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FUNDAMENTALS OF THE SYSTEM SIMULATION METHODOLOGY "PERSON-MACHINE" IN PROJECT AND PROGRAM MANAGEMENT

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ABSTRACT

In the article, the authors examined the problematic aspects of project management; the study focuses on the optimization of the crew of the vessel – the project team based on the simulation method. Within the framework of the approach proposed by the authors, a model has been developed for the formation of the crew of the vessel – the project team, which allows one to identify its composition, the most suitable and stable (balanced) for managing a specific project in terms of its competence, complementarily of crew members on the vessel (synergism principle) and its psychological characteristics. Digital modeling cannot be considered as an attempt to copy the per-minute and daily change of a real situation arising from group interaction using a computer; high tension in the work of individual functional groups of the project should be attributed; total duration of the project; load factors of certain types of equipment for the organization. A model has been developed for *optimizing the number of ship crews on the basis of simulation modeling of the behavior of the “person-machine” system in the process of project implementation.*

Keywords: Ship's crew, Simulation modeling, Method, Project resource management, Project management methodology

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1. INTRODUCTION

In recent decades, in the scientific and business fields, computer forecasting of the general results of complex operations and the sequence of possible events in “person-machine” systems has become common. The important features, characteristics and functioning results of many systems, both existing and designed, have already been reproduced in digital form using a process called “digital imitation”. This method provides significant assistance to managers and systems analysts in such diverse fields as transport, economics, international relations, demographic research, military operations and the organization of the rear services. The purpose of the method is to provide quantitative estimates of the functioning, performance, efficiency or “value” of systems or the approaches considered. The implementation of this method gives the most effective results based on the use of simulation models [1]. Digital modeling cannot be considered as an attempt to copy every minute the change in the real situation that occurs during group interaction using a computer. Rather, this method allows predicting the appearance of various critical life situations by a large number of factors that reveal the essence of those variables that modern leading experts in the field of social psychology unanimously consider to be the main ones in the activities of a person included in a closed social collective [2]. Thus, taking into account the catastrophic consequences of wrongdoing practically every crew member who has the basic characteristics of the project team, the proposed study should be considered relevant.

2. ANALYSIS OF RESEARCH AND PROBLEM STATEMENT

In particular scientists [3-11] focus mainly on the general principles of project team formation and methodologies. Unfortunately, an adequate model would allow at the same time to carry out both quantitative and qualitative optimization of project composition teams, especially in the context of incomplete workload definitions, are not available today exist. In addition, existing methods do not take into account the specifics of the conditions of performance projects by teams such as ship crew, namely elevated levels work hazards, hours of work, closed space and restriction of movement of team members, its international composition, language barrier and so on.

The aim of the study is to improve the simulation model of implementation project in the conditions of incomplete determination of the volume of works by which it is possible to determine the utilization of individual resources during the project implementation.

3. STATEMENT OF THE MAIN RESEARCH MATERIAL

The main features that lead to difficulties in forming the optimal crew, include researcher in [3], believes that the whole range of issues characterizing the problems of small groups can be divided into three categories: 1) the study of the behavior and structure of groups; 2) selection of interaction parameters; and 3) analysis of the characteristics of activity. In the first category, it includes interacting elements, existing norms and processes of social control, interaction and decision making, social roles and interpersonal choices. Among the parameters of interaction, scientist includes personal qualities, social characteristics, the size of the group, the communication network when performing the task, and leadership in the group [3]. In developing the problems of small groups, in [4] was retained a significant part of the previous classification, but, in addition, they talk about group cohesion, group pressure and group standards, individual and group goals, the impact of leadership on group performance, as well as about the structural properties of groups. Discussing the most important aspects of this area, in [5] was classified the variables in terms of social influence, changes in opinions and attitudes, social perception and formation of ideas, authoritarianism and tendency to subordination, social interactions and group processes, as well as in terms of intercultural relations. Researcher in [8] proposed classifications that more or less coincide with the previous ones, however, he suggested taking into account the reinforcement produced by the group (the influence of the group on its members). Reinforcement by social power and tension was also included in [7]. Finally, in [9] was made a solid literary review, which indicates the main and secondary variables and their mutual relations used in the field of the theory of small groups.

In an enlarged form, a block diagram that implements the mechanism of simulation modeling of the project team activity is presented in Fig. 1.

