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KRUGLIY, D. G. (https://orcid.org/0000-0001-7024-3858),
APPAZOV, E. S. (https://orcid.org/0000-0003-4277-1981),
ZINCHENKO, S. M. (https://orcid.org/0000-0001-5012-5029),
and NOSOV, P. S. (https://orcid.org/0000-0002-5067-9766)
Kherson State Maritime Academy,
20, Ushakov Ave., Kherson, 73000, Ukraine,
+380 552 49 5902, ksma@ksma.ks.ua

CHOICE OF THE FRACTAL METHOD FOR VISUALIZATION OF INPUT DATA WHILE DESIGNING SUPPORT SYSTEMS FOR DECISION-MAKING BY NAVIGATOR

Introduction. *The constant increase in the amount and intensity of traffic requires organization and precise management.*

Problem Statement. *In the present-day conditions, when the number of vessels engaged on internal and external routes has been growing, without the vessel driver/navigator all alone are not physically able to assess the navigation situation and to make the right decision how to operate his vessel. The need to develop and to implement algorithms that help address the issue of navigation safety is an important task, especially when it comes to the management of groups of vessels.*

The main approaches that allow generalizing the information flows to ensure continuous and safe navigation are the formation of a structured system of processing and evaluation of input factors and related output parameters. This enables controlling the ergatic system of vessel, given a significant number of factors.

Purpose. *The purpose of this research is to create new approaches to controlling the vessel ergatic system for making an optimal and timely decision.*

Materials and Methods. *Fractal methods for representation of the primary information and applied computer programs of mathematical simulation have been used.*

Results. *The proposed model of information processing as part of the vessel ergatic system is designed to comprehensively ensure the safety of vessels, while providing control and optimization of both operational and organizational parameters and diagnostic functions, with the ability to predict and to prevent failures of the vessel engineering system.*

Conclusions. *The applicability of general algorithms for the processing of information and its structuring according to the degree of impact has been shown. The application of these approaches solves the problem of overloading the navigator with excessive navigational information and reduces decision-making time. The developed algorithm allows creating an automatic control system for groups of vessels in real conditions of difficult navigation environment.*

Keywords: decision support system, ship ergatic system, and navigation safety.

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The changes in the economic and social situation worldwide require revising approaches to the transportation of goods by sea. Thus, today's problems related to the optimization of maritime transport necessitate finding the advanced approaches to their solution.

The constant increase in the vessel traffic amount and intensity requires proper organization and precise management of the marine transport. To do this, it is necessary to identify the factors that inhibit this process. According to general statistical survey, one of the most important is the human factor. Therefore, it is necessary to find a way for its complete exclusion from the management process, at the final stage.

Maritime transport has not always been seen as a promising area for the application of information technology. This was caused both by the traditional conservatism of the industry and a long cycle of ship design and operation, as well as by a fairly high degree of regulation, especially in terms of safety, by national and international organizations.

The issues related to designing decision support systems in navigation are now becoming particularly important because of a much higher level of automation of modern vessels and the increasing number of maritime accidents caused by the human factor. According to available statistics, navigator's wrong decisions on the vessel control are the main cause of more than 80% of marine accidents. This is confirmed by the growing number of maritime events. Reducing the impact of the human factor on the accidents is an urgent research and practical problem that needs to be addressed by improving the processes of interaction between the navigator and modern technical means of vessel control. The creation of a vessel ergatic system is one of the most promising areas for reducing the accidents and increasing the intensity of cargo flows. The interaction between the navigator and the equipment is complicated by a significant increase in the amount of navigation information that is available in real time through the use of modern information technology. On the other hand, the rapid development of information technology and the active application of the principles of artificial intelligence in the technology have created favorable conditions for the development and implementation of decision support systems (DSS) in navigation.

In our opinion, the solution to this problem can be found in the field of creating systems that help find non-standard approaches to achieve an ultimate goal. The creation of new approaches to the control of the vessel ergatic system significantly improves the conditions of controlling an individual ship or groups of vessels. This should be understood as the optimal and economically justified goal in the transportation of goods by sea. Making optimal and timely decisions is the major task. The need to develop and to implement algorithms that help ensure navigational safety is also an important task, especially when it comes to managing groups of marine vessels.

Finding the main directions of research and vectors of the development of decision support systems is the initial stage of creating a vessel ergatic system for decision-making in complicated and uncertain processes. This is directly related to the field of traffic management.

