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DEVISING AN APPROACH TO SAFETY MANAGEMENT OF VESSEL CONTROL THROUGH THE IDENTIFICATION OF NAVIGATOR'S STATE

Pavlo Nosov
Corresponding author
PhD, Associate Professor
Department of Innovative Technologies and Technical Devices of Navigation*
E-mail: pason@ukr.net

Oleksiy Koretsky
Captain of Long-Distance Navigation, Postgraduate Student
Department of Innovative Technologies and Technical Devices of Navigation*

Serhii Zinchenko
Doctor of Technical Sciences, Associate Professor
Department of Ship Handling at Sea*

Yurii Prokopchuk
Doctor of Technical Sciences, Associate Professor, Leading Researcher
Department of System Analysis and Control Problems
Institute of Technical Mechanics of the National Academy of Sciences of Ukraine
Leshko-Popel, str., 15, Dnipro, Ukraine, 49005

Igor Gritsuk
Doctor of Technical Sciences, Professor
Department of Ship Power Plants Operation*

Ihor Sokol
PhD
Maritime Applied College
Ushakova ave., 14/1, Kherson, Ukraine, 73000

Kostiantyn Kyrychenko
PhD, Senior Lecturer
Department of Health and Safety, Professional and Applied Physical Training*
*Kherson State Maritime Academy
Ushakova ave., 20, Kherson, Ukraine, 73000

The object of this study is the processes of automated management of maritime safety by analyzing the manifestations of the human factor of sea navigators.

The task solved is justified by the need for formal and logical analysis and intelligent identification of mental motivational states (MMS) of marine navigators whose actions can cause dangerous situations during the control of the ship's movement. High accident rates due to the fault of the navigators, in the absence of automated means of monitoring their condition, cause a contradiction between the existing means of safety control in controlling the movement of the vessel and the modern requirements of navigation, which needs to be resolved.

A safety management approach was devised that takes into account the specificity of navigational tasks and the p-adic classification of dangerous MMS for navigators. This has made it possible to create three security modes that are activated depending on the detected state of the navigator's MMS.

Features of the results are the combination of analysis by means of p-adic systems and intelligent methods of data processing. As a result, sufficient identification accuracy was obtained for more than 75 % of MMS through neural network training.

Experimental data collected during the navigation watch, as well as on the Navi Trainer 5000 navigation simulator (Wärtsilä Corporation, Finland), became the basis for simulation by means of neural networks. In turn, the training of neural networks made it possible to obtain sufficient identification accuracy by performing up to 3000 iterations. Overall, the learning rate of the neural network was 0.98, which indicates a high level of identification.

From a practical point of view, the results could be used for the automated management of shipping safety, as well as for evaluating the level of adaptation of the navigator to dynamically changing conditions. The proposed approach provides opportunities for the application of modern intelligent technologies in the field of maritime transport safety, namely artificial neural network tools that determine notification modes or activation of automatic ship traffic control modules.

The specified contradiction requires the design of specialized systems for automated safety management of ship traffic control based on the identified states of navigators

Keywords: safety management, intelligent system, motivation, identification, p-adic systems, neural networks

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1. Introduction

Undoubtedly, the human factor is defined as the main contributor and inevitable driver that causes catastrophic situations in maritime transport [1, 2]. Many researchers around the world are engaged in the analysis of the potential definition of marine disasters in order to meet safety and security requirements. This issue will certainly help prevent possible accidents in the future. However, the development of management systems faces real challenges, trying to take these processes under control, taking into account the degree of risk. In turn, the complexity and multifacetedness of identifying the reasons for which marine navigators (it would be appropriate to provide a brief description of a marine navigator, his functions, because the research is interesting not only for specialists in the maritime industry but also for other types of transportation, taking into account the presence of close problems, for example, in air transport) change the usual patterns of actions when driving a ship, makes it problematic [3]. It should be taken into account that a marine navigator is a specialist responsible for the safe management of a ship, who ensures the accurate determination of the ship's location, plans the optimal route, and avoids dangers on the way. He analyzes meteorological conditions, monitors radio communications, and ensures the maintenance of the necessary documentation. The navigator is responsible for monitoring the technical condition of the vessel and its equipment. In critical situations, he coordinates rescue operations and can provide first aid.

The situation is worsened by the fact that ship owners are faced with a lack of funds, which leads to the absence of a full-time psychologist on board the ship. In addition, the introduction of psychological surveys gives only a relative assessment of the mental state of the sea navigator during the process of recruiting a crew in companies.

Meanwhile, some studies pay great attention to the influence of mental motivational states (MMS) of an individual on the result of the completed task, especially in critical, dangerous situations [4, 5]. In turn, the mental motivational states of marine navigators are a partial example of psychological states that influence their decisions and actions while controlling the movement of the vessel. These conditions can be caused by various factors, such as stress, fatigue, overconfidence, fear, etc., and can lead to dangerous situations at sea because they affect the perception, reaction, and decision-making of navigators in difficult situations.

It has been studied that the navigator's motivation is closely related to his expectations, which, in turn, play an important role. On the one hand, this factor can undoubtedly be called formative in creating a behavior strategy, predicting the desired result, but at the same time it is difficult to detect [6–8].

Given the above, the relevance of research into the influence of the human factor on the safety of ship management is extremely important, and therefore there is an urgent need for additional research and development in the field of intelligent identification of the mental motivational states of navigators. This involves the use of automation of the specified processes on board the ship in real time, which will make it possible to implement effective maritime safety management systems that can respond to changes in MMS. The development and implementation of such systems will be a decisive step in ensuring the safety of maritime transport, preventing disasters, and adapting the strategies of navigators' behavior to changing circumstances.

The relevance of this scientific and applied topic is quite high since the human factor, in particular the MMS of marine navigators, affect the safety of navigation, and stress and other psychological states can significantly affect decision-making during the control of the ship's movement. The lack of stable psychological support on board ships complicates the situation, as there is no identification and correction of the condition of the crew. However, there is potential for technical innovation, such as the development of systems that can identify navigators' MMS in real time and implement corrective measures. This becomes especially important in the context of the global role of maritime transport and the need to ensure its safety at the international level, and the data obtained from the research could have a wide scope of applications, including other modes of transport, such as air and rail.

2. Literature review and problem statement

In [9], such a comprehensive approach to assessing the risk of capital investment of ships is proposed, including parameters of use such as the closest point of approach (DCPA), the time to the closest point of approach (TCPA), and the capital increase risk index (CRI). However, despite the thoroughness of these methods, the cited article does not take into account the human factor, in particular, the states and actions of the shipmaster during the navigation watch. This indicates insufficient accuracy of the ship collision risk model and may lead to an underestimation of the real risk since the human factor plays a key role in the safety of maritime shipping. Thus, despite significant advances in risk quantification, the cited paper leaves room for further research and improvement, including a more in-depth analysis of the human factor.

Works [10, 11] consider in detail the errors of operations on board the ship: operations on board the ship are the main factor contributing to 70 % of accidents. However, it is important to consider that these mistakes can be caused not only by technical shortcomings but also by motivational factors of the captains. This is also seen in MASS (Marine Autonomous Surface Vessel) operations, where an operator must remotely intervene in the operation of the autonomous vessel, although the human element is not considered in MASS design. In this sense, the considered alarm management system seems to be insufficiently effective for use in situations where shore operators need more time to react in critical situations. There is also the issue of delineating roles, duties and responsibilities between different team members.

Papers [12, 13] analyze the causes of the accident using the system analysis and classification of the human factor in marine accidents using HFACS-MA methods. The analysis of causes and their differentiation is divided into categories: external factors, organizational influences, unsafe management, suggestions, and unsafe actions of operators. However, the study is based on a large number of accidents but does not take into account their severity or type. This limits the ability to conduct a more in-depth analysis and understand how different types and severities of accidents may affect different risk factors. This fact does not allow a deep investigation of the negative manifestations of the human factor as a cause of accidents because some accidents are not reported by pilots, and therefore they are not known to SHPA and are not included in their database.

In works [14, 15], an analysis of marine accident reports registered in MAIB from 2010 to 2019 was carried out, and it was found that the causes of the accident are mainly related to two categories of the human factor. Using the HFACS-MA method and multiple linear regression, the authors confirmed that exposure to these categories can reduce accidents and improve overall shipping safety. It should be noted that the research was conducted taking into account all types of merchant ships but did not investigate the specificity of the relationship between the classes of ships and the influence of the human factor. It is possible that different classes of vessels may have unique parameters and risk factors related to the human factor of navigators. This is an objective reason that limits the research methodology.

Typically, the main focus is on the technical aspects of the safety of marine systems, including automated testing and risk analysis [16]. The research data focuses on the analysis of navigator data using AIS data and data analysis tools. They define the safety profiles of navigators, including risky and safe, and confirm the ability to identify these profiles from AIS data. The research also includes simulation tests of the navigators' actions in a ship collision situation and the creation of models to identify the navigator's profile. Although a direct analysis of navigators' motivation is not mentioned, the cited study can serve as a basis for understanding navigators' behavior and analyzing motivational factors.

In order to solve the issues of improving maritime security, administrative management is being strengthened, which introduces significant subjectivity [17]. The authors analyze the risks and threats to maritime safety using a fuzzy and complex analytical process through the study of crew training models based on the professionalism of the marine surveyor and the marine accident investigation system. The study includes tests to identify the navigator's safety profile based on AIS data and simulation tests of navigators' actions in ship collision situations. As a result, a model is built to identify the profile of the navigator. However, while the study recommends the creation of standard safety assessment procedures, it is still unclear how these procedures will be developed, deployed, and overseen at the global shipping level. The research also highlights the need to develop and implement policies to improve shipping safety. However, concrete strategies for the implementation of these policies are still being developed.