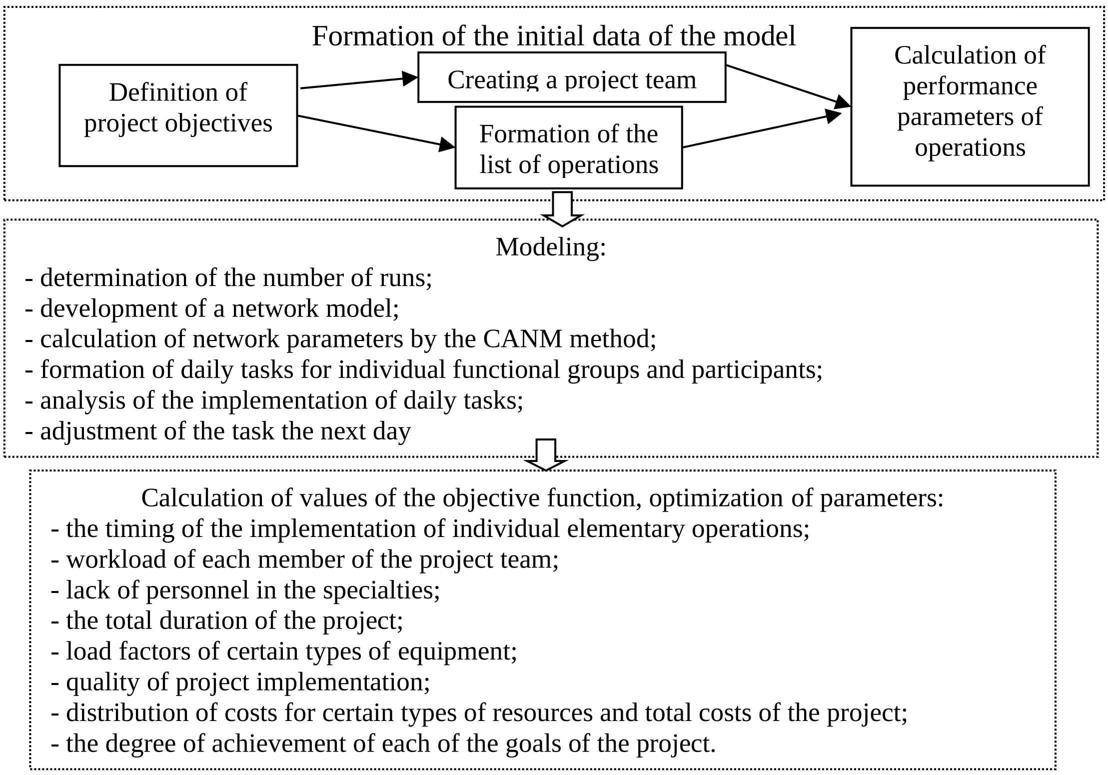

Figure 1. The enlarged algorithm of the simulation process

The first of the main segments of the model is the block for generating the initial data, as can be seen from Fig. 1, divided into four modules. The first module is developed by the project management team, which determines the main parameters of the project [12]: project duration – T; goals of the project E_1; E_2 etc – quantitative characteristics, the achievement of which indicate the success of the project [10]. At this stage, it is necessary to take into account both the standard goals of such projects and the specific ones arising from the uniqueness of the project product or the conditions for its implementation; the number of functional groups of the project team N.

The project team at the first stage is formed in a minimal composition on the basis of the functional principle of dividing into groups, as shown below. Having distributed the functions and volumes of work, we can begin to form the optimal team composition by setting the objective function. We introduce the following notation: N_0 – many agents – candidates for inclusion in the team, $|N_0| = n_0$; N is the composition of the team (a solution to the problem of forming the composition), $|N| = n \leq n_0$; $F(N)$ is the efficiency functional, which associates with each possible composition N € N_0 is a real number. Note that the efficiency functional can be obtained as a result of solving (in the general case for each of the possible compositions) problems of the distribution of functions and volumes of work. Formally, the task of forming a team is to find its composition N*, which has maximum efficiency:

