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MODEL OF ATTENTION DISTRIBUTION OF THE NAVIGATOR WHILE KEEPING A NAVIGATIONAL WATCH

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The aim of the article is to develop a formal model and its geometric approximation that allows to describe the logic of the distribution of attention of the navigator while maneuvering including the possibility of discrete forecasting. To build this model, an analysis of international maritime regulations and situations was carried out, which allowed to determine the formal structure and logical principles of the model close to real situations while solving navigation problems.

The article provides formal approaches that take into account individual factors of the navigator's predisposition to the perception of navigational situations and the associated dangers. A geometric approximation of the model in the form of a Cartesian cube divided into eight quadrants with local coordinate systems is proposed. This made it possible to combine data on the distribution of attention relative to eight objects according to STCW-78. Formal and logical constructions that allow to separate the conditions of the attention distribution model depending on the stage of the execution of a navigational task within the cycle have been developed. In this regard, the approaches for predicting model states using Markov discrete circuits in the conditions of continuous time have been proposed. Automation of the forecast made it possible in real time to obtain data about the speed of perception and processing of navigational data for transition to subsequent states in order to reduce the likelihood of catastrophic situations related to sea transport.

Keywords: *model of attention distribution, human factor, navigator, catastrophe forecasting, maritime safety.*

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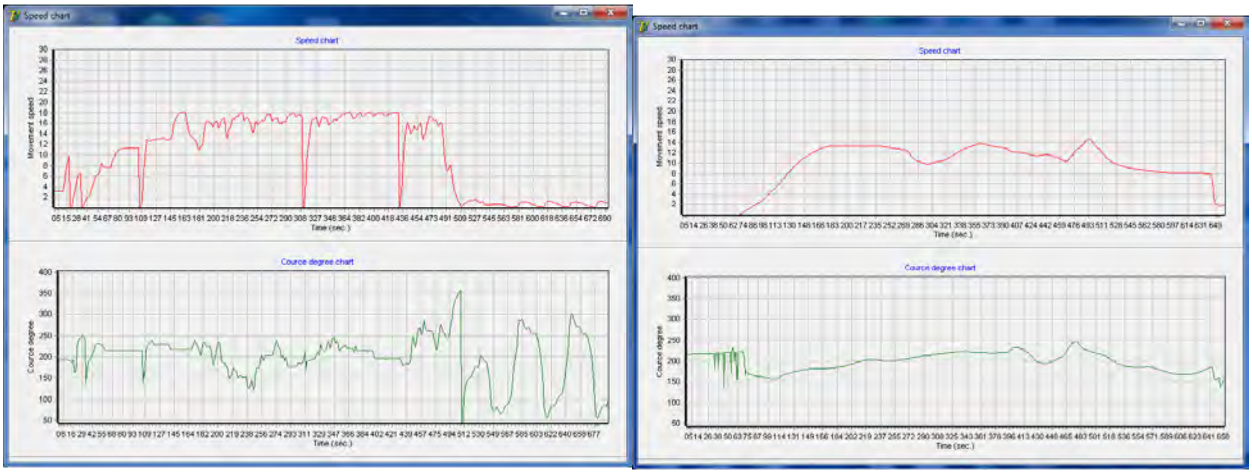
Introduction. When keeping a navigational watch, the boatmaster faces a number of tasks that require concentration on certain objects or phenomena. According to convention STCW-78 [1] the navigator has great requirements that imply universal control of many factors affecting the operation of the vessel. The situation becomes even more complicated in the case of complex maneuvers in bad weather conditions and peculiarities of location mapping [2]. Given the high accident rates while watch keeping on sea transport, an important task is to reduce the risk indicators associated with loss of attention at important navigational objects and phenomena.