The problems of the negative impact of the human factor are also important for cyber-physical security in the maritime sector, including a review of research and legal initiatives [18]. In particular, methods of cyber security risk assessment for cyber physical systems and processes of risk processing are considered, including design and control of cyber security. The authors highlight the importance of global communications for the maritime industry and the complexity of the cyber architecture that supports process functions. However, a proper security and operations audit of critical components and processes of marine assets is not performed, which may reveal unknown vulnerabilities in ship management systems and processes. There are also problems with the convergence between land-based and maritime cyber-physical security systems, which can complicate the implementation of security policies and improve the detection of threats in the face of negative manifestations of the human factor.

Nevertheless, this does not mean that the current state of the navigator is not important in controlling the movement of the ship [19], but on the contrary, it indicates insufficient identification of the motivation and behavior of operators, which significantly affects the efficiency of navigation. This can be especially important when moving to e-navigation, as it involves changes in the roles and responsibilities of navigators. However, this is practically not taken into account in the form of complexity and uncertainty in the identification, formalization, and algorithmization of the parameters of the motivational state of navigators.

The review of the above sources indicates insufficient attention to the psychological state and motivational mechanisms of decision-making by navigators in the context of maritime navigation safety, especially when transitioning to e-navigation. At the global level, there is a problem of developing, deploying, and monitoring objective and formalized safety assessment procedures for ship traffic management that integrate technical and human factors. There is significant complexity and uncertainty in the identification, formalization, and algorithmization of the parameters of the motivational state of navigators, which complicates the timely detection and correction of potentially dangerous conditions and can worsen the safety of navigation.

3. The aim and objectives of the study

The purpose of our research is to devise an innovative approach in the study of the MMS of sea navigators using p-adic systems to identify the negative human factor in the tasks of safety management in maritime transport. This will make it possible to introduce a real-time safety management system for controlling the movement of the ship by means of automated identification of additional factors influencing the effectiveness of decision-making by navigators in critical situations.

To achieve the goal, the following tasks were set:

– to develop a formal and logical approach to the structural identification of the navigator's MMS with the aim of covering the widest spectrum of his functional activity during the navigation watch by means of p-adic systems;

– to build a scheme for managing the safety of navigation on ships based on the identification of dangerous MMS;

– to conduct simulations on the training of intelligent systems based on artificial neural networks, which will allow obtaining sufficient accuracy of automated identification of dangerous MMS.

4. The study materials and methods

The object of this study is the process of structural identification of navigators' MMS during navigation watch.

Hypothesis: the use of p-adic systems for the analysis of MMS of sea navigators will allow identifying dangerous conditions based on non-linear methods, as well as improving the safety management system.

An important element of research is obtaining the exact structure of interrelated situations of a particular navigator. In turn, the research hypothesis assumes the following: the construction of a geometrically structured map, with a high probability, will allow determining the areas of distribution of MMS, as well as mechanisms for determining the possible actions of navigators.

In the course of the study, statistical data were calculated and identified, which reveal the dependence between the MMS of navigators and the sequence of their actions when performing sea maneuvers [20, 21]. It should be emphasized that one of the available results was the clustering of naval teams according to typical patterns of behavior in relation to MMS. Thus, the following groups were identified, which define four models of behavior and, accordingly, four dominant MMS (Table 1).

Table 1

Correlation matrix of MMS structure

Navigator state	Mental motivational state			
	Ego motivation	Confrontation motivation	Motivation to receive	Avoidance motivation
Ego motivation	1.000	–0.036	–0.033	–0.113
Confrontation motivation	–0.036	1.000	–0.010	0.231
Motivation to receive	–0.033	–0.010	1.000	–0.049
Avoidance motivation	–0.113	0.231	–0.049	1.000

«Ego-Motivation»: The ship's captain can greatly influence the actions of the navigators through his willpower and internal motivation, sometimes replacing them in some situations. This can lead to passivity among team members.

«Confrontational motivation»: Navigators often choose tactics based on the priority of tasks rather than their quality, which can lead to violations of navigation rules [22].

«Motivation to obtain»: Navigators seek to achieve a potential outcome, even if this may lead to a careless attitude to maneuvering safety.

«Avoidance motivation»: Navigators may choose cautious steering tactics, which may lead to temporary pauses or forced return of the vessel to the starting point.

Correlation analysis revealed that there were non-random relationships that warrant further investigation. One of the main tasks of the scientific analysis considered in the article is the construction of a map of the mental motivational states of navigators. This aspect will make it possible to structurally and accurately determine the initial cause of the emergence of critical situations and navigational hazards [23].

During the passage of the channel, navigators are used to follow a certain strategy, which is formed, accordingly, owing to a certain MMS.

However, it should be noted that the chosen strategy cannot be considered equally effective at all stages of the long transition. The navigators' ship management strategy during the transition according to the single MMS does not allow success during the entire route.

Therefore, navigators have to adjust the strategy that causes changes in MMS and, accordingly, significantly affects the model of navigator behavior when carrying a watch [24]. Faced with the problem that arises in such situations where the chosen strategy is not justified, the navigators have to change MMS immediately [25]. Since situations are critical, time may not be enough for rapid changes in a strategy that affects the safety of navigation [26].

As a result of the above, the trajectories of the ship's movement are characteristic unstable curves. It is at these moments when the MMS of the navigator is restructured that there is a high probability of accidents [27]. Fig. 1 shows the repetition of changes in the ship management strategy. However, you can see that some fragments of the curve indicate a violation of the navigation rules.

The above trajectories of the vessel indicate the intervals of time when the transformation of the navigator's MMS takes place. Therefore, close time monitoring of the actions of navigators during the use of the Navi Trainer 5000 navigation simulator will make it possible to determine their dynamic behavior patterns and reveal the reasons for deviations from the established recommendations when controlling the movement of the vessel. One of the important factors was the increase in the ship's speed, which indicates changes in the strategy of the navigators' behavior. So, for example, Fig. 1 clearly shows that the initial and safe strategy was able to cope with the dangerous turn. Another chosen tactic, which can be observed, significantly exceeds the first in terms of speed, despite all warnings about being in a difficult navigation area of the terrain (Fig. 2).

It turned out that navigators with an unstable motivational structure at the age of 40–45 often find themselves in similar situations. Usually, senior mates are of this age, and therefore more than 70 % of navigators are potentially prone to getting into critical situations.

Accordingly, in this case, the main problem is not determining the causes of such states and identifying the nearest possible states relative to the current ones. Taking into account the circumstances that arose during the study, there is a task to significantly expand the area of the navigator's MMS, along with the possibility of their identification through observation, as well as through automated systems and auxiliary means of navigation information systems. Such an approach will make it possible to distinguish all possible problematic situations while at the same time reducing navigational risks for the safety of navigation.

A large number of scientific sources provide a detailed description of personality MMS, their causes and subsequent consequences. However, the mechanisms shaping the space of such MMS in relation to the specific individual experience of the navigator are poorly described. This issue is considered a real problem that has not yet been resolved at the current stage of leveling the human factor in shipping. Therefore, one should try to approach the solution of this problem with the help of formal approaches that make it possible to obtain the necessary accuracy in the positioning of the navigator's MMS in the logical-geometric space.

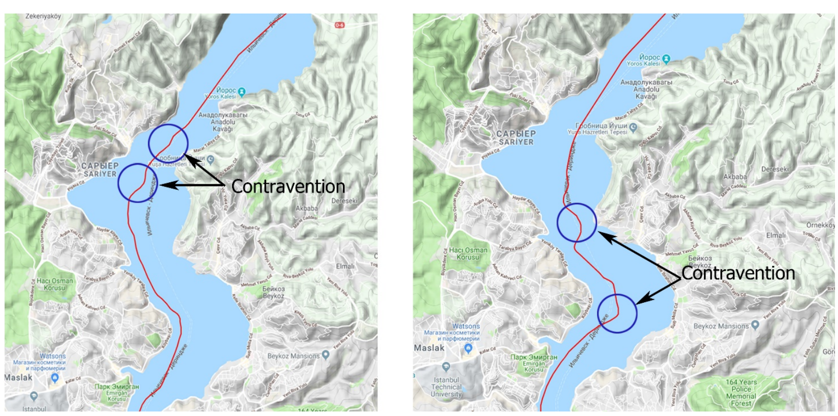

Fig. 1. Fluctuations of the ship's course at the time of dangerous mental motivational states based on experimental data using the Navi Trainer 5000

