of IP is organized within the framework of conceptual solutions based on the dynamic theory of catastrophes [6] and is characterized by the interaction of functional components: fuzzy (FUZZY), neuro-fuzzy (NF) and neuroevolutionary (NE) systems. The real-time mode problem is provided by the service-oriented architecture [13], [14] in UC mode, and the problem of

uncertainty is within the concept of the minimum description length (Minimal Decision Length (MDL) [4] and complexity theory [10].

In the practice of operation the situations take place: due to uncertainty the vessel's characteristics of interest are not available for direct observation and measurement, at the same time the data of a physical experiment can be quite complex and involve large financial costs. In this case, some indirect information about the interaction dynamics is acquired based on the interpretation of the results of a computational experiment [6] - [8]. Thus, the tasks of on-board IE and the integrated complex of the ECC are considered to determine the causes according to the results obtained as a result of measurements. The tasks of this type are usually called inverse [11]. The causal inverse tasks are individual and are used in the construction of mathematical models of interaction based on the dynamic theory of catastrophes [6].

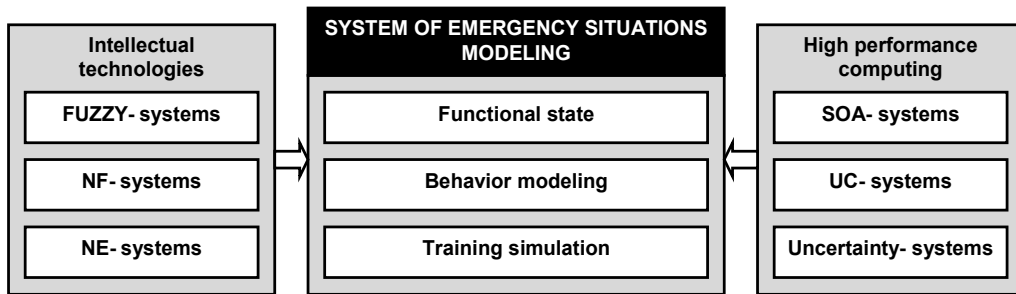


Figure 1. Information processing paradigm of emergency modeling

2 METHODS AND MODELS USING FOR EMERGENCY SITUATIONS INTERPRETATION

The procedure for solving tasks in the treatment of causal relationships is often associated with overcoming serious mathematical difficulties. The success of the solution strongly depends both on the quality and quantity of the information obtained from the experiment, and on the method of its processing [2]. That is why the dynamic theory of catastrophes provides creation of a multi-model program complex (MMPC) using a geometric and analytical interpretation of the vessel's behavior in emergency situations. Based on this representation, the solution is carried out within the framework of the Soft Computing [17] and Data Mining [1] procedures using mathematical models based on the modified Mathieu and Duffing [6] differential equations. In this case, the solution of the inverse problem is preceded by the study of the properties of the direct problem on the basis of a formal conceptual analysis [16]. It is assumed that the original data have large dimensions (many factors and conditions of the vessel), do not always obey the normal distribution, are incomplete, inaccurate and noisy. It is believed that in non-standard situations in conditions of considerable uncertainty, the initial data is extremely difficult to establish as a result of specially organized physical modeling and the only way to obtain information is a computational experiment. This characteristic of the source data allows us to formulate the following basic requirements for a mathematical model of the interaction of functional elements of the EVC:

- informative interpretability using the concept of Soft Computing and Data Mining based on the geometric and analytical components of the dynamic catastrophe model [6];
- effective computability based on parallel information processing algorithms in a multiprocessor computing environment [6] - [8].

It is these two requirements that determine the construction of the interaction model in the development of the information environment and algorithms for controlling emergencies, as well as testing the knowledge base of IE (Fig. 2).