In order to objectively assess the possible risks associated with missing the necessary information to perform navigation tasks and maneuvering, it is necessary to develop a model for the distribution of attention the navigator. In known scientific literature, classifiers of factors affecting human error in the course of controlling a vessel are presented [3]. However, there is no a description of the mechanism of attention distribution on the basis of a formal model. Along with this, in many literary sources there are descriptive recommendations aimed at reducing the risks associated with the human factor in general [4, 5]. A number of scientific papers are devoted to the analysis of the psychological and physiological components, which significantly complements the idea of this article, but does not allow us to solve the task in full [6–10].

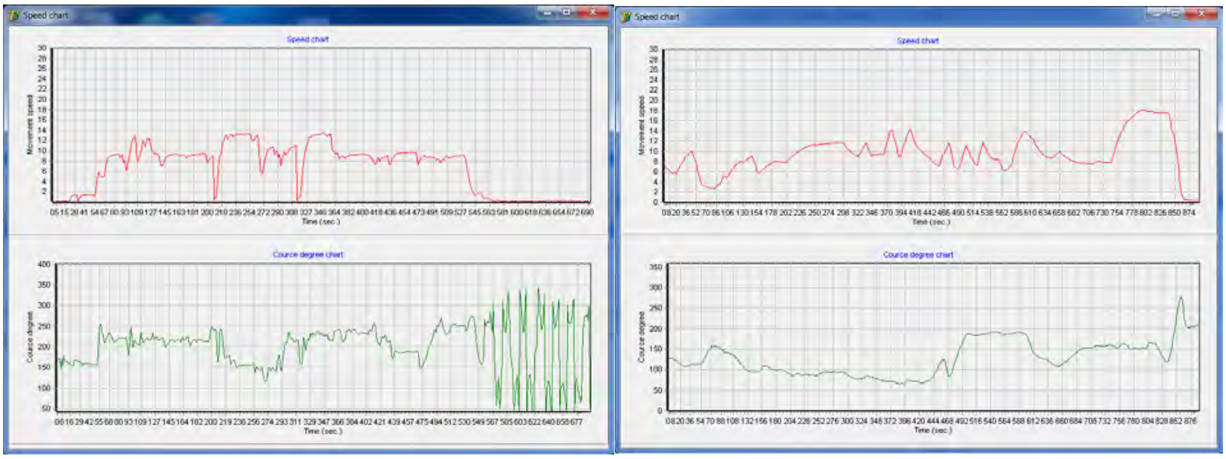


a *b*

Figure 1 – Differences in the curvature of the trajectory during the passage of the Bosphorus

A series of experiments based on navigation simulator NTPRO 5000 of Kherson State Maritime Academy for two years allowed to identify random fluctuations in the behavior of boatmasters, the nature of which is not fully determined. Figure 1. *a, b,* shows that the passage of a complex turn in the Bosphorus Strait according to the parameter of speed and turn of the rudder of the wheel by watch 1 and watch 2 differs in the curvature of the trajectory.

Three months later, the maneuver of turning the same level of difficulty with the same watch teams in the Hong Kong location resembles the maneuver in the Bosphorus (Fig. 2 a, b).