$$N^* = \arg \max_{N \subseteq N_0} F(N) \tag{1}$$

Task (1) relates to discrete optimization problems. Allowable line-ups of the team can be additionally superimposed both on the requirements for the mandatory inclusion of certain groups of agents (ensuring the implementation of certain functions), as well as prohibitions on the inclusion of certain groups of agents. Vacancy filling is as follows. A hierarchical "tree" of functional groups is constructed, as shown in Fig. 1. At the first stage, the captain of the vessel is selected. A person with the most suitable technical competencies for the project conditions is assigned to this role. The further formation of group 1 is based on the analysis of the temperaments of the senior assistant and the senior mechanic in such a way that the tension between them and the senior mechanics, both in magnitude of neurology and in magnitude of neuroticism, is minimal and does not exceed 4 points, that is, it is insignificant:

$$\Delta = \sqrt{\Delta_V^{\ 2} + \Delta_N^{\ 2}} \leq 4 , \tag{2}$$

where Δ_V and Δ_N are the difference, respectively, between vertically and neurotism in persons of senior command personnel of the vessel.

If it is impossible to select persons from the entire database of senior assistants or senior mechanics whose temperament would satisfy the condition of insignificant tension, then we select another captain who is technically competent. This approach will maximize the avoidance of conflicts among senior command staff during the cruise [13]. As a result of the simulation, the following parameters are determined:

- the minimum numerical composition of each group is Z_i;
- the name composition of the group z_1; z_2; …; z_i;
- group characteristics of temperament:
- group frailty – V_i
- neuroticism of the group – N_i
- maximum tension in the group – H_i
- relative speed of operations – OC_i
- accuracy of operations – T_i
- manageability of the group – Y_i
- fund of working hours of each member and group as a whole – F_1; F_2; F_y;

The base of elementary operations contains the following information:

- number j and the name of the operation;
- the priority of operation Π_j is set by the head of the functional group or on a 100-point scale: if the priority is less than 50, then the work can be delayed the next day so as not to resort to overtime;
- the average execution time of the operation τ_j;
- the number of functional group i, which is assigned to perform operation j;

- numbers of operations preceding operation *j*;
- numbers of operations following operation *j*;
- the point in time when you can start the operation $t^{н}_{j}$;
- the point in time by which the operation t^{o}_{j} should be completed;
- the duration of the *j*-th operation of the *i*-th functional group:

$$\tau_{ij} = K_{OC} \cdot \tau_{j}, \tag{3}$$

where K_{oc} is a coefficient that determines the ratio of the execution time of the *j*-th operation of a particular *i*-th functional group to the average execution time of this operation:

$$K_{OC} = \left| \frac{\sqrt{2} \cdot \rho_{Yi} \cdot cos\left(\phi_{Yi} - \pi/4\right)}{6} \right|, \rho_{Yi} = \sqrt{V_i^2 + N_i^2}; \phi_{Yi} = arctg\left(\frac{N_i}{V_i}\right). \tag{4}$$

the quality of the operation of the *i*-th functional group

$$K_{К} = -\left| \frac{\sqrt{2} \cdot \rho_{Yi} \cdot cos\left(\phi_{Yi} - \pi/4\right)}{6} \right|. \tag{5}$$

3.1. Simulation of the Functional Groups of the Project

The crew’s actions are simulated for each task day by performing arithmetic operations on data for elementary operations. Following the imitation of an elementary operation, the time worked for each member of the group is specified in accordance with the results of the activity. If necessary, the results obtained by simulating each elementary operation and the current values of the corresponding variables are recorded for subsequent analysis. A similar process is repeated sequentially for each elementary operation with new data and in new conditions in accordance with the daily routine. For each day of work, the crew morale index is calculated; persons are selected for promotion in accordance with a certain “policy”; some crew members are placed in the category of "sick" or removed from this category to simulate real medical histories; calculated indicators of the effectiveness and efficiency of the project. Summarized activity data and final conditions are reflected in the conclusion on the crew’s work prescribed for each day [11].