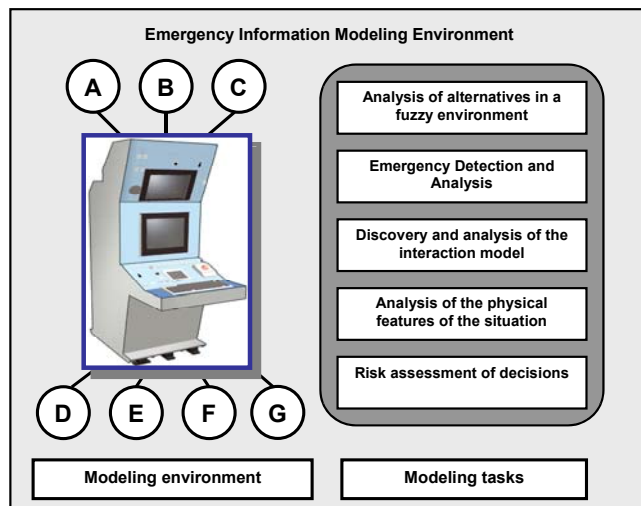


Figure 2. Information environment of interpretation of decisions when modeling emergency situations: A - numerical analysis; B - phase plane method; C - graph theory; (D - G) - dynamic environments of fuzzy (D), neural network (E); F - cognitive (F) and physical (G) modeling

The functional analysis of the information environment modeling ensures that the tasks and modeling tools are consistent with the ECC computer complex used. As the initial time point t_0 to monitor the current situation in the information environment, the set of necessary tasks $\text{Task}(t_0)$ and their set of functions $\text{Opt}(t_0)$ are allocated:

$$\text{Cet}(t_0) = \bigcup_{p(t_0)} C_i, (\forall (i_1, i_2) \in p) \wedge (C_{i_1} C_{i_2}), \quad (1)$$

i.e. the full set of tasks $\text{Cet}(t_0)$ is divided into classes C_i in accordance with their purpose in the operation of the ECC.

A tool for describing tasks C and the order of their distribution is the interaction matrix. The elements of the matrix denote the intensity of data transmission during the operation of tasks that provide identification, approximation and forecast of the vessel dynamics by moving from the j -th stage of the selected sequence to the i -th.

3 THE GENERATION OF ALTERNATIVES AND THE CHOICE OF DECISIONS IN THE EMERGENCY SITUATIONS CONTROL

The construction of the multi-model program complex(MMPC) and the generation of alternatives when choosing a solution that includes various

scenarios of interaction in emergency situations is carried out in the form of a situational model of the game with a dynamically changing class of strategies and a controlled scenario (Fig. 3). To solve this problem, the scenario described by a finite graph [6] - [8] is formulated:

$$G = (S_s, W_s), \quad (2)$$

where the S_s structure is the union of all considered S_s^{ij} emergencies taking into account the moments of time defining controls on the implementation interval at a given moments $t_j, j=1, \dots, N$, and the structure $W_s \subseteq S_s \times S_s$ describes transitions between situations by displaying a set of the IE operator tactics as a decision maker (DM).

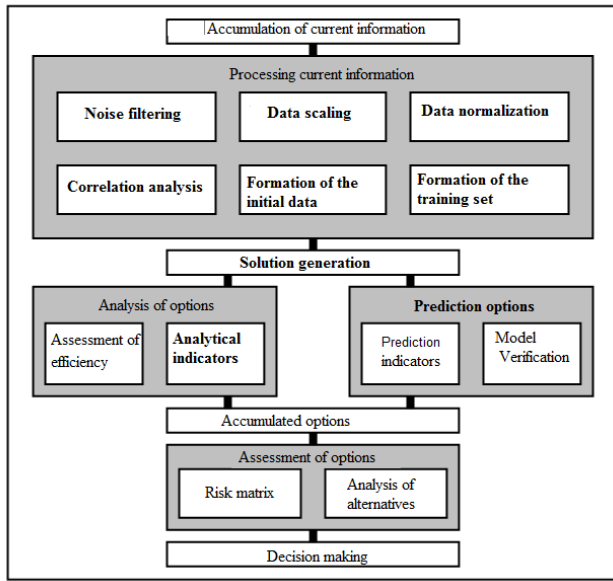


Figure 3. Information Processing Model for Emergency Control

The problem under consideration is adjacent to the problem of controlling an ensemble of trajectories under conditions of uncertainty [5]. However, the approach to the generation of alternatives involves the study of the behavior of nonlinear nonstationary systems (NN-systems) for isolated trajectories which is equivalent to the task of controlling an ensemble.

Axiom 1. When the conditions of irregularity and control with geometric constraints are met, an ensemble prediction of trajectories under uncertainty can be achieved by building solutions generated by elements minimizing the function of interpreting the behavior space at a given stage of system evolution within the framework of a dynamic theory of catastrophes [6].