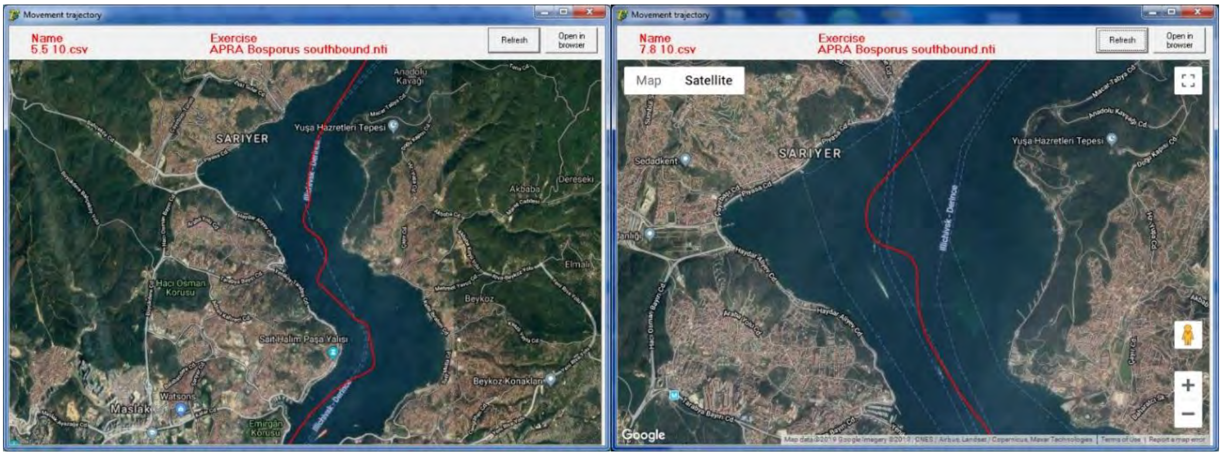


a *b*

Figure 2 – A typical pattern of behavior in Hong Kong

The question arises, what is the logic of the perception of the situation and the distribution of attention by the navigatorwhile maneuvering? Is it possible to build a formal model that would not only determine the causes of random fluctuations in decision-making, but also determine the mechanisms for predicting such situations at discrete intervals?

After analyzing the experimental data, it should be noted that fluctuations occur both at the micro level and at the macro level, as evidenced by the trajectory of the maneuver in the Bosphorus Strait (Fig. 3 a, b).



a *b*

Figure 3 – The trajectory at the macro level (satellite)

Obviously, the difference between the two observed situations consists in the time of manifestations, the time or cycle of analysis-action of the navigatorcan vary significantly. It should be noted that the nature of the manifestations is identical in both cases; it is important to determine the individual time range that forms the decision-making cycle.

The **purpose** of the article is to develop a formal model and its geometric approximation, which allows to describe the logic of the distribution of attention the navigator while maneuvering including the possibility of discrete forecasting.

The solution of the problem. To solve the main problem of the article, it is necessary to perform a number of steps that can be divided into groups:

- development of a formal-geometric model for the distribution of attention by the navigatorwhile navigating;
- determination of the logic and mechanisms of attention distribution within the framework of the model;
- prediction method selection;
- development of software for automatic execution of the forecast.

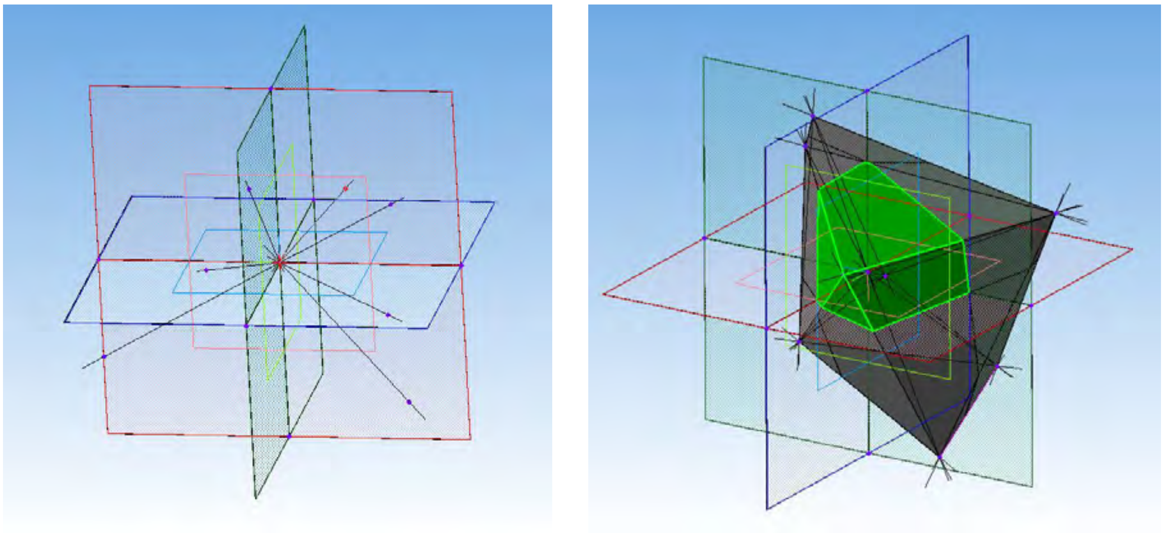
During the analysis of situations arising at the time of operation of the vessel and the maintenance of the navigational watch, a feature was found that formed the basis of the developed model for the distribution of attention of the navigator. This feature consists in the fact that attention tied to objects has its own limitations, that is, it cannot be infinite and depends on the number of objects. In the studies of Professor V.A. Krisilov, it is indicated that the maximum number of objects ranges from 7 to 9 [11]. In addition, the amount of attention also has limitations and “fades” or “depletes” over time. So at a certain point in time, the amount of attention is constant and can be unevenly distributed to objects of concentration. If we represent this model in a geometric form, then it will be fair to determine that if some object is given more attention, then in other dimensions - less.