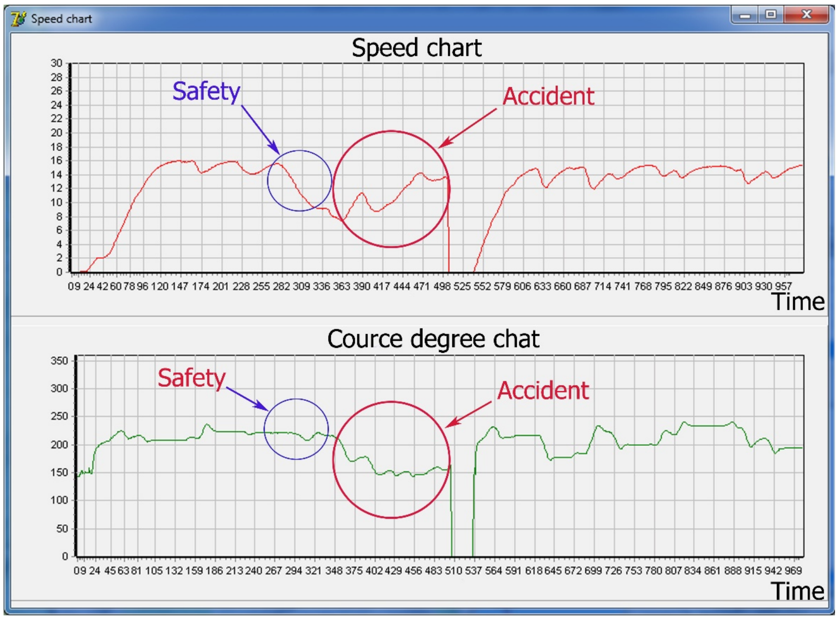

Fig. 2. The diagram of changes in speed parameters in two different mental motivational states during passage of the Bosphorus using Navi Trainer 5000 navigation simulators for containership class ships

So, first of all, it is necessary to explain the basic principles of the proposed approach to the formation of the marine navigator's MMS space:

1. Given the peculiarities of the formation of MMS, the space should be considered as hierarchical in its structure.
2. MMS and their component identifiers must be uniquely expressed, avoiding overlap, and marked as separate from each other.
3. The distribution of MMS should be based on the main feature that is taken to form their tree-like structure.
4. Conventionally accepted formal motivational space should be represented in the form of a geometric system where a separate state focuses on a certain nodal point.

Hence, the basic principles mentioned above probably introduce some foundations for finding suitable formal systems. Therefore, among the diverse range of mathematical theories, systems of p-adic numbers are considered the closest to the formal description of the motivational space of navigators. It is worth noting that the axioms of this theory do not contradict the above-mentioned basic principles of the proposed approach, offering practical use in the management of shipping safety processes [28].

Based on the above, when constructing the motivational space within the framework of p-adic systems, it was assumed that only one state was formed for each navigator at a certain time. These states were generated by external information signals, which formed the vector:

$$x=(\alpha_1,\alpha_2,\ldots,\alpha_n,\ldots),\ \alpha_j=0,1,\ldots,m-1,$$

at $x=\alpha_0,\alpha_1\ldots\alpha_k\ldots\equiv\alpha_0+\alpha_1 m+\ldots+\alpha_k m^k+\ldots$.

Which in turn assumed the coding of states, and transitions between them based on the Hamming metric [29], according to:

$$\rho(x,y)=\sum_{j=0}^{N}|\alpha_j-\beta_j|,\ x=(\alpha_j),\ y=(\beta_j).$$

This also led to the possibility of a formal description of the MMS of navigators according to the associative series of the hierarchical structure in the following form, simple (1) or complex (2):

$$A_s=\{x=(\alpha_0,\ldots,\alpha_M)\in X_{MMC}:\alpha_0=s\}\subset X_{MMC}, \tag{1}$$

$$A_{s_0\ldots s_l}=\{x=(\alpha_0,\ldots,\alpha_M)\in X_{MMC}:\alpha_0=s_0,\ldots,\alpha_{l-1}=s_{l-1}\}. \tag{2}$$

Therefore, it became obvious that MMSs by association belong to the corresponding actions when working with navigation equipment and means of controlling the movement of vessel B. Then the associative series in the form of $A_{s_0\ldots s_l}$, will take the representation:

$$B=f(A_{s_0\ldots s_l})=\{y=f(x):x\in A_{s_0\ldots s_l}\}.$$

Also, based on principle No. 2, which states that each MSS must not be mixed or incomplete, all numbers must be integers. Additionally, taking into account principle No. 3, it is assumed that the significant values of external signals α_j that come to the navigator's attention should have a degree of influence from the largest α_0 and, in accordance with the order of numbers, to the smallest [29].

Threfore, the location of the construction of the navigator's MMS space mainly depends on his experience of bonds and formed behavior patterns x_0, as well as the initial state $f_s(x)$.

Therefore, the transition to a new MMS, bearing in mind principle No. 1, is possible only from the previous one by transforming it, while the new signals α_j appear in the form:

$$f:Z_p\to Z'_p,\quad x\to f(x),$$

where Z_p is specified as the state space at time t, just as Z' is at time t+1. Therefore, the effect of «attraction» of the new MSS is described in relation to the condition x_0. It is this effect that can be depicted in the form of an attractive force: $A(x_0)=\{x\in Z_p:|x|_p=1\}$. Given the above formal approaches, the construction of a map for the main four MMSs within p-adic systems is possible for derivation. Thus, the spatial representation of the MSS of navigators is probably achieved as a result of obtaining a set of p-adic numbers.

For $p=4$ and size 4, the numbers from 1 to 64 and beyond in the p-adic system will be written in the form of an infinite sequence of digits from 0 to $p-1$:

$$\alpha_0+\alpha_1 p+\alpha_2 p^2+...+a_k p^k...,$$

where $\alpha_0, \alpha_1, \alpha_2,...,\alpha_k \in \{0,1,..., p-1\}$.

Then we have a classification series such that:

1=1, ..., 8=20, ..., 16=100, ..., 24=120, ..., 32=200, ..., 40= =220, ..., 48=300, ..., 56=320, ..., 64=1000.

Consider the application of this approach to the formation of the navigator's mental motivational map in its primary form for a variety of states from 1 to 64.

So, the calculations and the resulting map undoubtedly illustrate the nodal points, which are the mental motivational states of sea navigators. Accordingly, in this case, a related parallel question arises regarding the determination of spaces close to MSS during the performance of a specific task of steering the vessel. In addition, the main goal of this study is to obtain an order of the nearest MMS and to identify the most unstable ones, which are most likely to lead to catastrophic consequences.

So, in order to build a map of MSS, it was proposed to introduce a methodology for determining the motivational structure of an individual. It includes the use of the Level of Person Claims (LCI) questionnaire with four combined blocks. Suppose that these blocks are in the following sequence of marine navigator preferences, where $\alpha_i=[\alpha_0, \alpha_1, \alpha_2, \alpha_3]$.

Using this principle, it becomes possible to carry out a deep classification of the navigator's motivational structure. The obtained data can be represented in the form of an information map of the mental motivational state of the navigator as a subject of the «man-machine» system in maritime transport. It is more convenient to represent this map in the form of a graph with a p-adic fractal structure based on non-Archimedean principles of number theory [30]. To build an information map of the navigator's motivation, it is necessary to take a p-adicity with dimensionally 4 and a structural series of four numbers δ, φ, λ, γ. The basic branches of the navigator's MMS map are labeled: α_0 (Fig. 3, *d*); α_1 (Fig. 4, *c*); α_2 (Fig. 3, *b*); α_3 (Fig. 3, *a*).

However, taking into account the complexity and diversity of the research object, it is proposed to expand the space of classification features by two orders of magnitude in the p-adic system, where $p=4$, and the order will be equal to 5.

5. Simulation results in the management of safety processes using automated ship traffic control systems

5. 1. Development and formalization of the method of structural identification of mental motivational states of the navigator by means of *p*-adic systems

The information diagram (Fig. 4) shows the input and output signals of the intelligent automated MMS identification system. To determine the components of information signals in the p-adic system, a corresponding hierarchical coding was developed.

The proposed coding is performed in the last three dimensionalities of the classification numbers in each branch of the graph for a separate navigator. For four months, the network was tested based on the analysis of the marine navigator's motivational map. Below are the identification results.

Therefore, the structure of the classification of motivational states of the navigator, of type $\alpha_{i\delta_j\varphi_k\lambda_n\gamma_m}$, where $i=0...3$, will be represented by a logical and lexical aggregate of sets:

1. $\alpha_0 \rightarrow \alpha_{0\delta_0}$ – Time indicators of the navigator's motivation $\rightarrow \alpha_{0\delta_0\varphi_{0...3}}$ (identifier) – quality of motivation: to what extent the navigator is sure that his actions are important for the successful completion of the task (T_o, time for performing general operations with the navigation equipment) $\rightarrow \alpha_{0\delta_0\varphi_{0...3}\lambda_{0...3}}$ – participates in the planning and implementation of the route (T_{op}, time to create and track a route in ECDIS and GPS) $\rightarrow \alpha_{0\delta_0\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – level of responsibility during the preparation and correction of sea charts and navigation equipment settings (T_{opc}, time to create correction elements of electronic cartography).

Mental motivational state #1 (Uncertainty): a00002, a00102 (where a is the study number, in this example $a=1$):

00320, 00332, 00301, 00301, 00002, 00011, 00023, 00030, 00102, 00113, 00121, 00133, 00203, 00211, 00221, 00233.

2. $\alpha_0 \rightarrow \alpha_{0\delta_1}$ – Actions of the navigator predicting success $\rightarrow \alpha_{0\delta_1\varphi_{0...3}}$ (identifier) – orientation of motivation: how clearly the navigator understands what should be done to achieve success (A_n, clarity and sequence of actions with navigation equipment) $\rightarrow \alpha_{0\delta_1\varphi_{0...3}\lambda_{0...3}}$ – clearly understands what actions should be performed (A_{nr}, sequence of actions with verification, connection: source of information – action) $\rightarrow \alpha_{0\delta_1\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – understands how wind, current, and other factors can affect the movement of the vessel and takes measures to maintain the specified speed and course (A_{nrp}, actions involving appropriate mathematical calculations).

