NUMERICAL METHODS OF DEVELOPMENT OF MARINE ENGINEERING SYSTEMS

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ABSTRACT

Active development of the World Ocean dictates the need to intensively develop marine engineering systems, designed to solve a wide variety of scientific research, geological, prospecting, search, and other tasks.

Basing on the analysis of scientific works and research in this field, the authors aim to find the optimal mathematical model for increasing the efficiency of such complexes using the example of an underwater unmanned vehicle (UV). As a result, the conclusion is made that the application of mathematical-statistical methods allows correctly and evenly distribute resources (finance, time, labor, etc.), determine the level of innovation, and also more fully and rationally assess the conditions for formation, maintenance and operation of UV. At the same time, the authors especially noted the importance of having quality-related solutions within the requirements (standards) of a single system synchronously working at the stages of design, maintenance and operation of marine engineering systems.

Keywords: marine engineering systems, unmanned vehicles, mathematical model, physical principles, quality management system, statistical data, scientific research, algebraic solutions.

Background. *In the course of research of the ways to improve the efficiency of formation of marine engineering systems [1] (using the example of UV – unmanned vehicles), after analyzing the types of underwater vehicles [2] and standards [3], the problem of creating a mathematical model for designing and operation of UV arose [4]. This is necessary to calculate correct and uniform distribution of possible resources (finances, time, people, etc.), determining the conditions for repair and operation [5]. In order to find an adequate mathematical solution to the problem, a number of papers (studies) were analyzed in which certain mathematical aspects of consideration of technical systems are singled out [6–9].*

Objective. *The objective of the authors is to consider different numerical methods of development of marine engineering systems.*

Methods. *The authors use general scientific methods, mathematical methods, statistics, comparative analysis, evaluation approach.*

Results. *For example, the doctoral thesis «Development of scientific and technical and organizational foundations for raising the innovative level of shipbuilding production to ensure implementation of the provisions of the Maritime Doctrine of the Russian Federation in the field of transport systems» [6] assesses the impact of the main components of globalization of the economy on technical and economic indicators of industrial and economic activities of the Marine industry-transport complex, experience of operation of the first domestic interbranch management system for shipbuilding projects PUSK. At the same time, the author paid attention to the structure of CALS-system of the Marine complex, developed a mathematical-statistical method for determining the indices of reducing labor intensity of building ships by raising the technical level of shipyard production.*

First of all, price of innovations, labor intensity, and energy costs were determined. Well-known algorithms of the mathematical-statistical method of expert evaluations are used, namely:

$$\sum_{1}^{10}\left(r_i-\frac{1}{10}\sum_{1}^{10}r_i\right)^2=S;\qquad S_{\max}=\frac{1}{2}m^2n\left(n^2-1\right);$$

$$W=\frac{6S}{S_{\max}}. \qquad (1)$$

Coefficient of coordination W and its statistical significance are the basis for all further calculations. After finding some coefficients for evaluating the results of innovations in the shipbuilding industry, regression equations were proposed and coefficients for reducing labor intensity, costs, raising the technical level, innovative returns were determined.

Based on the results of the innovative analysis of normative and technical documentation at technical level, technical and economic indicators of innovations are developed, characterized by regression equations: reducing labor intensity of building ships through raising the technical level of shipyard production; costs of innovation.

Further, to determine the efficiency with respect to different items f(x) according to the prescription of the method of least squares the function is used

$$y(x)=\alpha+\beta(x),\ x\in\left[c,d\right], \qquad (2)$$

where

$$\beta=\rho\frac{\sigma(y)}{\sigma(x)},\ \alpha=\overline{y}-\beta\overline{x},$$

$$\rho=\left(\frac{1}{n}\sum_{1}^{n}x_iy_i-\overline{xy}\right)/\,\sigma(x)\sigma(y)\rightarrow\rho\in\left[-1,+1\right].$$

The measure of deviation of f(x) from y(x) is the upper bound (sup) of the modulus of difference |f(x) – y(x)| from the normalized σ(y(x)).