Let us consider the application of this axiom in constructing an ensemble of trajectories of a dynamic catastrophe model by generating solutions of an NN system within the framework of the UC concept [15]. Suppose that the initial state of the system is not known in advance and the restriction on admissible values of the quantity under investigation is given $x^0 \in X^0, \Gamma \subseteq X^0$ is a given compact set in R^n .

Then at each moment of time t many alternatives are known

$$X(t, u(\bullet)) = X(t, u(\bullet), X^0) = U\{x(t, u(\bullet), x^0) | x^0 \in X^0\}, \quad (3)$$

uniting all trajectories of the system with a known control $u = u(t)$ and with all possible vectors $x^0 \in X^0$.

Thus, we have a trajectory ensemble [5]:

$$X(t, u(\bullet)), t_0 \leq t \leq t_k \quad (4)$$

generated by the X^0 and the control $u(\bullet)$ for a given perturbation $w(t)$. By choosing the function $u(t)$, one can control the set of the ensemble in the control space. The control goal on the implementation interval is to bring the ensemble $X(t, u(\bullet))$ into a Euclidean ε -neighborhood \mathfrak{R} , at a given time, and the optimality requirement is that the quantity be minimal.

Let control be defined in a given class of functions $u(\bullet) \in U$, and \mathfrak{R} - be a set in R^n . Then the Euclidean distance of a point x to \mathfrak{R} in the form of a symbol $d(x, \mathfrak{R})$ has the form :

$$d(x, \mathfrak{R}) = \min\{x - z | z \in \mathfrak{R}\}, \quad (5)$$

and the corresponding ε -neighborhood $\mathfrak{R}(\varepsilon)$ set $\mathfrak{R}(\varepsilon)$ is defined by the inequality

$$\mathfrak{R}(\varepsilon) = \{x | d(x, \mathfrak{R}) \leq \varepsilon\}. \quad (6)$$

For a given function $u(\bullet)$ of the control space, the set $X(t, u(\bullet))$ will completely lie in $(u(\bullet)) - \varepsilon(u(\bullet))$ -neighborhoods

$$\varepsilon(u(\bullet)) = \max\{d(x, \mathfrak{R}) | x \in X(t, u(\bullet))\}. \quad (7)$$

Consequently, the optimal control u^0 , formed on the basis of the evaluation of the function of interpretation of the space of behavior, must satisfy the condition

$$\varepsilon^0 = \varepsilon(u^0(\bullet)) = \min\{d(x, \mathfrak{R}) | x \in X(t, u^0(\bullet))\} = \min_{u(\bullet)} \max_x \{d(x, \mathfrak{R}) | u(\bullet) \in P, x \in X(t, u(\bullet))\}, \quad (8)$$

$$P = \{u(\bullet) | u(t) \in P(t)\} \quad \forall t \in T, \quad (9)$$

where $P(t)$ - convex compact set in space R^P .

Generation of scenarios for the interaction of the vessel with the external environment on the basis of relations (3) - (7) is carried out on the basis of the model of the "essence-relationship" type [6] - [8]. In accordance with this structure, alternatives are formed (emergency scenarios) comparing and choosing the preferred alternative. A generalized criterion for the transformation of information when comparing alternatives can serve as an indicator of information efficiency [3]. With regard to the problem of choosing a solution for controlling the dynamics of a ship in an emergency, this criterion takes the form:

$$CR(E) = 1 - E_\alpha E_x, \quad (10) \quad x^*(X, W) < 0, \forall (X, W) \in B, x^* \in X^*, \quad (16)$$

where

$$E_\alpha = (\alpha_d - \alpha(X_i)) / \alpha_d \quad (11)$$

- relative change of the current parameter $\alpha(X_i)$ characterized by the dynamics of the interaction of the emergency vessel with the external environment (equilibrium landing parameters, restrictions on the emergency stability parameters) from the maximum allowable α_d ;

$$E_x = (X - X_i) / X \quad (12)$$

- relative change of the current value of the determining parameter (factor) X_i ($X_i \leq X$) from selected value X in the specified interval (a, b) . Here X can be a regular, random and fuzzy value.