In this regard, the purpose of this research is to determine the principles of the formation of automatic systems and decision support systems; to choose among them the most convenient and useful factors to achieve the ultimate goal, based on the analysis; proceeding from this to identify the main factors of the automatic control process for further improvement of the existing decision support systems; and to create our own, more flexible, user-friendly system as a final product.

In the present-day conditions, when the number of vessels engaged on internal and external routes is growing, the navigator is not physically able to assess the navigation situation and to make the right decision how to operate his vessel. The solution to this problem is to create an automated system for preventing ship collisions. Various aspects of such systems have been considered in [1—6]. In [7], the principles and architecture of the automated system for ensuring vessels to pass clear of each other, which is under development, with a navigation subsystem for assessment of the situation have been described. The main task solved by this subsystem is the comprehensive assessment of the current navigation situation, including the assessment of the risk of collision with other vessels, the risk of getting ashore, and the like.

The analysis of accidents and incidents at sea in recent years has led to the gradual departure of the international maritime community from a one-sided approach focused on the technical requirements for ship design and equipment. This analysis has drawn attention to the approach that recognizes the role of human factors in safety at sea, with the navigator and the ship considered as a single system.

The hazard assessment process is based on the retrieved information and identifies priority measures to control the vessel safety, so the main task of risk analysis is to provide a sound basis for risk management decisions.

Risk analysis may be not only quantitative, in which the main results are obtained by calculating risk indicators, but also qualitative, in which the results are presented in the form of text descriptions, tables, diagrams by applying qualitative methods of hazard analysis and expert assessments. When choosing methods of risk analysis in navigation, it is necessary to take into account the criteria of acceptable risk, the parameters of the situation, and the nature of hazard, the availability and the nature of the necessary information, experience and qualifications of the navigator, as well as other factors.

Starting with the simulation of the operator-ship system, one shall consider a human-engineering system with the two main components: the human being and the ship. It should be borne in mind that the main link in the complex chain of this system is the human operator with his subjective factors [4]. The sea accidents data have shown that neither automation nor equipping vessels with cutting-edge control instruments may guarantee their complete safety. The main causes of accidents are subjective (or human) factors.

Since the 1960s, in the industry, to prevent the manifestation of the human factor, more attention has been paid towards separating ergatic systems from the control ones. In the ergatic system, control over the human factor is achieved through the use of the probabilistic approach by changing or decreasing the entropy of its individual elements, including a particular operator. In the navy, this has been already reflected in the fact that the vessels collect some statistics on the reliability of each crew member [5].

Strengthening the role of the human factor in the accident in the navy requires joint consideration of control systems and ergatic systems to improve control over it. The analysis of publications on control systems and ergatic systems has shown that there are several researches on either control or ergatic systems [6—10].

Currently, more than six different control systems have been implemented on vessels. Each their data system contains a requirement to determine in advance a potential failure of ship operations and hardware, which may lead to undesirable results. In different standards, these failures are referred to differently, for example, the sudden operational failures of critical equipment and technical systems, in the International Code for Safe Operation of Ships and Pollution Prevention (the International Safety Management, ISM Code); the potential nonconformities, in the Quality Management System (ISO 9001:2008); the potential threats to the safety of ships, crew, and shore facilities, in the International Code for the Protection of Ships and Port Facilities (ISPS Code); the environmental aspects, in the Environmental Management Systems (ISO 14001:2004); the potential threats to human health, property or the operating environment, in the Occupational Health and Safety Management System (OHSAS 18001:2007).

In addition, the majority of maritime legislation requires, before the ship starts operations, to assess the potential risks of failures to prevent them in every application. In the case of actual or potential failure, the management system shall control it and prevent the recurrence of human factor by modifying and/or improving the structural and/or functional elements of the control system [11].

Ergatic system is a system consisting of the following elements: the operator, the machine and environment, and the control system of the interactions of these elements. It allows precautionary measures directly to the element, i.e. a particular operator, engineering system or equipment [12].

In the case of the human factor, the actual or potential failure, the ergatic system changes the given state of the structural elements of the control system and, accordingly, increases their entropy and the entropy of the management system. Control over the prevention of the human factor is established by reducing the entropy of its elements on the basis of the probabilistic approach through changing the probabilistic states of these elements.