Similarly, the overall task is simulated day after day, and for viewing the total results of the task and the conditions prevailing at the time of its completion are recorded. This simulation is repeated *N* times to average the effects caused by random processes, after which the final results are calculated and recorded [14]. Then, the initial data are automatically adjusted by changing the quantitative or qualitative composition of the project groups, taking into account the load factors of individual performers in each specialty obtained in the previous calculation. A series of *N* simulations of the entire assignment is subsequently repeated until the quantitative composition of the crew is determined in the next series and the results are recorded. The total number of runs (the entire set of simulations) *N1* is set before the simulation. It`s also possible to establish parameters, the achievement of which automatically terminates the modeling process [7]. For the description, planning, analysis and optimization of projects, the most suitable were network models that have proven themselves in practice. In network modeling, it is most often assumed that the duration of the work constituting the project is clearly defined. The advantages of this approach to network modeling of complex tasks are quite obvious: thanks to such a network, a complete and clear idea is obtained regarding the whole range of works; the connections of all elements of the complex are clearly identified; identifying the critical path allows you to establish work that determines the progress of the entire complex (i.e., critical work); there is complete clarity regarding the time reserves for which it is possible to postpone the performance of individual works that are not on a critical path, and this, in turn, allows more efficient management of cash resources [10].

However, the use of deterministic network models in solving our problem is inefficient, due to many random influences, lack of information, and the inability to predict the entire set of jobs.

The PERT method, which is widely used in project management practice, essentially repeats the critical path method with the difference that the deterministic durations of operations are replaced by the expected ones. Three time estimates are used to calculate the expected time to complete operations:

- the minimum (optimistic) estimate of the execution time of the elementary operation t_{min}, which characterizes the duration of the work under the most favorable conditions;
- pessimistic assessment of the execution time t_{max} – under the most adverse conditions;
- realistic estimate of runtime t_{real} – under normal conditions.

The beta distribution is used as an a priori for all works, and the calculation of the expected duration t_e and variance σ^2 is estimated by the formulas:

$$t_e = \frac{t_{\min}+4\cdot t_{real}+t_{\max}}{6}, \sigma^2 = \left(\frac{t_{\max}-t_{\min}}{6}\right)^2 \tag{6}$$

It is most difficult to determine the realistic estimate of the t_{real} execution time, therefore, a simplified (although less accurate) estimate of the average duration of work is usually used based on only two time estimates $t_{min}(i, j)$ and $t_{max}(i, j)$. In this case, the expected operation time and variance are estimated as:

$$t_e = \frac{3\cdot t_{\min}+2\cdot t_{\max}}{5}, \sigma^2 = \left(\frac{t_{\max}-t_{\min}}{5}\right)^2 \tag{7}$$

The following disadvantages can be distinguished in the PERT method [14]:

- the theoretical justification of the expressions for determining the time parameters is based on a very dubious assumption about the beta distribution of the duration of operations;
- when using the PERT method, it must be remembered that the hypothesis of a normal distribution of the actual time of the end of the project has less evidence, the greater the statistical dependence of the duration of the individual operations;
- the method does not take into account the semantics of the network;
- the multivariance of the project is not taken into account;
- the method does not allow simulating the flow of technological processes along an alternative path, as well as producing cyclic repetition (a finite number of cycles) of a part of the process.

A new approach is proposed in the works, which is a synthesis of stochastic and generalized network models – cyclic alternative network models (CANM). The main advantage over other models is that CANM allows you to simulate the flow of the production process along an alternative path, including cyclic repetition of part of the process using simulation. The resulting model can be "carry out" in time and get the statistics of the ongoing processes as it would be in reality. In a simulation model, process and data changes are associated with events. "Carry out" of the model consists in a sequential transition from one event to another [13].

Some unit production project can be represented by a cyclic alternative network model *G(F, A)* consisting of a set of project events *W* and *arcs(i, j)* (events *i* and $j \in W$) defined by the adjacency matrix $A=\{p_{ij}\}$. $0\leq p_{ij} \leq 1$, moreover, $p_{ij}=1$ defines a deterministic *arc(i, j)*, and $0< p_{ij} <1$ defines an alternative event *i*, which is connected by the arc with event *j* with probability p_{ij}. The $i \in W$ event can display [14]: the emergence of conditions that open up the possibility (admissibility) of the start of one or more operations of the project; the admissibility of the end of one or more operations; the fact of the beginning of the operation or part thereof; the fact of the end of the operation or part thereof. $i = 0$ is the initial event of the project implementation process, and $i = W$ is the final event.

Technological or organizational relationships between randomly selected moments can be defined using the inequality:

$$T_j - T_i \geq \xi_{ij}, \tag{8}$$

where ξ_{ij} can take both positive and negative values.

In Figure 2 a general description of CANM is given and it is shown under what conditions all known network models become its special case.