When interpreting solutions, different models can be used. The simplest model is associated with the construction and analysis of the selection function [7], [8], which allows for the targeted narrowing of many alternatives in the decision support system (Decision Making Process) when choosing and justifying the best decision based on the principle of competition [6]:

$$\Phi(Q) = \{q_i \in Q \mid U\}, \quad (13)$$

where q_i – object from the set Q , selected by condition U .

The selection condition is represented as a tuple

$$U = \langle \sigma(t), \pi(R) \rangle, \quad (14)$$

where $\sigma(t)$ – current vessel's condition information; $\pi(R) = \langle R, T \rangle$ – set of selection rules. R – relationship between elements x_i, σ_i , T – type of choice (equivalence, match, preference).

4 EVALUATION OF THE EFFECTIVENESS OF DECISIONS IN THE EMERGENCY SITUATIONS CONTROL

We formalize the task of evaluating the effectiveness of the DMP system in controlling emergency situations in the ECC models. The implementation of the control function depends on the parameter vector $X \in R^n$ determining the dynamics of the vessel and the state vector of the environment $W \in R^m$ in an emergency. If $[X, W] \in A$, then the solution with the parameter vector X maintains the condition of the vessel in a dynamic environment characterized by vector W . If $[X, W] \in B$ then the generated solution leads to inefficient system operation DMP. The above conditions determine the solution to the problem of choosing a solution:

$$x^*(X, W) > 0, \forall (X, W) \in A; \quad (15)$$

where x^* – selected class of separating functions.

When conditions (15), (16) are implemented the range of possible values of the controlled parameters of the vessel is established in the models of the ECC computer complex, which is limited by various factors, including the features of operation and the level of intelligent technologies used. Each specific implementation of the technical solution corresponds to certain values of the parameters that satisfy the conditions [8]:

$$X_{1\min} \leq X_i \leq X_{n\max}, i = 1, \dots, n. \quad (17)$$

Thus, in the n -dimensional parameter space for each implementation, you the vector of parameters can be represented

$$X = (x_1, \dots, x_n)^T, \quad (18)$$

which belongs to the parameter space defined by inequalities (17).

The vector of parameters (18) uniquely defines the characteristics of the vessel, the set of which we denote by $(Ch)_j, j = 1, \dots, m$.

The number of characteristics is determined by the characteristics of the vessel's dynamics in various operating conditions.

Let us associate each set of characteristics with the vector

$$H = ((Ch)_1, \dots, (Ch)_m)^T \quad (19)$$

m -dimensional space.

In this case, the ship can be considered as a system with n inputs for parameters $x_i \in X$ and m outputs for characteristics $(Ch)_j$.

To each vector X of the parameter space (18) such a system associates the space vector of the characteristics of an emergency situation defined by (19). The considered model allows us to construct a geometric interpretation of various versions of the tasks, their analysis and optimal mapping in the ECC system.

The choice of solution depends on the complexity of the situation being controlled, in emergency situations, especially in conditions of considerable uncertainty, a collective decision strategy is used by the experts of the ECC. When developing this strategy, you can use the approach [9], the development of which in this application is related to the following features. Consider the feedback characterizing the implementation of the choice of solutions in the presence of two choices, which we denote α и β . The degree of reliability of these features is characterized by the numbers A_α и A_β . The number of experts ECC who made a choice α or β is denoted by X_α и X_β . At the same time, in the course of the situation development it is possible to change the decisions of experts. Relative number of

experts willing to change the decision α in the process of development of the situation is in proportion to the number of those experts who have already made a choice β . In this case, the preference of choice is defined as $A_\beta/(A_\alpha+A_\beta)$. Similarly, the number of experts willing to change the selection β to α will be proportional X_β in accordance with the formula $A_\alpha/(A_\alpha+A_\beta)$. This leads to a system of equations for X

$$dX_\alpha/dt = \alpha X_\alpha \left(X_\beta A_\alpha / (A_\alpha + A_\beta) - X_\alpha A_\beta / (A_\alpha + A_\beta) \right) \quad (20)$$

or considering that $X_\beta = N - X_\alpha$, where N - total number of experts

$$dX_\alpha/dt = \alpha X_\alpha \left(N A_\alpha / (A_\alpha + A_\beta) - X_\alpha \right) \quad (21)$$

Thus, various choices affect the efficiency of the DMS system which is a function of the instantaneous state of the vessel due to its dependence on the variables characterizing the emergency. These considerations can be generalized to the case of an arbitrary number of elections K , taking into account the real situation, when the preference of the i -th option depends on the number of the expert group, which must make a choice:

$$dX_i/dt = \alpha X_i \left(1 - X_i / \left(\sum_{j=1}^k N_j A_j / \sum_j A_j \right) \right), \quad (i=1, \dots, K). \quad (22)$$

Here the group of experts is heterogeneous and falls into several subgroups, each of which has its own idea of the relative preference of this choice.