Vessel ergatic system shall achieve various objectives of management. It should be noted that each goal requires a different number of entropies of ergatic systems. When developing an ergatic system, the input data are legislative and regulatory requirements, as well as the interaction of elements of the ergatic system "operator — ship — environment", which are implemented as operator-ship, operator-environment, operator-operator, ship-operator, environment-operator pairs.

Thus, increasing the level of automation of modern vessels, the widespread introduction of advanced means of navigation makes it possible to successfully solve the problems of effective planning and implementation of transoceanic transitions by creating DSS for the navigator [13]. The world largest companies involved in the marine transportation of goods have been studying the problems of optimizing the performance of maritime transport both at the planning stage and in the conditions of sea crossing.

PRESENTATION OF THE MAIN MATERIAL

DSS shall provide information and analytical support to decision-making processes in the event of the occurrence of or threat to traffic safety on the basis of information processing of operational, analytical, reference, expert, and statistical data. The DSS is created on the basis of integration of functional, informational, and software-hardware means of separate elements; the integration is focused on the use of generalized information flows to obtain a timely and objective assessment of traffic safety.

The subsystem for collecting, pre-processing, and storing information is designed to collect, store, backup, and to retrieve the necessary data for further processing. There are both manual and automated methods for information input. Data are stored based on the databank technology that provides object-oriented allocation of resources and information references [4].

Designing a DSS for the practical implementation of integrated safety of vessels starts with the development of an algorithm. The principle of the DSS algorithm is typical. However, in certain cases, it may differ, since each vessel has different equipment and different sailing area. An important basis for the DSS is its integrated structure formed on the basis of operational configuration of information subsystems and areas, which ensures their interaction.

When designing DSS, it is obvious that the final decision to be made shall comply with the following model:

$$S = (P, K, A, E, M),$$

where P is data area; K is area of knowledge; A is area of solutions; E is area of expertise; and M is area of graphical simulations.

The data area is primarily the characteristics of a vessel, in particular its maneuverability.

$$D = (m, k, d, w, c),$$

where m is seaworthiness; k is stability; d is buoyancy; w is propulsion; and c is controllability.

The designed DSS shall allow the navigator to independently build the intended route of passage. For a given route, the DSS, with the required interval, offers a graphical (on the route map) or tabular detailed analysis of weather phenomena. Based on the ship maneuverability, the expected speed of the ship is predicted, depending on the weather conditions. It should also be possible to construct a route, depending on the requirements of the navigator (which boundary zones in terms of the wind strength, the height of wind waves, and ripples shall be avoided on the route).

The field of knowledge is a formalized assessment of environment is as a set of factors that have different nature and cause disturbances and possibly negative interactions with the ship and the navigator and may lead to dangerous situations.

$$K = (ph, p, o, r),$$

where *ph* is phenomena; *p* is processes; *o* is objects; r is relations (links).

In fact, such a representation of the field of knowledge allows us to identify the concept of safe navigation systems with the concept of its structure. In this context, the concept of safety system structure refers to the interconnection of the following elements, the relationship of which is the object of further analysis and development. In the first phase, there are several different and interconnected fields:

- the internal that is influenced and controlled by the crew;
- the environment in which impacts on the ship are formed;
- the macro-environment that forms the general requirements for navigation safety.

The area of expertise is

$$E = (a, l, pr, s),$$

where *a* is compliance with the MLSW; *l* is technical (technological) restrictions; *pr* is priorities between vessels; *s* is the maneuver impact on the safety of the ship.

The area of graphical simulations in a simplified form may be represented as a situational assessment of the movement of two or more vessels:

$$M = (l, v_1, v_2,... v_n\ k_1, k_2,..... k_n,),$$

where l is distance between the vessels; $v_1, v_2,... v_n$ are relative speeds of vessels; $k_1, k_2,... .. k_n$ are course changing speeds.

In this case, the time until collision may be calculated based on the original data. The formalization of these conditions is determined by the specific interpretation of the concept of dangerous situation. Here, it is advisable to refer to the experience of practical navigation, which has shown that the most important thing is the observance of a safety zone [16] around vessel to which other vessels are not allowed. There are many models of a safe zone ("domain") around a vessel, depending on its type, condition, speed, etc. To do this, it is most appropriate to use the following algorithm:

- to identify vessels in the area of possible collision;
- to monitor and to analyze the parameters of the motion of the vessels and their dynamics, given the errors of observations and measurements;
- to classify the vessels in terms of degree of danger;
- to determine the possible behavior of vessels in accordance with COLREG-72;
- to simulate possible scenarios for the development of the navigation situation; and
- to work out possible measures for preventing and avoiding dangerous situations with alternative solutions.