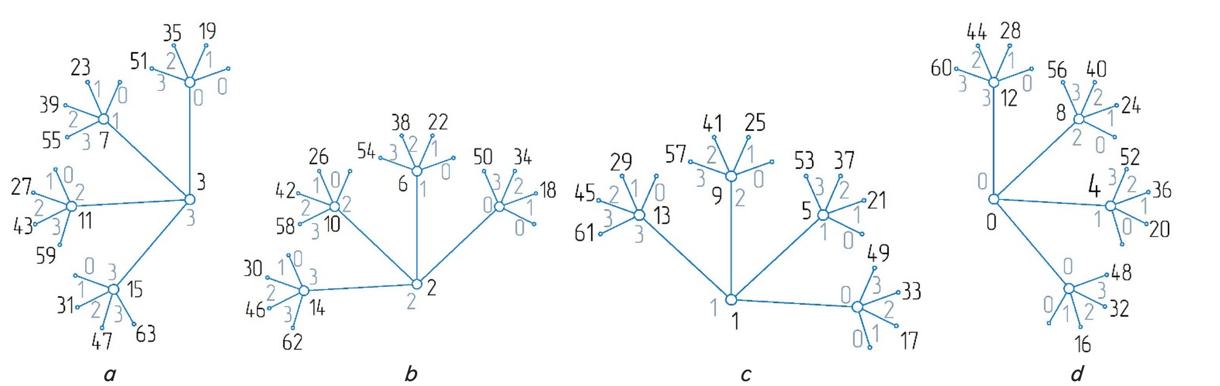

Fig. 3. Map of mental motivational states of the navigator in *p*-adic numbers with order 3: *a* – indicators of the navigator's own strategy; *b* – positional features of the navigator in the environment; *c* – signs of self-development of the navigator; *d* – functional indicators by activity

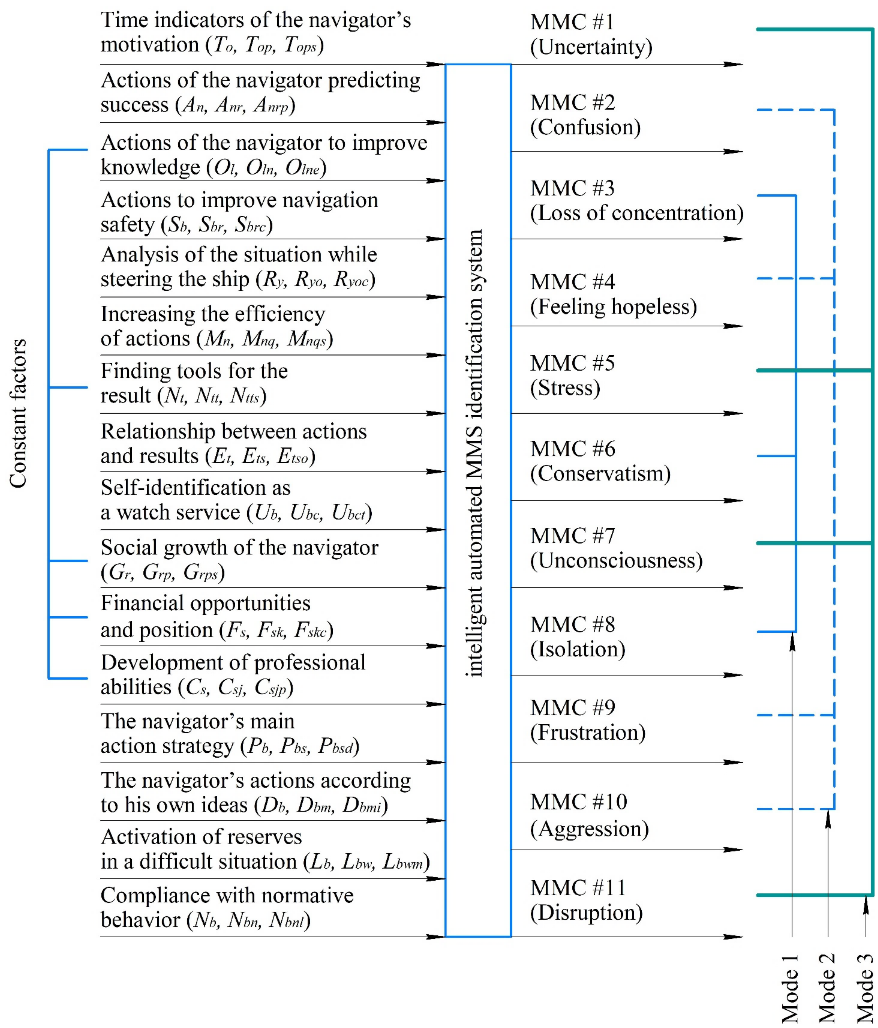

Fig. 4. Input and output signals of the intelligent automated identification system of the navigator's mental motivational state

Mental motivational state #2 (Confusion): a01001, a01010, a01100:

01001, 01010, 01022, 01032, 01100, 01110, 01121, 01132, 01203, 01210, 01220, 01233, 01300, 01310, 01323, 01331.

3. $\alpha_{0\delta_2}$ – Actions of the navigator to improve knowledge $\rightarrow \alpha_{0\delta_2\varphi_{0...3}}$ (identifier) – ability to self-organize: to what extent the navigator is ready for self-education (O_l, number of requests to specialized literature) $\rightarrow \alpha_{0\delta_2\varphi_{0...3}\lambda_{0...3}}$ – ready to improve his navigation skills (O_{ln}, number of requests to new navigation literature) $\rightarrow \alpha_{0\delta_2\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – study of new methods of navigation and navigation equipment under different weather conditions and sea routes (O_{lne}, number of requests for specialized navigation courses).

Mental motivational state #1 (Uncertainty): a02000, a02101, a02010:

02000, 02111, 02302, 02003, 02310, 02311, 02222, 02023, 02122, 02101, 02010, 02123, 02021, 02301, 02232, 02312.

4. $\alpha 0 \rightarrow \alpha_{0\delta_3}$ – Actions to improve navigation safety $\rightarrow$ $\rightarrow \alpha_{0\delta_3\varphi_{0...3}}$ (identifier) – attachment to safety: to what extent the navigator is ready to strive to ensure safety (S_b, there are no deviations in the time of filling out checklists) $\rightarrow \alpha_{0\delta_3\varphi_{0...3}\lambda_{0...3}}$ – ready to make efforts to ensure the safety of the vessel (S_{br}, checking the safety parameters of navigation devices) $\rightarrow \alpha_{0\delta_3\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – traffic control, timely notification of any danger, especially when approaching the port, entering narrow passages, etc. (S_{brc}, control/checking of safety parameters in the actions of the watch team).

Mental motivational state #3 (Loss of concentration): a03001, a03010:

03202, 03131, 03002, 03203, 03331, 03020, 03011, 03101, 03223, 03122, 03001, 03312, 03210, 03303, 03320, 03010.

5. $\alpha_{1\delta_0}$ – Analysis of the situation while steering the ship $\rightarrow \alpha_{1\delta_0}$ (identifier) – the level of concentration on achieving the result: the navigator believes that the result affects his confidence (R_y, computer analysis and concentration of the navigators' gaze) $\rightarrow \alpha_{1\delta_0\varphi_{0...3}\lambda_{0...3}}$ – shows great interest in the results of his work (R_{yo}, checking the ship's movement indicators after the actions performed) $\rightarrow$ $\rightarrow \alpha_{1\delta_0\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – discusses the results of his work with the captain (R_{yoc}, analysis of requests for conversations with the captain, messages).

Mental motivational state #4 (Feeling hopeless): a10000:

10120, 10011, 10330, 10000, 10211, 10131, 10232, 10003, 10013, 10322, 10220, 10321, 10133, 10222, 10201, 10123.

6. $\alpha_{1\delta_1}$ – Increasing the efficiency of actions $\rightarrow \alpha_{1\delta_1\varphi_{0...3}}$ (identifier) – the level of confidence in his abilities: how much the navigator is ready to increase the efficiency of his work and use new methods and approaches (M_n, computer analysis of non-standard algorithms of actions and sequences) $\rightarrow$ $\rightarrow \alpha_{1\delta_1\varphi_{0...3}\lambda_{0...3}}$ – looks for new methods and approaches to improve the efficiency of one's work (M_{nq}, search for data on quick and effective solutions) $\rightarrow \alpha_{1\delta_1\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – he studies the latest scientific and technological achievements in the field of navigation (M_{nqs}, search for data on new navigation technical means, analysis of the use of new modes of operation of equipment).

Mental motivational state #5 (Stress): a11200, a11000:

11330, 11320, 11312, 11302, 11233, 11220, 11210, 11200, 11130, 11123, 11111, 11102, 11033, 11021, 11012, 11000.

7. $\alpha_1 \rightarrow \alpha_{1\delta_2}$ – Finding tools for the result $\rightarrow \alpha_{1\delta_2\varphi_{0...3}}$ (identifier) – flexibility of thinking and ability to learn: to what extent the navigator is ready to learn new tools (equipment) (N_t, requests to the captain/company to install new equipment) $\rightarrow \alpha_{1\delta_2\varphi_{0...3}\lambda_{0...3}}$ – ready to learn new technologies (N_{tt}, search and study of technologies for working with a complex of new equipment) $\rightarrow \alpha_{1\delta_2\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – he studies new software and applications for navigation, data processing

methods (N_{tts}, search and study of software/system modules for new equipment).