Risk assessment of decisions made on the basis of the developed strategy is carried out using various interpretations [2], [6] - [8]. The theory, methods and technologies for developing various classes of tasks in a risk assessment system cover various problem areas [4] - [6]. The complexity and interrelation of these areas bring to the fore the problem of assessing the quality of models, analyzing and streamlining the choice of the most preferable models for solving applied problems. The urgency of the problem is exacerbated if the dynamics of the vessel are described by a multi-model computing complex [2] which may include heterogeneous and combined models each of which is evaluated by its own system of indicators.

5 CRITERION BASIS OF EMERGENCY CONTROL

A conceptual model of a ship's behavior in emergency situations formalizes the processes of building applied tasks and criterial functions for interpreting interaction processes in the implementation interval. Figure 4 presents the sequence of operations that determines the criterial basis for assessing the safety of a vessel in the form of the main stages of determining the parameters of the environment, the dynamics of interaction, as well as the stage of evolution in predicting the behavior of the vessel.

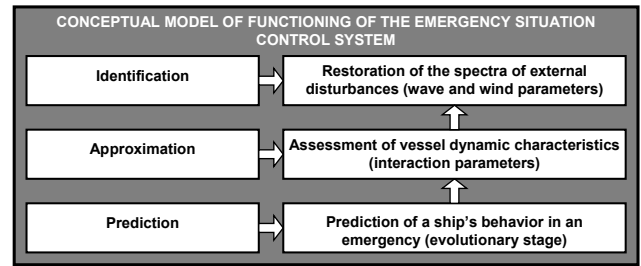


Figure 4. Criteria basis for assessing the dynamics of the vessel at the stages of operation of the behavior space

Improvement of the theoretical, methodological and technical support of operational control of emergency situations is associated with the use of two systems of criteria-based assessments (Fig. 5). The first (local) criteria system is related to ensuring the safety condition and can be implemented on the basis of the developed standards in the form of an embedded procedure of inference rules. The second (global) system includes national and international requirements, which are ensured regardless of the particular dynamics of the vessel.

The local system is developed in the process of creating a dynamic knowledge base and takes into account the characteristic features of the vessel under study. Improvement of the local system is carried out in the direction of creating a fuzzy criteria system based on the methods of formalizing information with regard to its incompleteness and uncertainty within the framework of the concept of "soft calculations" [17].

The transition from a local system to a global one is carried out through a description (a conceptual model of the system), which fixes information about the vessel being modeled and the process of interaction in terms of typical competing mathematical models and knowledge structures. When choosing a simulation scheme for an emergency, the concept of a functioning environment is introduced, which makes it possible to use information of an applied nature on the purpose of modeling, the laws of system evolution, the existing mathematical apparatus for studying methods and algorithms for making decisions on ship management. Thus, the object of the considered applied theory of rationing of vessel characteristics is the modeling process.

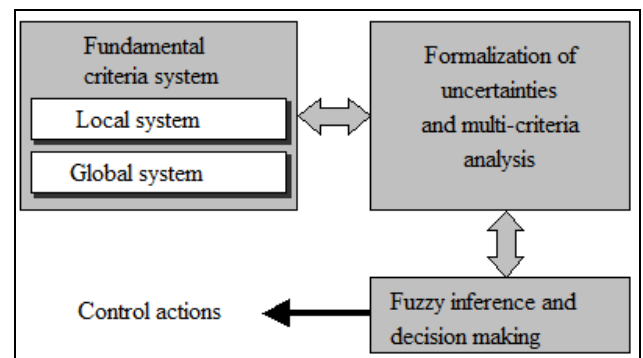


Figure 5. Criterion basis for the rationing of extreme situations

The practical implementation of the formulated approach is associated with the creation of a fuzzy

system of logical rules for the knowledge base of the IE [2], [6] - [8]. One group of rules allows you to define an assessment of the danger of a situation, the other is aimed at preventing it and can be directly managed to make decisions on reducing the speed of DO and changing the course angle