After analyzing the international convention STCW-78, it becomes logical to identify eight objects of attention in real time that form parallel information channels that require constant attention the navigator captain. These objects include:

1. Weather condition, visibility.
2. Attention necessary when navigating traffic separation schemes.
3. Traffic intensity.
4. The proximity of navigational hazards.
5. ECDIS.
6. RADAR.
7. Steering.
8. Machine telegraph.

Of course, the greater the experience of the boatmaster, the greater the filling of the hypercube, while the lack of attention at a particular object indicates an inability to fully assess the navigational situation.

Thus, a geometric model is formed, which in each of the eight 3D quadrants will characterize the concentration of attention of the navigator.



a *b*

Figure 4 – Geometric approximation of the attention distribution model

The formation of the model involves the determination of a point in each of the 3D quadrants, which represents a vector with a metric dependence on three axes: x – «vision»; y – «hearing»; z – «bridge orientation and motor activity». Such an interpretation of the model allows to obtain its geometric structure in this form (Fig. 4 *a*, *b*).

As it can be seen in Figure 4a, the points have a different position relative to each of the 3D quadrants, which allows us to judge the individual perception of each navigator during the navigation task. Under the same conditions and input, these two specialists will have their own model of attention distribution, spending its total volume depending on individual preferences, fixed by experience.

Analyzing this model, we can find analogies in the works of A. Einstein and L. D. Landau [12, 13], in which closed space and a bunch of matter in a vacuum are considered. The formation and distribution of the geometry of a given substance are also similar in principle to the proposed model, but its boundaries are more blurred than in this interpretation. Meanwhile, for both cases it is necessary to specify a metric such that it describes the characteristics of the model and determines its adequacy. Approaches in theoretical physics give an initial impetus to the definition of metrics (1):

$$ds^2 = -e^{\alpha}\left[dR^2 + a_0^2 \sin^2 \frac{R}{a_0}\left(d\theta^2 + \sin^2\theta d\psi^2\right)\right] + e^{\gamma} d\tau^2; \quad (1)$$

$$a = a(\tau),\ \gamma = \gamma(\tau),\ R \in (0,\ \pi a_0).$$

However, it should be noted that this model cannot be fully applied in this study because it is more “smoothed» due to the complexity of determining the coordinates of the forming points. In turn, this approach is applicable from the point of view of local isolation and volume limitation.

We define the logic and mechanisms of attention distribution based on formal models of A.S. Tanguiane [14], in the framework of set theory and probability theory [15, 16].

We set the number of objects of attention $\upsilon_1,...,\upsilon_n \in V$, $n = 8$ and concentration vectors regarding their $P_1,...,P_n$. Under the conditions that the individual navigator model implies a repetition in a number of similar cases, the following condition will be true:

$$v\{f: f\in F,\, f(\upsilon_1)=P_1,\ldots,f(\upsilon_n)=P_n\}=\prod_{i=1}^{n} v\{f: f\in F,\, f(\upsilon_i)=P_i\}. \quad (1)$$

where, the navigation situation is presented as a display $f: V\to\Re$ и $f(\upsilon)\in\Re$.