Obviously, the proposed approach to building a decision support system for a ship owner causes a vast array of information to be obtained. These data are different in terms of the source from which they are obtained, accuracy, reliability, relevance, etc.

At the first stage, all the information received can be divided into several groups:

- very relevant information;
- relevant information;
- useful information; and
- irrelevant information.

It is important to continuously monitor and process the parameters of the vessel diagnostic equipment, which directly affect the ship safety. For this purpose, it is necessary to provide for monitoring of vessel technical means, which allows considerably expanding the possibilities of diagnostics, especially at the early stages of the development of dangerous processes, in particular, the hidden ones. In addition, the analysis of the interdependent parameters of different vessel technical equipment reduces the errors and influence of the operating parameters of one system on those of others.

In this regard, there is a need to sort out the information by the above parameters and to determine for the data obtained by the data system the coefficient of impact on the simulation result. In our opinion, the array of data obtained shall be represented by fractals, because they are self-similar.

The reason for the self-similarity of traffic is the integrated nature of the data set. This data set is used simultaneously to provide the system with information from the data area and the knowledge area in the form of standard messages. The data array, formalized rules, measurement results, messages, and commands are transmitted by a single system with a single software and control laws. Therefore, we may assume that the probability of an event (providing new information, a new data packet) depends on the occurrence of the event in past time intervals, i.e. the event flows are flows with some function of allocating time intervals between events. In most known systems, it is accepted that the probability of occurrence of the next event depends only on the time that has elapsed since the occurrence of the previous event and does not depend on the history of events.

Describing a simple object and moving on to a complex one that is similar to it, one can significantly simplify the solution of a multilevel problem. Fractals have the ability to display complete information about an object or phenomenon, defining its part that is similar to the whole. As a tool, in this case, it is convenient to use fractal objects, work with which is interesting and relevant both in terms of mathematical research and in terms of practical applications. In the case of uncertainty, this can help due to random changes in some parameters. For example, the influence of hydrometeorological conditions, difficult navigation situation, the state of the cargo, and so on.

Mandelbrot set as a fractal consisting of individual points on a complex plane may be identified as the most realizable:

$$Z_0 = 0,\ Z_{n+1} = Z_n^{\,2} + C.$$

Moreover, this sequence of individual points C does not go to infinity. Thus, for each point C, one may write as

$$C = x + i{\cdot}y;$$

$$Z_0 = 0;$$

$$Z_1 = Z_0^{\,2} + C = x + i \cdot y;$$

$$Z_2 = Z_1^{\,2} + C = (x + i \cdot y)^2 + x + i \cdot y =$$

$$= x^2 + 2\, i \cdot y\, x - y^2 + x + i \cdot \mathrm{y};$$

$$Z_3 = \ldots\ldots .$$

The Mandelbrot set is usually represented as an unlimited number of simple shapes around a large one that touches them. Each large figure has a set of smaller figures around them, the size of which goes to zero. This process is infinite, with the formation of a fractal [17].

Thus, it is advisable to present the parameters obtained by vessel systems in the form of fractals to simplify the procedure for their classification and processing. Another important property of fractal is its small dimension. This allows a more detailed and objective consideration of the impact of each parameter on the simulation results. This is an illustration of the dynamic chaos in this system with limited predictability and fundamental impossibility of accurate prediction, given the randomness of the choice of the motion trajectory of each point on one of several branches. The divergence of adjacent trajectories leads to the uncertainty of the position of the point after a while, creating a cloud of uncertainty. The behavior of the system is predicted for a small period of time and unpredictable for a rather large period, as the system starts behaving chaotically, for which only a statistical description is possible.

Fractal dimension may take both whole and small values. The calculation of the fractal dimension D of the time series allows us to conclude on the nature of the process. In [3], a fractal scale of estimation of measurement results of a complex dynamic system has been proposed. This scale can be used to evaluate the measurement results of complex systems mentioned above.

The most appropriate is the R/S analysis algorithm:

$$R/S = (\sigma \cdot t)^{\mathrm{H}},$$

where σ is constant value as correction factor; R is the range between the maximum and the minimum values of parameter over a given period of time; S is the root mean square deviation for a certain time period. H is the Hearst index.