The normalized random variable

$$U_\infty=\sup_{x\in\left[c,d\right]}\frac{\left|f(x)-y(x)\right|}{\sigma\left(y(x)\right)}\Bigg/\sqrt{\frac{(x-\overline{x})^2}{\sum_{1}^{n}(x_i-\overline{x})^2}+\frac{1}{n}} \qquad (3)$$

is subject to distribution function

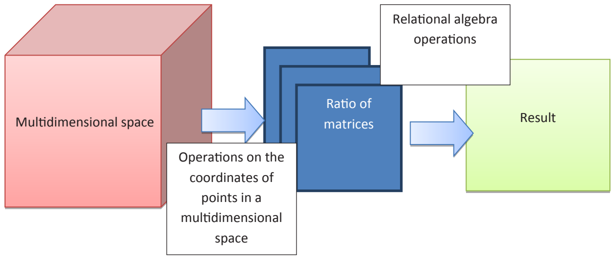
$$U_\infty\in P(U_\infty\geq u)=\frac{\psi}{\pi}\exp(-u^2/2)+$$
$$+\frac{2}{\pi}\int_{0}^{ctg(\psi/2)}\exp\left\{(-1+x^2)u^2/2\right\}\frac{dx}{1+x^2}$$
$$u\geq 0, \qquad (4)$$

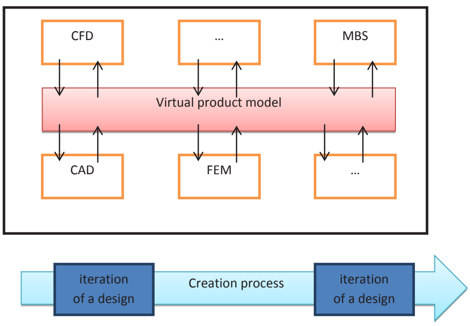
where

$$\psi=\arccos\frac{1+nCD}{\sqrt{(1+nC^2)(1+nD^2)}};$$

$$C=\frac{c-\overline{x}}{\sqrt{\sum_{1}^{n}(x_i-\overline{x})^2}};\ D=\frac{d-\overline{x}}{\sqrt{\sum_{1}^{n}(x_i-\overline{x})^2}}. \qquad (5)$$

Pic. 1. Multidimensional OLAP-cube for database processing.





Pic. 2. The technical state of each node is determined by a group of diagnostic parameters using the software.

If the statistic σ(y(x)) is unknown, then the measure of deviation of |f(x)-y(x)| is a random variable

$$U_\gamma = \frac{\sigma(y(x))}{S} U_\infty, \quad S^2 = \frac{1}{\gamma}\sum_{1}^{n}\left(y_i - y(x_i)\right)^2; \quad \gamma = n-2. \quad (6)$$

According to the relations

$$U_\gamma = \sup_{x\in[c,d]} \left|f(x)-y(x)\right|/S = \sqrt{\frac{(x-\bar{x})^2}{\sum (x_i-\bar{x})^2} + \frac{1}{n}}. \quad (7)$$

The random variable U_γ is subordinated to the distribution function

$$U_\gamma \in P(U_\gamma \ge u) = \psi/2\left(1+\frac{u^2}{\gamma}\right)^{-\gamma/2} + \frac{2}{\pi}\left(1+\frac{u^2}{\gamma}\right)^{-\gamma/2}\cdot\int_0^{ctd(\psi/2)} \frac{dx}{(1+x^2)\left(1+\frac{u^2x^2}{u^2+\gamma}\right)^{\gamma/2}}. \quad (8)$$

From the values of the random variable $\cos\psi = \frac{1+nCD}{\sqrt{(1+nC^2)(1+nD^2)}}$ three values of the distribution function of the quantity U_γ are determined.

$$\frac{1+nCD}{\sqrt{(1+nC^2)(1+nD^2)}} = 1, \quad \psi = 0 \to U_\gamma \in S'_\gamma(x). \quad (9)$$

The random variable U_γ is subordinated to the Student's distribution function (t-distribution) with the number of degrees of freedom n-2:

$$U_\gamma \in P\left(\left|t_{n-2}\right| \le \alpha\right) = P_d. \quad (10)$$

Further, confidence areas are found for the purpose of determining effectiveness.

Another thesis «Development and study of the decision support subsystem for a complex technical object» [7] is devoted to the project of practical production work on the basis of a hybrid electronic system (ES) and intellectual data analysis (IAD) using computer-aided design tools. To solve the problem of information overloading of the operator, the integration of IAD means in ES is offered, which demonstrates an innovative approach to the problem of database (DB) analysis when diagnosing complex technical objects.