TRADITIONAL MODEL
ij are positive constants, $p_{ij} = \{0,1\}$
Communication only "end-to-start"

GENERALIZED MODEL
ij - constants from - to +, $p_{ij} = \{0,1\}$.
Generalized connections (including inverse) between arbitrary points of work

PROBABILITY MODEL
ij - positively distributed random variable (mainly beta distribution), $p_{ij} = \{0,1\}$
Communication only "end-to-start"

ALTERNATIVE MODEL
ij - random variable distributed according to some law in the range from 0 to +, $0 p_{ij} 1$
Communication only "end-to-start"

TARGET ALTERNATIVE NETWORK MODEL – finite, oriented, cyclic graph, consisting of many events and arcs *(i, j)*, *(I, j)*, determined by the adjacency matrix $A = \{p_{ij}\}$, $0 p_{ij} 1$, moreover $p_{ij} = 1$ defines a deterministic arc *(i, j)*, and $0 p_{ij} 1$ defines an alternative event *i*, which with probability p_{ij} connected to the arc of the event *j*.

$$\boldsymbol{T_j - T_i \;\; ij} \tag{1}$$

where T_i is the time of completion of the *i*-th event; *ij* – in the general case, a random variable distributed according to some law in the interval from - to 0 or from 0 to +.
(1) provides the task of generalized, probabilistic or alternative technological connections (including inverse) between arbitrary points of work. In addition, absolute restrictions at the time of implementation are possible *i*:

$$\boldsymbol{l_i T_i L_i} \tag{2}$$

Figure 2. General description of cyclic alternative network models

Since almost always there are several alternative options for implementing the project, with respect to simulation tasks, the most interesting are the options with probabilistic and alternative network models. In the variant with the probabilistic model, inequality (3) in the case of a positive value ψ_{ij} defines an estimate of the minimum duration of a certain job *ij*. Moreover, the distribution of ψ_{ij} is unimodal and asymmetric, like a beta distribution. Thus, the minimum duration of work is a random variable $\xi_{ij}=t_{min}(i,j)$, distributed according to the law of beta distribution on the interval *[a, b]* with a density:

$$\phi(t)=C\cdot(t-a)^{p-1}\cdot(b-t)^{q-1}, \tag{9}$$

here *C* is determined from the condition $\int_a^b \varphi(t)dt=1$.

Negative $-\xi_{ij}=t_{max}(j, i)$ on the interval $-\infty$ to *0* means the distribution of the length of the maximum time interval during which work *(i, j)* must be started and completed (even with minimal saturation of it with a determining resource). For this value, the distribution has the form similar to (4). The value ξ_{ij} defines the distribution of the time dependence between the events *i* and *j* for the arc connections *(i, j)*. A positively distributed value ξ_{ij} corresponds to a relationship of the type “not earlier”, and a negatively distributed quantity ξ_{ij} determines a relationship of the type “not later”. Thus, a generalization of technological relations is obtained. At the same time, it is taken into account that they can have not a discrete, but a probabilistic character.

It should be added that the sum of the duration of the work determines the timing of the events. With a sufficiently large number of such works, the distribution of the random variable T_i tends to normal (with the parameters being the mathematical expectation MT_i and the variance DT_i) between the events. As a parameter of the arc ξ_{ij}, we can also consider any characteristic parameter that has additivity along arcs of any path (for example, the cost of work), and with the help of the equivalent GERT transform [14] we obtain the mathematical expectation and variance of the cost of a network fragment or a project as a whole. Setting explicit and implicit, external and internal goals in the form of absolute restrictions is carried out by means of inequalities of the form:

$$T_i \geq l_i, \text{ or } T_i \leq L_i \tag{10}$$

for some events i, that are decisive for the above purposes.