The standard deviation may be represented as:

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n} \overline{x_i - (x)^2}}.$$

The range between the maximum and minimum values of parameter over a given period of time

$$R = (R(t_0) - R(t))^{\mathrm{H}},$$

In this case, the Hearst index H may be defined as:

$$H = 2 - D.$$

This index is important because it indicates the stability of the parameters under study. The results of the experiments have shown that:

- $H = 0$ corresponds to unpredictable and chaotic processes;
- $0 < H < 0.5$ shows that there is a tend towards return to the average prevails, which makes it impossible to rely on this indicator;
- $H = 0.5$ characterizes random processes;
- $0.5 < H < 1.0$ characterizes a steady tend that can be used in predicting the development of events. An increase in H indicates a stronger trend in the parameter over time.

The fractal scale has the three distinctive criteria:

- at $D = 1$, the measurement result is interpreted as strictly deterministic behavior of the system, with the possible equation of the behavior of the process;
- at $D = 2$, the system behaves in a regular manner, but the variation of the measured values is very large, which makes it impossible to use methods of processing the measurement results;
- at D = 1.5, the process is random, statistical methods are used to analyze such systems;
- at $1 < D < 1.5$ the process under consideration is persistent and approaches the deterministic one;
- at $1.5 < D < 2$, the process is antipersistent and has a random scatter that exceeds the magnitude of slow variations.

Thus, over time, the systems whose behavior is determined by the rules that do not include randomness show unpredictability because of growth, amplification of small uncertainties, and fluctuations.

Designing these systems is complicated by the existence of many ways to bring these parameters to a single numerical estimate, and this significantly affects the calculation results. The user of this system shall not be guided by the principles of this system, methods of formalization, and calculation algorithms. Thus, the developer of this product shall take into account not only specific numerical parameters and dependencies, but also possible alternatives.

The software part of the designed system consists of separate blocks, each being responsible for a separate vessel engineering system. This allows the use of standardized input parameters without taking into account the algorithms of each of them. When forming the final product, it is possible to add or to exclude individual blocks from the general software module, depending on the tasks, which makes the system more versatile and simplifies its adaptation to a particular vessel or region of navigation, as the conditions of navigation and the behavior of vessels differ significantly.

At the first stage, information is collected from the primary transducers and the primary database is formed of the input parameters of the projected system.

The database includes as follows:

- results of the measurements of kinematic and dynamic parameters of the vessel (speed, course,

wave and wind load on the hull, sway, draft, controllability of the vessel, stress and condition of individual elements of the hull);
- results of the measurement of cargo parameters and possible impact on the condition and controllability of the vessel;
- a set of meteorological data: results of the measurements of wind direction and speed, visibility, precipitation, agitation, ice conditions by its own meteorological station and the analysis of incoming meteorological reports and forecasts;
- information on the navigation environment coming through the channels of the automatic identification system of vessels;
- information coming from shipborne radar systems,
- international rules for the prevention of vessel collisions;
- information on flight parameters;

This database allows optimizing in more detail the operation of DSS for a particular vessel, given the area of navigation, season, cargo, crew composition, etc. This process is extremely important, because errors in measurements, definitions, estimates lead to erroneous simulation results. This, in turn, not only complicates the decision-making process by the navigator, but also causes confusion and load-up with incorrect information. Therefore, it is advisable not only to continuously compare the obtained parameters with the maximum permissible ones, but also to compare them with each other using known dependencies.

The second stage deals with the processing of the obtained primary information in an intelligent system that simulates the current processes to identify possible negative prospects for changes in operating parameters and the parallel verification of combinations of primary parameters in accordance with analytical algorithms and a complete knowledge base, which allows early identification of unfavorable situations:
- anticipation of possible actions of vessels in the maneuvering area;
- assessment of the current situation in the maneuvering area and classification of vessels in terms of the risk of collision;
- assessment of the possibility of maneuver by the vessel, etc.

In the case of correct definition of boundary conditions and coefficient of influence of each parameter by means of the MATLAB software it is possible to receive correct results of modeling the development of a navigation situation with graphic display of difference, convergence, and motion of vessels. For example, analyzing the meteorological data received in the form of messages and results of measurements in combination with time dynamics allows predicting the development of a meteorological situation for given vessel in specific conditions. The cargo characteristics and the data of the primary transducers on the specific voltage of individual elements of the vessel enable warning the navigator about the dangerous condition at an early stage. To do this, it is necessary to provide an intelligent system with a continuous flow of information at certain intervals. The information representation in the fractal form enables studying in more detail the impact of each element.