Mental motivational state #6 (Conservatism): a12010:

12330, 12321, 12312, 12302, 12232, 12221, 12212, 12201, 12130, 12122, 12111, 12103, 12030, 12021, 12010, 12003.

8. $\alpha_1 \rightarrow \alpha_{1\delta_3}$ – Relationship between actions and results $\rightarrow \alpha_{1\delta_3\varphi_{0...3}}$ (identifier) – the level of awareness of his role: how much the navigator is aware of his role and responsibility in ensuring the safety and efficiency of the work performed (E_t, analysis of actions with equipment corresponding to his status) $\rightarrow \alpha_{1\delta_3\varphi_{0...3}\lambda_{0...3}}$ – aware of his role and responsibility in ensuring navigational safety (E_{ts}, analysis of equipment operations, regarding checking/adjustment of parameters according to the status) $\rightarrow \alpha_{1\delta_3\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – monitors the accuracy and relevance of navigation data, provides navigation skills to other crew members (E_{tso}, analysis of equipment operations, optimally and according to the situation).

Mental motivational state #7 (Unconsciousness): a13300, a13010:

13031, 13110, 13221, 13300, 13003, 13132, 13222, 13320, 13010, 13123, 13232, 13303, 13033, 13130, 13212, 13313.

9. $\alpha_2 \rightarrow \alpha_{2\delta_0}$ – Self-identification as a watch service $\rightarrow \alpha_{2\delta_0\varphi_{0...3}}$ (identifier) – motivation for cooperation and teamwork: the navigator values his role in the team and seeks to cooperate with other crew members (U_b, interaction density, analysis of movements on the bridge) $\rightarrow \alpha_{2\delta_0\varphi_{0...3}\lambda_{0...3}}$ – active participation in discussing navigation issues and making decisions (U_{bc}, interaction density, analysis of reports to the captain/proposals) $\rightarrow \alpha_{2\delta_0\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – cooperation with other professionals on board, such as engineers and electrical officers (U_{bct}, analysis of requests to mechanics, electro-mechanics for optimization of the ship's motion control) .

Mental motivational state #8 (Isolation): a20200, a20001:

20331, 20320, 20312, 20303, 20231, 20222, 20212, 20200, 20132, 20122, 20113, 20103, 20032, 20020, 20013, 20001.

10. $\alpha_2 \rightarrow \alpha_{2\delta_1}$ – Social growth of the navigator $\rightarrow \alpha_{2\delta_1\varphi_{0...3}}$ (identifier) – motivation to satisfy social needs: the navigator strives for social recognition of his work and success (G_r, requests for recommendations from the captain/company) $\rightarrow \alpha_{2\delta_1\varphi_{0...3}\lambda_{0...3}}$ – active participation in presentations and reports on the work of the crew (G_{rp}, quantitative and qualitative indicators of participation) $\rightarrow \alpha_{2\delta_1\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – participation in press conferences and interviews, as well as in the publication of articles in professional journals about his work (G_{rps}, quantitative and qualitative indicators of publications).

Mental motivational state #9 (Frustration): a21110:

21212, 21302, 21321, 21110, 21203, 21132, 21031, 21333, 21210, 21113, 21320, 21222, 21123, 21230, 21030, 21301.

11. $\alpha_2 \rightarrow \alpha_{2\delta_2}$ – Financial opportunities and position $\rightarrow \alpha_{2\delta_2\varphi_{0...3}}$ (identifier) – motivation for material reward: the navigator aims to receive a financial reward for his work and strives for financial security (F_s, requests for increased financing to the company) $\rightarrow \alpha_{2\delta_2\varphi_{0...3}\lambda_{0...3}}$ – strives for financial security, can actively participate in the competition for salary increases and for the improvement of working conditions on board (F_{sk}, requests for increased funding to the captain) $\rightarrow \alpha_{2\delta_2\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – aspiration to work on ships with higher salaries (F_{skc}, requests for obtaining a position in other ships/companies).

Mental motivational state #9 (Frustration): a22300:

22121, 22213, 22331, 22020, 22300, 22222, 22113, 22201, 22232, 22011, 22133, 22303, 22112, 22320, 22003, 22021.

12. $\alpha_2 \rightarrow \alpha_{2\delta_3}$ – Development of professional abilities $\rightarrow \alpha_{2\delta_3\varphi_{0...3}}$ (identifier) – motivation for professional growth and development: the navigator strives to improve his professional skills and knowledge (C_s, requests/participation in training in training centers) $\rightarrow \alpha_{2\delta_3\varphi_{0...3}\lambda_{0...3}}$ – participation in the further educational and training process, reading specialized literature (C_{sj}, inquiries/participation in work at training centers) $\rightarrow \alpha_{2\delta_3\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – exchange of experience with other professionals in this field (C_{sjp}, participation in work at leading seafarer training centers).

Mental motivational state #9 (Frustration): a23110:

23220, 23131, 23030, 23222, 23022, 23321, 23132, 23203, 23110, 23012, 23302, 23112, 23211, 23113, 23032, 23210.

13. $\alpha_3 \rightarrow \alpha_{3\delta_0}$ – The navigator's main action strategy $\rightarrow \alpha_{3\delta_0\varphi_{0...3}}$ (identifier) – what values are generated by his/her main actions: the navigator's priority choice (P_b, signs of a certain action strategy, own decisions) $\rightarrow \alpha_{3\delta_0\varphi_{0...3}\lambda_{0...3}}$ – people's safety (P_{bs}, definition of a security strategy, not savings fuel) $\rightarrow \alpha_{3\delta_0\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – the navigator recommends changing the route or slowing down the ship, even if this will delay the delivery of the cargo and lead to financial losses (P_{bsd}, readiness to make complex decisions according to the safety strategy).

Mental motivational state #10 (Aggression): a30100:

30003, 30320, 30301, 30032, 30211, 30131, 30220, 30010, 30100, 30112, 30133, 30030, 30232, 30302, 30210, 30322.

14. $\alpha_3 \rightarrow \alpha_{3\delta_1}$ – The navigator's actions according to his own ideas $\rightarrow \alpha_{3\delta_1\varphi_{0...3}}$ (identifier) – how the navigator's personal experience and beliefs affect his decisions and actions in difficult situations: priority for personal approaches (D_b, fixing non-standard, but conscious actions) $\rightarrow \alpha_{3\delta_1\varphi_{0...3}\lambda_{0...3}}$ – the navigator can offer his own method of determining the position of the ship or maneuvering (D_{bm}, fixing non-standard maneuvers, refusing to use the autopilot) $\rightarrow \alpha_{3\delta_1\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – demonstrates his method to other crew members and makes sure that they understand its principles (D_{bmi}, implementation of own methods, publications, speeches).

Mental motivational state #1 (Uncertainty): a31002:

31002, 31113, 31211, 31033, 31221, 31302, 31332, 31131, 31220, 31031, 31321, 31322, 31301, 31111, 31012, 31203.

15. $\alpha_3 \rightarrow \alpha_{3\delta_2}$ – Activation of reserves in a difficult situation $\rightarrow \alpha_{3\delta_2\varphi_{0...3}}$ (identifier) – how the navigator uses his internal resources: ability to manage emotions, concentration of attention, physical endurance (L_b, stress level, heart rate and blood saturation) $\rightarrow \alpha_{3\delta_2\varphi_{0...3}\lambda_{0...3}}$ – in severe weather conditions, the navigator can use his emotional management skills (L_{bw}, stress level, heart rate and blood saturation in the storm) $\rightarrow \alpha_{3\delta_2\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – he concentrates on his navigational duties and tasks. He uses emotion management techniques (L_{bwm}, stress level, heart rate and blood saturation during periods of high mental activity).

Mental motivational state #5 (Stress): a32020:

32013, 32332, 32121, 32230, 32020, 32301, 32313, 32032, 32111, 32320, 32203, 32102, 32031, 32311, 32122, 32220.

16. $\alpha_3 \rightarrow \alpha_{3\delta_3}$ – Compliance with normative behavior $\rightarrow$ $\rightarrow \alpha_{3\delta_3\varphi_{0...3}}$ (identifier) – ability to work in a team: adaptation to new people and situations (N_b, stress level, pulse and blood saturation during communication with team members) $\rightarrow$ $\rightarrow \alpha_{3\delta_3\varphi_{0...3}\lambda_{0...3}}$ – the navigator can conduct additional training for newcomers and work in close cooperation with new crew members (N_{bn}, stress level, heart rate and blood saturation during communication with new team members) $\rightarrow$ $\rightarrow \alpha_{3\delta_3\varphi_{0...3}\lambda_{0...3}\gamma_{0...3}}$ – cooperation with new multilingual crew members (N_{bnl}, stress level, heart rate and blood saturation during communication with new members teams).

Mental motivational state #11 (Disruption): a33020, a33300:

33133, 33322, 33311, 33030, 33120, 33222, 33301, 33020, 33211, 33003, 33220, 33203, 33300, 33213, 33132, 33201.