Pic. 1 shows a multidimensional OLAP-cube that has three dimensions: diagnostic parameters, cylinder number and measurement time. The basis of IAD is multidimensional OLAP-data cubes («online analytical processing») – database processing technology. The goal of creating cubes is to optimize formation of DB and minimize the processing time of requests that extract the required information from the actual data using algorithms to detect important patterns.

The use of time (date) as a parameter of the system makes it possible to carry out a retrospective analysis and make forecasts of the occurrence of malfunctions. The main advantage of IAD methods, in contrast to the logical search algorithms («if – then») in the database is that they do not have the problem of enumerating the variants in an acceptable time. Thus, OLAP technology acts as a kind of access interface for a decision-maker to multidimensional, multiply connected data in large and super-large databases that are issued in a predefined and convenient form for analysis.

When operating complex technical objects, continuous monitoring of the parameters by standard monitoring systems is carried out. The most informative parameters reflecting the technical state of the object are called diagnostic ones. When solving problems of technical diagnostics, the object is considered as a «box»: inputs – controlled parameters (CP_n), outputs – diagnostic parameters (DP_k). The technical state of each node is determined by a group of diagnostic parameters, for example, various software, as shown in Pic. 2 [5].

Let's consider one more topic: «Development of methods for increasing reliability of the process», the purpose of which is to evaluate the indices directly determining the system's efficiency in the process of its operation, and also such an important issue as reliability [8].

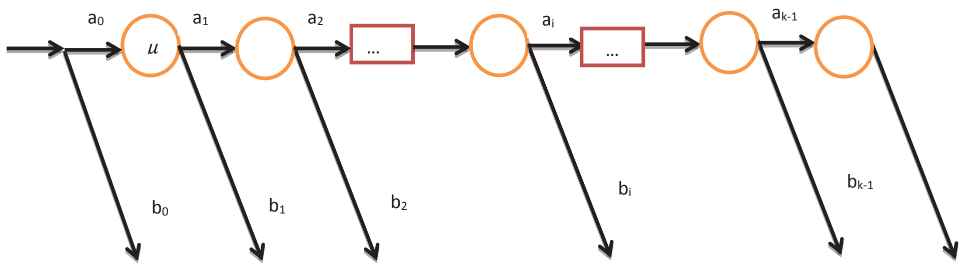
The main analytical results are formed by the author thanks to models of technical systems. They can be obtained by approximating arbitrary operations whose length distribution functions have the Laplace transform, namely:

$$\bar{F}(s) = \frac{E(s)}{\bar{B}(s)}, \quad (11)$$

where E(s) and B(s) are polynomials used in the design of degrees.

The class of distribution functions possessing a rational Laplace transform is quite broad and includes the exponential distribution, the Erlang distribution, the hyperexponential distribution, and so on.

The Erlang distribution of the k-th order is a k-fold convolution of exponential distributions with an average 1/kμ. Therefore, it can be interpreted as the distribution of the operation, which consists of k



Pic. 3. Distribution functions of duration of operations.

consecutive sub-operations distributed exponentially with the parameter kμ.

Using the method of stages allows us to obtain a wide class of distribution functions for duration of operations that have a rational Laplace transform. The illustrated scheme (Pic. 3) shows representation of the generalized distribution function.

For duration of parametric failure operations, the normal (Gaussian) distribution is considered to be the most appropriate. Since uptime of a product cannot be negative, its theoretical normal distribution will be concentrated on the positive semiaxis, so we can assume that the theoretical conditions are met.

Conclusions. *When studying mathematical approaches to solving the problems posed, it can be concluded that in order to increase the efficiency of creating marine engineering systems, it is appropriate to apply mathematical and statistical methods to determine the level of innovation, labor, financial allocations, etc. And it is necessary to fix this within the requirements (standards) in order to raise not only the quality of UV, but also to enhance the management and quality management system (QMS).*

Since the existing QMS reflects the reality of the last century, and for current developments there is no single system for creation, maintenance, operation of marine unmanned vehicles and engineering systems at different stages of project development and implementation, updating the system through algebraic solutions and mathematical models is actual and inevitable.

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