The presented relations are a generalization of the corresponding inequalities in the description of generalized network models, where the parameter ξ_{ij} and the adjacency matrix A are deterministic in nature [14]. Absolute restrictions on the timing of events reflect the corresponding directive, organizational and technological restrictions on the timing of work or parts thereof, specified in the "absolute" (real or conditional) time scale. Absolute restrictions are also characterized by the type of “not earlier” or “not later” and takes the form:

$$T_i - T_0 \geq l_i, \text{ or } T_0 - T_i \geq -L_i \tag{11}$$

Thus, absolute constraints of the form (6) are a special case of constraints of the form (4) for certain arcs. The introduction of a stochastic adjacency matrix A in combination with generalized relationships provides additional opportunities for describing the process of creating a complex project. Let $L(i, j)$ be a path connecting events i and j:

$$L(i,j) = \{i = i_0 \rightarrow i_1 \rightarrow i_2 \rightarrow \ldots \rightarrow i_n = j\} \tag{12}$$

This path is deterministic if for all $k \in [1, n]$ the fair equality:

$$P(i_{k-1} \rightarrow i_k) = 1 \tag{13}$$

and stochastic, otherwise. Thus, the stochastic path contains at least one arc, the probability of "execution" of which is strictly less than 1.

Deterministic and stochastic contours are defined in a similar way.

$$K(i) = \{i = i_0 \rightarrow i_1 \rightarrow i_2 \rightarrow \ldots \rightarrow i_n = i\} \tag{14}$$

Such events i are called "contour". If events i and j are connected by $L(i, j)$, then the probability of occurrence of event j, provided that event i occurred $P(j / i)$, is the product of the coefficients of the adjacency matrix A corresponding to the arcs of the connecting path:

$$P(j / i) = \prod_{k=1}^{n} (P_{ik-1 \rightarrow ik}) \tag{15}$$

If events i and j are connected in several ways, then the equivalent GERT transform of a given fragment of the network is performed in accordance with [15], the generating function $\xi_{ij}(s)$ of the transformed fragment is calculated, and the probability of occurrence of event j under the condition that event i has occurred $P(j / i) = \xi_{ij}(0)$. According to the corresponding formulas, the mathematical expectation $M(j / i)$ and the variance $\sigma^2(j / i)$ of the completion time of event j relative to the completion time of event i are also determined. The length of the path $L(i, j)$ is a random variable whose mathematical expectation $ML(i, j)$ is the sum of the mathematical expectations of the lengths of all the arcs making up this path, and the variance $DL(i, j)$ is equal to the sum of the variances.

Under these conditions, the path (contour) length can take negative values, which is interpreted as follows: if $L(i, j)<0$ and the *arc(j, i)* has a negatively distributed parameter ξ_{ji} then event j must occur no later than $-\xi_{ji}$ days after event *i*. The ξ_{ji} parameter is probabilistic, which allows more flexible description of the logical-temporal relationships between events [16]. Run results contain the following data:

- optimal timing of the performance of individual elementary operations;
- the workload of each member of the project team as the ratio of the time worked by him during the implementation of the project to the working time fund of this contractor;
- lack of personnel by type of personnel as a function of crew size;
- professional capacity of each crew member during and at the end of the assignment;
- tension in the work of individual functional groups;
- the total duration of the project;
- load factors of certain types of equipment;
- the quality of the project as a percentage of operations performed satisfactorily the first time, without alteration;
- distribution of costs for certain types of resources and total costs of the project;
- the degree of achievement of each of the objectives of the project [15].

It is possible to repeat the task with different values of such parameters as the temperament of individual participants and functional groups, time and quality of individual elementary operations. The use of a variety of equipment, the increase or decrease in the time to complete tasks, and the use of different numbers of personnel in a particular specialty can also be planned and modeled. Each run ends with the release of new data for printing, which the system analyst can use to compare alternative systems, select the composition and number of the project team, and also to compare job options in order to optimize the planned activity, taking into account the restrictions imposed by the doctrine, finances, and technical capabilities.

4. CONCLUSIONS

Based on the analysis of various models of the formation of the project management team, the feasibility of using a simulation model to solve the problems of forming heterogeneous project teams has been proved. The proposed model allows the process of modeling the composition of the project management teams, portfolio of projects or programs based on the criterion of the minimum cost of the costs of their functioning, as well as taking into account the possibility of developing professional competence by members of project teams. A model for simulating the behavior of “the operator-ship system” has been developed with the goal of quantitatively optimizing the crew of the ship depending on the characteristics of the ship (type, age, technical condition), the cargo being transported, and the planned voyage. The model provides for the possibility of seafarers owning several professions and allows using them in extreme situations not in their main specialty. In addition, the model allows you to take into account the psycho-physiological, moral state of the crew member of the ship, which affects the efficiency and quality of the functions and work performed on the ship.

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