5. 2. Development of a scheme for managing the safety of navigation on the ship according to the identification of dangerous mental motivational states

Numerical modeling was carried out within the framework of the adopted *p*-adic structure:

$\alpha \in \{ij333...ij000\}$: *ij*333, *ij*332, *ij*331, *ij*330, *ij*323, *ij*322, *ij*321, *ij*320, *ij*313, *ij*312, *ij*311, *ij*310, *ij*303, *ij*302, *ij*301, *ij*300, *ij*233, *ij*232, *ij*231, *ij*230, *ij*223, *ij*222, *ij*221, *ij*220, *ij*213, *ij*212, *ij*211, *ij*210, *ij*203, *ij*202, *ij*201, *ij*200, *ij*133, *ij*132, *ij*131, *ij*130, *ij*123, *ij*122, *ij*121, *ij*120, *ij*113, *ij*112, *ij*111, *ij*110, *ij*103, *ij*102, *ij*101, *ij*100, *ij*033, *ij*032, *ij*031, *ij*030, *ij*023, *ij*022, *ij*021, *ij*020, *ij*013, *ij*012, *ij*011, *ij*010, *ij*003, *ij*002, *ij*001, *ij*000.

The variability of the proposed classification is $\alpha_i = 1024$, in each branch $\alpha_{i\delta_j} = 256$ in each sub-branch $\alpha_{i\delta_j\varphi_k} = 64$, this indicates the possibility of high accuracy in the identification of navigator's MMS. It should be clarified that the information map will be created for each navigator separately. This is due to the fact that the coding of states for any map point within the limits $\alpha_{i\delta_j\varphi_k\lambda_n\gamma_m}$, will be based on the identification of an individual navigator during the watch on the bridge.

With the aim of obtaining reliable data for modeling for two years (2019–2022), experiments were conducted in the navigation training center with 54 marine navigators using the navigation simulator Navi Trainer 5000 (NTPRO 5000).

Our data made it possible to clarify the principles and approaches to the formation of the space of classification features with the dimensionality of the fractal structure of 64 states (Fig. 4, *a–d*) and the methods for identifying the nodes of the graph for each individual cadet-navigator.

Taking into account the objective complexity associated with the need to identify the critical states of each individual navigator in real time, it was proposed to use the information technology of artificial neural networks.

In addition, the need to build an individual motivational map for each navigator is caused by the fact that a separate mental-motivational state (MMS) is formed in each individual node of the graph.

According to experimental data, a certain state in relation to a group of nodal points on the map can lead to significant stress and loss of orientation, concentration of the navigator and, as a result, to a significantly higher probability of an accident. At the same time, the same map code for another navigator will not have such an effect on his mental state and will not create any risk. All this indicates that there are individual trigger codes on the map area, which cause certain psychophysiological states and affect the efficiency of watch duty and the safety of navigation in general. In turn, there are general states of navigators, which are most often formed in each separate branch/subbranch of the graph.

According to the identified MMS, appropriate automated modes of operation are triggered to increase the safety of navigation (Fig. 4).

For example, safety mode No. 1 (green) provides for the activation of additional information signals-tips for the corresponding navigator, which will make it possible to exit this MMS state and normalize your own actions. If the navigator does not exit the state for a long time, determined by the situation, safety mode No. 2 is activated.

Safety mode No. 2 involves notifying the captain's watch assistant about the danger, who makes a decision to replace the navigator or help in real time in the tasks of controlling the movement of the vessel, etc.

Safety mode No. 3 provides for the connection of the navigator's access to control the movement of the vessel, and the performance of actions affecting the safety of navigation. There is a switchover to automatic ship motion control modules according to the class of current maneuvers and operations. At the same time, the sound alarm on the bridge is activated and the captain is called to the bridge regardless of the time of day (Fig. 5).

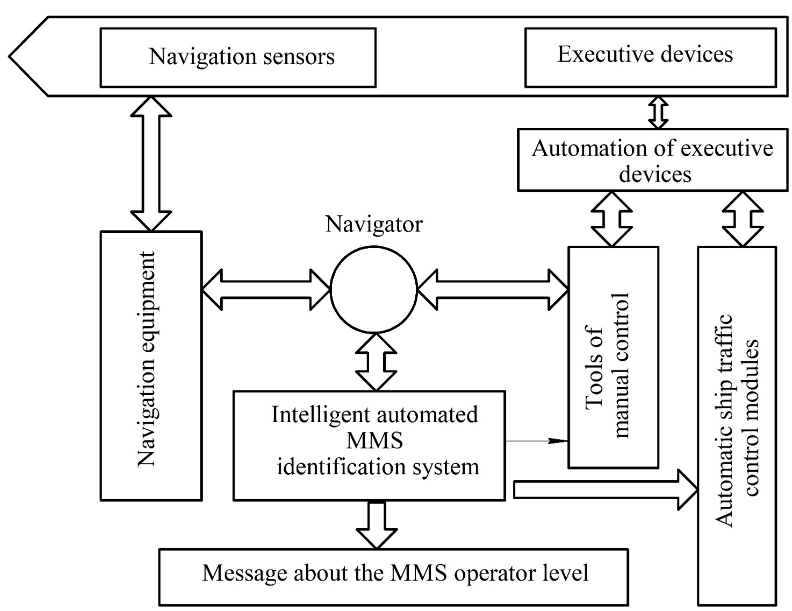

Fig. 5. Schematic diagram of navigation safety control in difficult navigation situations

Therefore, when appropriate MMSs are detected, automated operating modes are activated to increase safety in difficult sailing conditions. These modes may include the activation of additional information signals, the notification of the assistant captain, or emergency switching to the automatic modules of the control of the movement of the vessel according to the class of maneuvers. Overall, the proposed maritime safety management scheme aims to develop flexible and adaptive approaches to maritime safety.

5. 3. Modeling and processing of data of mental motivational states of navigators by means of neural networks

It should be taken into account that it will be difficult to perform identification across the spectrum of the map for all 1024 nodes for each navigator, especially in real time. In this case, the automated system will check the most dangerous node states of the map, those that are most likely to lead to accidents and critical situations. For this purpose, on the basis of experimental data obtained from the cadets of the Kherson State Maritime Academy (Ukraine) and from real conditions, general samples with a dispersion core of up to 90 % were taken.

To build a training sample of neural networks, 16 experimental measurements of the states of navigators were carried out, that is, 16 maps of motivational states in different situations according to the level of navigation complexity.

The above matrix with a dimensionality of 16 was formed for each navigator and was used for training the neural network (Fig. 6, *a*, *b*).

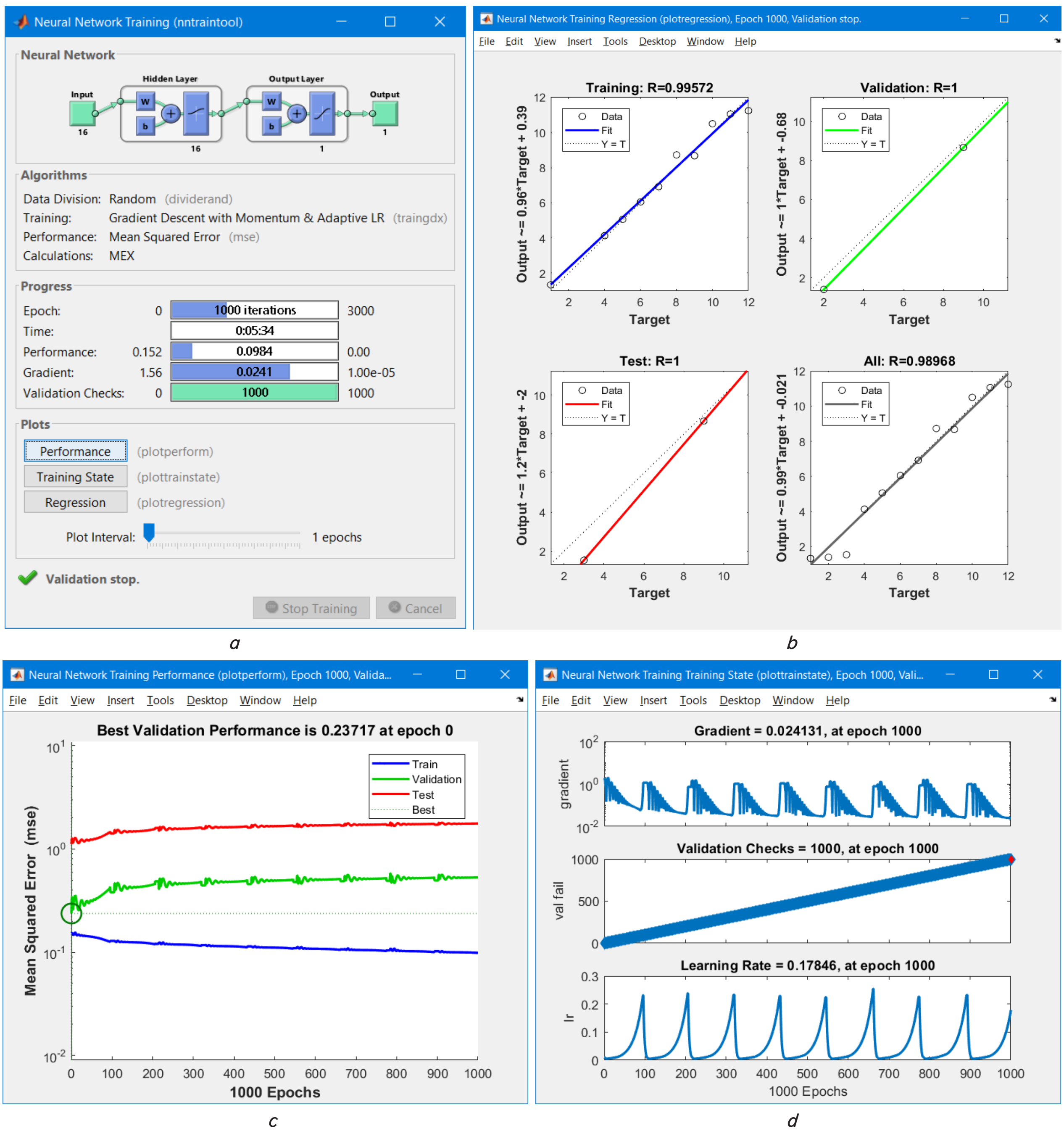

Fig. 6. Simulation indicators – neural network training: *a* – processes of automated neural network learning; *b* – training performance after 1000 iterations; *c* – dynamics of changes during training and testing of neural networks; *d* – load cycles in the processes of validation and training of neural networks)

The simulation analysis showed that a good MMS identification was initially obtained for states: #11, #6, #9, #4, #5, #7.