Using data flows, the system forms a set of precedents similar to each other. The precedent includes a situation that may be characterized by a set of data, a decision, and a result. The situation for which a precedent has been set is considered basic. The choice of the most worthy precedent in a particular situation allows making a decision on its basis in a ready form, or requires additional actions to adapt the decision in order to take into account differences in the contexts of the situation. This, in turn, creates a persistent similarity and repeatability of precedents, specific to a particular vessel. In our opinion, such a strategy of forming the structure of vessel ergatic system makes it possible not only to use data flows, but also to formalize the maritime experience in the form of saved solutions to a specific navigation situation.

Upon calculating these parameters with defined coefficients of influence and analyzing precedents, recommendations for navigators are generated, and alternatives based on the existing (saved) precedents are proposed. including changes and route of formation compliance and dnyh messaging modes of propulsion, preventive activation of auxiliary systems (system of change of a condition or parameters of cargo , etc.), and also a possibility of performance of operative maintenance for increase of operational reliability or restoration of working capacity of the vessel as a whole.

Conclusions. The proposed model of information processing as a part of the vessel ergatic system ensures complex safety of vessels. It provides for monitoring and optimizing both operational and organizational settings, and diagnostic functions, with the ability to predict and to prevent failures of vessel engineering systems. The two-tier architecture has been adopted for the construction of DSS, as the processing of initial data involves separate techniques for diagnostic and organizational parameters.

Further research aims at the formation and accumulation of a database and knowledge consisting of statistical information on dangerous phenomena, consequences, and mechanism of emergency development.

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Д.Г. Круглий (https://orcid.org/0000-0001-7024-3858),
Е.С. Аппазов (https://orcid.org/0000-0003-4277-1981),
С.М. Зінченко (https://orcid.org/0000-0001-5012-5029),
П.С. Носов (https://orcid.org/0000-0002-5067-9766)
Херсонська державна морська академія,
просп. Ушакова, 20, Херсон, 73000, Україна,
+380 552 49 5902, ksma@ksma.ks.ua

ВИБІР ФРАКТАЛЬНОГО СПОСОБУ ДЛЯ ВІЗУАЛІЗАЦІЇ ВХІДНОЇ ІНФОРМАЦІЇ ПРИ ПРОЄКТУВАННІ СИСТЕМ ПІДТРИМКИ ПРИЙНЯТТЯ РІШЕНЬ СУДНОВОДІЄМ

Вступ. Постійне підвищення обсягу перевезень та їх інтенсивності потребують організації та точного керування ними.

Проблематика. В сучасних умовах, коли кількість суден, зайнятих на внутрішніх та зовнішніх шляхах, зростає, судноводій фізично не може самостійно оцінити навігаційну обстановку та прийняти правильне рішення щодо управління своїм судном. Необхідність розроблення та втілення алгоритмів, які сприятимуть вирішенню питання забезпечення навігаційної безпеки, є важливим завданням, а особливо якщо це стосується керування групами морських суден.

Основними підходами, які дозволять, узагальнити інформаційні потоки для забезпечення безперервного та безпечного плавання, є формування структурованої системи обробки та оцінки вхідних факторів та пов'язаних з ними вихідних параметрів. Це дозволить керувати судновою ергатичною системою з урахуванням значної кількості факторів.

Мета. Створення нових підходів при керуванні судновою ергатичною системою для прийняття оптимального та своєчасного рішення.

Матеріали й методи. Використано фрактальні методи представлення первинної інформації, прикладні комп'ютерні програми математичного моделюваня.

Результати. Запропоновану модель обробки інформації в складі суднової ергатичної системи призначено для комплексного забезпечення безпеки суден, при цьому передбачено здійснення контролю та оптимізації як оперативних й організаційних параметрів, так і діагностичних функцій, з можливістю прогнозування й попередження відмов суднової технічної системи.

Висновки. Показано можливість застосування загальних алгоритмів обробки інформації та можливість її структурування за ступенем впливу. Застосування цих підходів дозволить вирішити проблему переобтяження судноводія надмірною навігаційною інформацією та скоротити час прийняття рішень. Розроблений алгоритм дозволяє створити автоматичну систему керування групами суден в реальних умовах складної навігаційної обстановки.

Ключові слова: система підтримки прийняття рішень, суднова ергатична система, безпека плавання.