To determine the model metric, we introduce the dimension:

$$\{\upsilon:\upsilon\in V,\ (x,y,z)\in f(\upsilon)\}\in\aleph,\ \ \forall x,y,z\in X\ ,$$

where, X – sets of alternatives limited by V, and F – set of navigation situations.

Observations showed that the most preferred values are along the x axis – "vision", then:

$$p_{(x,y,z)}(\upsilon)=v\{f: f\in F,(x,y,z)\in f(\upsilon)\},$$

where, $v(f)$ – the probability of a situation f, such that $v: F\to[0;1]$.

We denote $\xi_{(x,y,z)}$ – as the significance of predisposition in the 3D space of alternatives.

At the same time, the complexity of the navigation situation lies in the fact that all υ_i are independent of each other and cannot be interchangeable:

$$v\{f: f\in F,(x,y,z)\in f(\upsilon_1),\ldots,(x,y,z)\in f(\upsilon_n)\}=\prod_{i=1}^{n} p_{(x,y,z)}(\upsilon_i).$$

The predisposition in the 3D space of alternatives is denoted as P_j, where $j=1,\ldots,|\Re|$, then the x-axis predisposition – "vision" will take the form:

$$X_j(x,y,z)=\begin{cases}\lambda\subset[0{,}5;1],\ \mathit{if}\ (x,\bar{y},\bar{z})\in P_j,\\ 1-\lambda,\ \mathit{if}\ (\bar{x},y,z)\in P_j,\\ 0,\ \mathit{if}\ (x,y,z)\notin P_j.\end{cases},$$

where is the probability that the object of attention υ_i will have a predisposition P_j:

$$p_j(\upsilon_i)=v\{f: f\in F,\, f(\upsilon_i)=P_j\}.$$

Then the generalized model for all objects and individual perceptual predispositions will have the form (2):

$$p_{(x,y,z)}(\upsilon)=\sum_{j=1}^{|\Re|} X_j(x,y,z)p_j(\upsilon). \quad (2)$$

Having received a formal description of the attention distribution model, we consider the situation when an insufficient level of qualification $p_{(x,y,z)}(W)$, and consequently the volume of attention does not allow to cover all eight navigation objects. In this case, the objects become dependent $\xi_1,\ldots,\xi_k$ and the distribution is incomplete $w_1,\ldots,w_k$, $i>k$:

$$P\{\xi_i=1\}=p_{(x,y,z)}(w_i)\Rightarrow P\{\xi_i=0\}=1-p_{(x,y,z)}(w_i).$$

Then the probability of attention of all objects will be equal:

$$p_{(x,y,z)}(W)=v\left\{f: f\in F,\ \sum_{i=1}^{k}\xi_1>\frac{k}{2}\right\}.$$

From the formal descriptions it follows that the probability of an incomplete model of the distribution of attention is quite high. Adding random distractions can greatly complicate the perception of navigation hazards and even affect their classification by importance.

Thus, it is necessary to provide control over the number of navigation objects of attention. Otherwise, this can lead to a sharp imbalance of the model and, as a result, important navigation risks will be missed, which will lead to a disaster.

Another approach to enhancing safe navigation can be the time factor. It can be assumed that by changing the range of time spent on a certain group of objects relative to the situation, it will be possible to avoid catastrophic consequences. A quick perception of the situation will make it possible to speed up the decision-making process on the captain's bridge and get extra time in unpredictable situations.

Let us single out 5 states in which the navigator may be when performing navigation tasks:

1 – assessment of the navigation situation;

2 – assessment of risks and opportunities to avoid them;

3 – defining a maneuvering strategy;

4 – real-time workflow;

5 – maneuvers.

Considering that the state data can have a random set of sequences, we make a forecast using the methods of discrete Markov chains with continuous time [17].

Then $S_1,...,S_n, n=5$ – states.

We set that at any time t the system S will be in only one of the states $S_1,...,S_n$, then: $\sum_{t=1}^{n} p_i(t)=1, \forall t \geq 0$.