Sufficient identification – for states: #1, #10.

And identification, which requires clarification of sources of information: #2, #3, #8, #12.

An additional analysis of navigators' gaze direction, heart rate, and blood oxygen saturation during watch duty was conducted. The analysis, taking into account additional indicators, made it possible to identify states #1 and #10 as being in the system identification zone.

In total, 18 neural networks were developed and improved through tuning, where the last one proved to be the best in terms of efficiency.

6. Discussion of results of investigating the application of the developed vessel traffic control safety management system

Empirical data obtained during observations indirectly indicate the influence of the human factor of the marine navigator on the change of the route and speed of the vessel, when it is not mandatory (Fig. 1). Despite the fact that, in some navigational circumstances, a speed and course control strategy is used when steering a ship, it is possible to observe trajectory fluctuations as evidence of an unusual or critical situation at that moment (Fig. 2). The complexity of such a situation, which is determined by trajectory data, is initially subjective and incomplete in terms of the amount of clarifying data. Such a problem was described several times in the considered set of publications; this gave rise to the need to develop and apply intelligent automated ship control systems, decision support systems. As a result, although the navigators have a sufficient level of qualification, at the same time, the negative influence of the human factor is quite common. This means that the use of documentary proof of training level alone is not sufficient, nor can experience guarantee safe navigation.

For its part, the navigator's motivation indicator during the watch can significantly influence the course and safety of his actions, which is the basis of this study. First, the data of the following MMSs were analyzed: «Ego-motivation», «Motivation to confront», «Motivation to receive», «Motivation to avoid». This has made it possible to determine their correlation and level of influence in specific situations (Table 1). However, this was not enough for implementation in real navigation practice.

The task was set to move away from such a process as a traditional questionnaire and move to the level of identification of actions directly during the navigation watch, mainly by automated means [27]. There was a need for a new approach to creating a classification of the navigator's activity; a classification capable of identifying dangerous MMS.

The clarified scientific facts of identification of mental states of the navigator by formal content parameters find their confirmation in studies of dominant mental states in other types of human activity, which is tangential in terms of cognitive component [28] and extreme psycho-emotional loads [29, 30].

Given the fact that a large volume of data, in some cases linguistic, is a complex form that is difficult to process automatically. In addition, another difficulty is the need to structurally separate groups and subgroups of data, to build such a classification of the navigator's motivational parameters. Moreover, the hierarchical structure of action motives is a space of sets, each of which must not overlap, that is, be separated, separately identified.

Thus, the theory of p-adic systems entered the perspective of research; this theory m has non-Archimedean principles and meets the described requirements for constructing a classification [31]. To describe the main identifiers of MMS, the metric $p=4$, dimensionality 3, and the number of hierarchical classification elements equal to 64 were used, as shown in Fig. 3. Moreover, taking into account the introduction of the level of motivational parameters in combination with the actions of the navigator on the bridge, the number of hierarchical levels increased to 1024, which became sufficient for the identification of MMS of the navigator within the set research tasks. At the same time, the coding principle allowed an even distribution of the elements of the classification structure.

It must be recognized that this approach limits the development of the structure due to the presence of dimensionality and, as a result, introduces the requirement to fill newly created elements at each step of the fractal dimension. However, if we take into account the logic of unification for a separate dimensionally, then such a circumstance will not lead to the appearance of empty elements in the classification; this is also confirmed by the analysis of experimental data. It also makes no sense to interpret the classification from a formal form to a geometric one. This is due to the fact that the following linguistic coding was proposed with real data – $\alpha_{i\delta_j\varphi_k\lambda_n\gamma_m}$, based on 16 main branches that create a classification structure.

Therefore, a large number of component motivational parameters obtained from the actions of each navigator and a real experiment on board the ship was obtained. This information is quite complex to process, and it requires the use of appropriate automated and intelligent calculation systems [32]. Taking into account the fact that for the identification of MMS it is necessary to process a rather large amount of information, taking into account its heterogeneity and the specificity of linguistic coding, it was proposed to implement intelligent systems, namely the apparatus of artificial neural networks.

This approach has made it possible to develop a formal and logical method of identification of the navigator's MMS, aimed at ensuring a comprehensive understanding of his functional activity during the navigation watch. This stage is important for the further development of effective management and control methods. On the basis of the proposed method, a navigation safety management scheme was developed on the ship, which is based on the identification data of dangerous MMS [33]. Identified MMSs provide for the use of means to manage maritime safety and increase the effectiveness of decision-making in critical situations [34]. By combining these two steps, the basis for a real-time navigation safety management system is created, which is able to automatically identify additional factors influencing the effectiveness of navigators' decision-making.

In order to automate the specified control processes, numerous training cycles of neural networks (NN No. 18) were conducted, in some cases up to 3000 iterations, and sufficient identification accuracy was obtained for more than 75 % of MMS. This approach has made it possible not only to obtain a tool for recognizing such complex formalized concepts as the motivation of the navigator but also to organize feedback, which allowed us to reveal inaccuracies in the linguistic coding of the branches of the classification. This is indeed a critical point in the proposed approach, but there is an opportunity to improve the situation and introduce appropriate precise adjustments. Thus, the generalized result is the final indicator of the learning rate of the neural regression network is 0.989, which is a high indicator.

These results open prospects for further scientific research in the field of maritime transport safety management, especially taking into account the high efficiency of the developed control scheme based on *p*-adic numbers and neural networks.

The limitations of the approach are that the complete cycle of tasks is performed on the basis of the data of one navigator, that is, the task becomes more complicated when a group of navigators of one ship or a separate shipping company is selected. Despite this, the effectiveness of this approach is obvious, and its effectiveness depends on the available controls and process automation. And therefore, the development of this research will be the construction of management models for the cooperative actions of navigators on the captain's bridge in difficult and off-duty situations, taking into account the already identified MMS maps.

The disadvantage of the study is a small sample, taking into account data on 54 navigators. To address this issue, future research should consider expanding the sample to include more navigators from different shipping companies and sailing areas.

Also, the influence of variable factors, such as weather conditions, technical condition of the vessel, etc., which can affect the navigator's MMS, was not sufficiently taken into account. This can be addressed by incorporating these factors into future neural network training models.

7. Conclusions

1. A procedure for in-depth classification of the navigator's motivational structure based on the use of formal-logical approaches has been devised. As a result, it became possible to analyze in detail and understand the mental and motivational state of the navigator as a key subject of the «man-machine» system in maritime transport. Our data were represented in the form of an information map of the navigator's mental motivational state, which allows for a visual presentation of complex motivational processes. To represent this map, it is proposed to use a graph with a *p*-adic fractal structure, based on non-Archimedean principles of number theory. The construction of the information map required the use of *p*-adicity with dimensionality 4 and the consideration of a structural series of four numbers δ, φ, λ, γ. The study included the analysis of the basic branches of the navigator's MMS map marked α_0, α_1, α_2, α_3. Our work can become a foundation for further scientific research in the field of maritime transport safety management.

2. A scheme for managing the safety of navigation on the ship was built, which was based on the identification of dangerous navigator's MMS. Artificial neural networks were used to analyze data about the navigator's condition in real time, and an information map was constructed that took into account his unique reactions to various navigation situations. During continuous monitoring of the navigator's condition, this map was compared with current data to determine whether the navigator's current MMS was unsafe and could lead to reduced performance or an accident. In the case of detection of a dangerous MMS, appropriate safety modes were activated: from additional informational signals-tips for the navigator to limiting his access to control the movement of the vessel and activation of automatic control modules. After stabilization of the situation, a detailed analysis of the event was carried out in order to identify the causes of the occurrence of dangerous MMS and measures were developed to eliminate them in the future. This scheme was aimed at minimizing the risks associated with navigator's MMS and ensuring a high level of maritime safety.