6 ASSESSMENT OF THE ADEQUACY OF MODELS OF THE VESSEL'S BEHAVIOR IN EMERGENCY MANAGEMENT

The strategy of assessing the adequacy of the ECC computing complex (Fig. 6) determines the formalization of the procedure based on the consideration of factors characterizing a priori information [2], the concept of MDL [4], and the problem of complexity [10]. As follows from this figure, the adequacy problem is solved by integrating a priori information which determines the choice of a solution in accordance with the conceptual model of the dynamic theory of catastrophes [6] which is adapted to the problem in question.

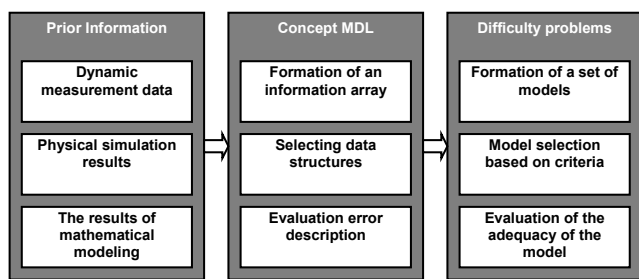


Figure 6. The flow of information that determines the strategy for assessing the adequacy of the model of interaction in an emergency

The assessment of adequacy is carried out on the basis of the modified O. Balchi scheme [12] for a specific application in order to take into account the data of physical, neuro-fuzzy and neuro-evolutionary modeling (Fig. 7). At the same time, improvements were made in considering the interaction model as an integral part of the practical application based on it - the task of modeling emergencies in the operation of a software package based on the principle of competition.

The first cycle is associated with the development of competing models (modeling - M), implemented on the basis of the neurodynamic system (ND-system) and methods of classical mathematics. In the process of performing this cycle, the structural and parametric synthesis of the neural network in the NF and NE modeling tasks is implemented, and for the competing model, the assessment of the overall structure and components is carried out within the framework of sequential statistical analysis procedures.

The second cycle refers to the implementation of the corresponding mathematical (imitation) experiments performed with competing models (simulation - S) for given initial conditions and elements of the input vector. Here are formed the NF and NE models of data bank analysis on the basis of

which the computational experiment, generation and analysis of alternatives and the assessment of adequacy are implemented. The construction and analysis of the competing model is carried out in accordance with the formalization of the problem under conditions of significant uncertainty in accordance with the algorithm [6].

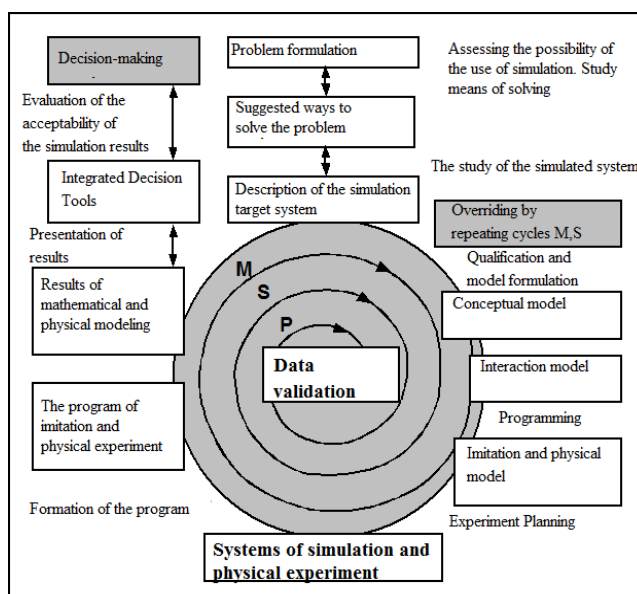


Figure 7. Modified methodological scheme for assessing the adequacy of neural network and standard (traditional) models: M, S, P - information conversion cycles

The third cycle is the most important. It is in carrying out physical (physical - P) experiments, on the basis of which the models are formed that provide an assessment of adequacy under conditions of complete uncertainty. On this cycle, in the ND system, the components of the NF and NE models are formed using physical modeling data, a computational experiment and an adequacy assessment are implemented.

Intellectual support of the procedures M, S, P is provided by the control system of calculations and visualization of simulation results. As assessments of the adequacy of fuzzy, neural network, and competing models, one should follow the recommendations set out in the paper [8].

7 CONCLUSION

The considered conceptual solutions implement the strategy of the dynamic theory of catastrophes which determines the evolution of the vessel under conditions of continuous changes in the behavior of the object and the external environment. The management of the interaction process is provided by the levels of functioning of the structural components of the ECC using an interactive control system that provides analysis of the state of the controlled vessel, development of management decisions and their implementation, based on the problem-oriented onboard IE.

The EEC multi-model complex contains interaction algorithms and operating environments as well as visualization models that implement computation

and data presentation using elements of modern cognitive computer graphics. Operations that determine the flow of information based on the dynamic theory of catastrophes and intelligent technologies are implemented within the framework of conceptual solutions for controlling emergencies in a non-stationary dynamic environment.

The implementation of operational and long-term planning of emergency scenarios is organized as a model with a dynamically changing class of strategies. The generation of scenarios is carried out on the basis of an entity-relationship type model. In accordance with this structure, alternative scenarios and the choice of the preferred computing technology based on the principle of competition are formed. A generalized criterion when comparing alternatives is the indicator of information efficiency and intelligence of the system.

LITERATURE

- [1] Barsegyan A.A., Kupriyanov M.S., Stepanenko V.V., Kholod I.I. *Metody i modeli analiza dannykh: OLAP i Data Mining*. – Sankt-Peterburg, BKHV-Peterburg, 2004.
- [2] Bondarev V.A., Nechayev YU.I. *Iskusstvennyy intellekt v chrezvychaynykh situatsiyakh moreplavaniya*. – Sankt-Peterburg, 2017.
- [3] Vasil'yev V.A. Prinyatiye resheniy pri proyektirovanii preobrazovateley informatsii // *Avtomatizatsiya i sovremennyye tekhnologii*. №11. 2003, s.30-33.
- [4] Kolmogorov A.N. *Teoriya informatsii i teoriya algoritmov*. – M.: Nauka, 1987.
- [5] Kurzhanskiy A.B. *Upravleniye i nablyudeniye v usloviyakh neopredelennosti*. – M.: Nauka, 1977.
- [6] Nechayev YU.I. *Teoriya katastrof: sovremennyy podkhod pri prinyatii resheniy*. – Sankt-Peterburg: Art-Ekspress, 2011.
- [7] Nechayev YU.I., Petrov O.N. *Nepotplyayemost' sudov: podkhod na osnove sovremennoy teorii katastrof*. – Sankt-Peterburg: Art-Ekspress, 2014.
- [8] Nechayev YU.I. *Topologiya nelineynykh nestatsionarnykh sistem: teoriya i prilozheniya*. – Sankt-Peterburg: Art-Ekspress, 2015.
- [9] Nikolis Dzh. *Dinamika iyerarkhicheskikh sistem*. – M.: Mir, 1980.
- [10] Solodovnikov V.V., Tumarkin V.I. *Teoriya slozhnosti i proyektirovaniye sistem upravleniya*. – M.: Nauka, 1990.
- [11] Tikhonov A.N., Arsenin V.YA. *Metody resheniya nekorrektnykh zadach*. M.: Nauka, 1986.
- [12] Balci O. Verification, validation and accreditation // *Proceedings of the 1998 Winter Simulation Conference*. – 1998, p.p.41–48.
- [13] Gallopoulos S., Housts E., Rice J. *Problem Solving Environment // IEEE Computational Science and Engineering*. Summer, 1994.
- [14] Lublinsky B. Defining SOA as an architectural style. 9 January 2007. [Электронный ресурс]: <http://www.ibm.com/developerworks/architecture/library/ar-soastyle/>
- [15] Urgent Computing Workshop 2007. Argonne National Lab, University of Chicago, April 25-26, 2007. [Электронный ресурс]: <http://spruce.teragrid.org/workshop/urgent07.php>.
- [16] Wille R. *Restructuring lattice theory an approach based on hierarchies of concept / ordered sets / Editor I.Rival*. – Dordrecht-Boston, 1982.
- [17] Zadeh L. Fuzzy logic, neural networks and soft computing // *Commutation on the ASM-1994*. Vol.37. №3, p.p.77–84.