3. In the course of our study, modeling and data processing of navigators' MMS was performed using 18 neural networks. Experimental data for training networks were obtained from cadets and from real conditions. Simulation analysis and additional analysis of navigator health indicators helped clarify the identification of MMS. The last of the designed networks showed high efficiency, achieving identification accuracy for more than 75 % of MMS and a learning rate of 0.989. Thus, the current study contributed to designing an effective tool for identifying and managing the mental and motivational states of navigators, which aims to improve navigation safety.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

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References

1. Antão, P., Soares, C. G. (2019). Analysis of the influence of human errors on the occurrence of coastal ship accidents in different wave conditions using Bayesian Belief Networks. Accident Analysis & Prevention, 133, 105262. doi: https://doi.org/10.1016/j.aap.2019.105262

2. Nosov, P., Zinchenko, S., Popovych, I., Safonov, M., Palamarchuk, I., Blakh, V. (2020). Decision support during the vessel control at the time of negative manifestation of human factor. Computer Modeling and Intelligent Systems, 2608, 12–26. doi: https://doi.org/10.32782/cmis/2608-2
3. Plokhikh V. V., Yanovska S. G. (2022). Sex differentiation in the organization of emergency sensorimotor action. Insight: The Psychological Dimensions of Society, 7, 24–39. doi: https://doi.org/10.32999/2663-970x/2022-7-3
4. Popovych, I. S., Blynova, O. Ye., Aleksieieva, M. I., Nosov, P. S., Zavatska, N. Ye., Smyrnova, O. O. (2019). Research of Relationship between the Social Expectations and Professional Training of Lyceum Students studying in the Field of Shipbuilding. Revista ESPACIOS, 40 (33). Available at: http://ekhsuir.kspu.edu/bitstream/handle/123456789/9358/5.pdf?sequence=1&isAllowed=y
5. Solovey, O., Ben, A., Dudchenko, S., Nosov, P. (2020). Development of control model for loading operations on heavy lift vessels based on inverse algorithm. Eastern-European Journal of Enterprise Technologies, 5 (2 (107)), 48–56. doi: https://doi.org/10.15587/1729-4061.2020.214856
6. Dinis, D., Teixeira, A. P., Guedes Soares, C. (2020). Probabilistic approach for characterising the static risk of ships using Bayesian networks. Reliability Engineering & System Safety, 203, 107073. doi: https://doi.org/10.1016/j.ress.2020.107073
7. Makarowski, R., Plopa, M., Piotrowski, A., Plopa, W. (2020). The Human Factor in Maritime Transport: Personality and Aggression Levels of Master Mariners and Navigation Students. Advances in Cognitive Psychology, 16 (4), 363–369. doi: https://doi.org/10.5709/acp-0310-5
8. Nosov, P., Ben, A., Zinchenko, S., Popovych, I., Mateichuk, V., Nosova, H. (2020). Formal approaches to identify cadet fatigue factors by means of marine navigation simulators. In: CEUR Workshop Proceedings, 2732, 823–838. Available at: https://ksma.ks.ua/wp-content/uploads/2021/03/2-LW.pdf
9. Li, W., Zhong, L., Xu, Y., Shi, G. (2022). Collision Risk Index Calculation Based on an Improved Ship Domain Model. Journal of Marine Science and Engineering, 10 (12), 2016. doi: https://doi.org/10.3390/jmse10122016
10. Hoem, Å. S., Fjortoft, K., Rødseth, Ø. J. (2019). Addressing the Accidental Risks of Maritime Transportation: Could Autonomous Shipping Technology Improve the Statistics? TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, 13 (3), 487–494. doi: https://doi.org/10.12716/1001.13.03.01
11. Man, Y., Lundh, M., Porathe, T., MacKinnon, S. (2015). From Desk to Field – Human Factor Issues in Remote Monitoring and Controlling of Autonomous Unmanned Vessels. Procedia Manufacturing, 3, 2674–2681. doi: https://doi.org/10.1016/j.promfg.2015.07.635
12. Zhang, X., Chen, W., Xi, Y., Hu, S., Tang, L. (2020). Dynamics Simulation of the Risk Coupling Effect between Maritime Pilotage Human Factors under the HFACS Framework. Journal of Marine Science and Engineering, 8 (2), 144. doi: https://doi.org/10.3390/jmse8020144
13. Wróbel, K., Gil, M., Chae, C.-J. (2021). On the Influence of Human Factors on Safety of Remotely-Controlled Merchant Vessels. Applied Sciences, 11 (3), 1145. doi: https://doi.org/10.3390/app11031145
14. Wang, X., Zhang, B., Zhao, X., Wang, L., Tong, R. (2020). Exploring the Underlying Causes of Chinese Eastern Star, Korean Sewol, and Thai Phoenix Ferry Accidents by Employing the HFACS-MA. International Journal of Environmental Research and Public Health, 17 (11), 4114. doi: https://doi.org/10.3390/ijerph17114114
15. Hasanspahić, N., Vujičić, S., Frančić, V., Čampara, L. (2021). The Role of the Human Factor in Marine Accidents. Journal of Marine Science and Engineering, 9 (3), 261. doi: https://doi.org/10.3390/jmse9030261
16. Pietrzykowski, Z., Wielgosz, M., Breitsprecher, M. (2020). Navigators' Behavior Analysis Using Data Mining. Journal of Marine Science and Engineering, 8 (1), 50. doi: https://doi.org/10.3390/jmse8010050
17. Lin, W.-C., Cheng, H.-H. (2021). Enhancing marine administrative management based on human factor through safety criteria. Journal of Marine Science and Technology, 29 (3), 268–279. doi: https://doi.org/10.51400/2709-6998.1432
18. Progoulakis, I., Rohmeyer, P., Nikitakos, N. (2021). Cyber Physical Systems Security for Maritime Assets. Journal of Marine Science and Engineering, 9 (12), 1384. doi: https://doi.org/10.3390/jmse9121384
19. Zhuravlova L. P., Lytvynchuk A. I., Grechukha I. A., Bedny I. S. (2023). Subclinical personal correlates of psychological safety. Insight: The Psychological Dimensions of Society, 9, 94–111. doi: https://doi.org/10.32999/ksu2663-970x/2023-9-6
20. Zinchenko, S., Tovstokoryi, O., Ben, A., Nosov, P., Popovych, I., Nahrybelnyi, Y. (2021). Automatic Optimal Control of a Vessel with Redundant Structure of Executive Devices. Lecture Notes on Data Engineering and Communications Technologies, 266–281. doi: https://doi.org/10.1007/978-3-030-82014-5_18
21. Zinchenko, S., Tovstokoryi, O., Nosov, P., Popovych, I., Kobets, V., Abramov, G. (2020). Mathematical support of the vessel information and risk control systems. In: CEUR Workshop Proceedings, 2805, 335–354. Available at: http://ceur-ws.org/Vol-2805/paper25.pdf
22. Rakić, T., Živković, S., Veljković, M. (2017). Hierarchy of work motives and motivators with the aim of forming more efficient working environment. Facta Universitatis, Series: Working and Living Environmental Protection, 087. doi: https://doi.org/10.22190/fuwlep1701087r

23. Nosov, P., Zinchenko, S., Plokhikh, V., Popovych, I., Prokopchuk, Y., Makarchuk, D. et al. (2021). Development and experimental study of analyzer to enhance maritime safety. Eastern-European Journal of Enterprise Technologies, 4 (3 (112)), 27–35. doi: https://doi.org/10.15587/1729-4061.2021.239093
24. Baksh, A.-A., Khan, F., Gadag, V., Ferdous, R. (2015). Network based approach for predictive accident modelling. Safety Science, 80, 274–287. doi: https://doi.org/10.1016/j.ssci.2015.08.003
25. Khraban, T. E., Silko, O. V. (2022). Combat and military-professional stress: the influence of emotions and emotional states on the choice of coping strategies. Insight: The Psychological Dimensions of Society, 8, 71–87. doi: https://doi.org/10.32999/2663-970x/2022-8-6
26. Mamenko, P., Zinchenko, S., Kobets, V., Nosov, P., Popovych, I. (2021). Solution of the Problem of Optimizing Route with Using the Risk Criterion. Lecture Notes on Data Engineering and Communications Technologies, 252–265. doi: https://doi.org/10.1007/978-3-030-82014-5_17
27. Khrennikov, A. (2004). Modeling thinking processes in p-adic coordinate systems. Moscow: Fizmatlit, 296.
28. Popovych, I., Blynova, O. (2019). The Structure, Variables and Interdependence of the Factors of Mental States of Expectations in Students' Academic and Professional Activities. The New Educational Review, 55 (1), 293–306. doi: https://doi.org/10.15804/tner.2019.55.1.24
29. Popovych, I., Hoi, N., Koval, I., Vorobel, M., Semenov, O., Semenova, N., Hrys, A. (2022). Strengthening of student youth's mental health using play sports. Journal of Physical Education and Sport, 22 (6), 1384–1395. doi: https://doi.org/10.7752/jpes.2022.06174
30. Popovych, I., Halian, I., Lialiuk, G., Chopyk, R., Karpenko, Ye., Melnyk, Yu. (2022). Research of young female handball players' self-actualizing mental states. Journal of Physical Education and Sport, 22 (7), 1599–1607. doi: https://doi.org/10.7752/jpes.2022.07201
31. Murtagh, F. (2016). Sparse p-adic data coding for computationally efficient and effective big data analytics. P-Adic Numbers, Ultrametric Analysis, and Applications, 8 (3), 236–247. doi: https://doi.org/10.1134/s2070046616030055
32. Amit, D. J. (1990). Attractor neural networks and biological reality: associative memory and learning. Future Generation Computer Systems, 6 (2), 111–119. doi: https://doi.org/10.1016/0167-739x(90)90027-b
33. Bradley, P. E. (2009). On p-adic classification. P-Adic Numbers, Ultrametric Analysis, and Applications, 1 (4), 271–285. doi: https://doi.org/10.1134/s2070046609040013
34. Serhii, Z., Oleh, T., Pavlo, N., Ihor, P., Kostiantyn, K. (2022). Pivot Point position determination and its use for manoeuvring a vessel. Ships and Offshore Structures, 18 (3), 358–364. doi: https://doi.org/10.1080/17445302.2022.2052480