In this case, the transition probability is: $\lambda_{ij}(t)=\lim_{\Delta t \to 0} \frac{p_{ij}(t;\Delta t)}{\Delta t}$.

State probabilities $p_i(t), i=1,...,n$ are a solution to a system of differential equations: $\frac{dp_i(t)}{dt}=-\left(\sum_{j=1}^{n}\lambda_{ij}\right)p_i(t)+\sum_{j=1}^{n}\lambda_{ji}p_j(t), i=1,...,n; t\geq 0$.

To solve the problem of forecasting the values of time ranges, we compose a system of Kolmogorov differential equations [18] based on statistical data from a study of the form (3):

$$\begin{cases} \frac{dp_1(t)}{dt}=p_2(t)\lambda_{21}-p_1(t)\lambda_{12}; \\ \frac{dp_2(t)}{dt}=p_1(t)\lambda_{12}+p_5(t)\lambda_{52}-p_2(t)(\lambda_{21}+\lambda_{23}+\lambda_{24}); \\ \frac{dp_3(t)}{dt}=p_2(t)\lambda_{23}-p_3(t)\lambda_{35}; \\ \frac{dp_4(t)}{dt}=p_2(t)\lambda_{24}-p_4(t)\lambda_{45}; \\ \frac{dp_5(t)}{dt}=p_3(t)\lambda_{35}+p_4(t)\lambda_{45}-p_5(t)\lambda_{52}. \end{cases} \qquad (3)$$

The complexity of solving differential systems of equations involves the development of automated tools. The developed software made it possible to obtain a real-time forecast for the next cycle of temporary states (Fig. 5).

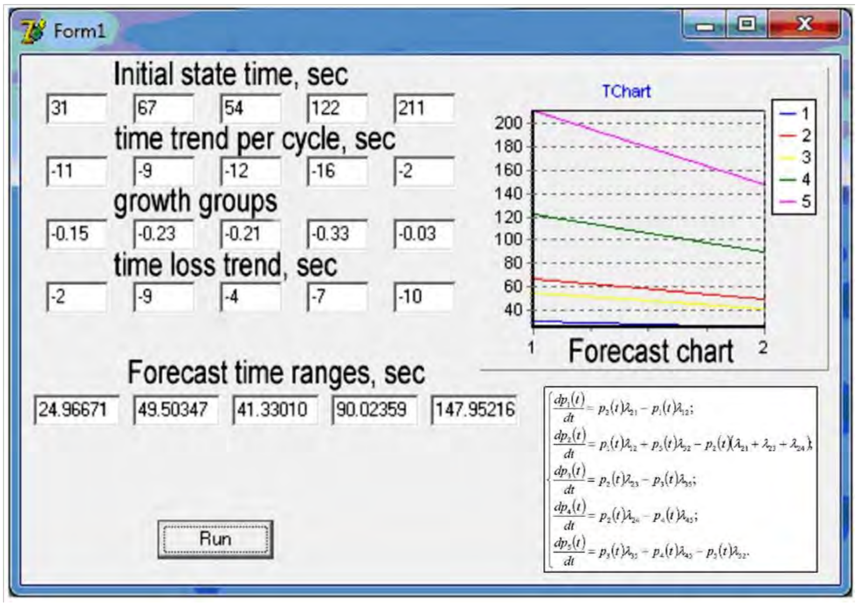


Figure 5 – Forecast System Interface

Synchronization of the developed model and software will make it possible to approach the fulfillment of the main task of the study and increase the level of security in short-distance transport. However, it should be noted that for a full-fledged result, a data extraction mechanism is needed that allows real-time identification of time ranges and growth groups depending on the navigation situation.

Conclusion. Thus, the developed geometric and formal logical model of the distribution of attention of the navigator(navigator) made it possible to determine the variability of the perception of navigation situations in operation of sea transport. The most probable distribution of attention relative to the main sensory organs on the scales of the *x, y, z* axes is determined. The logical constructions and conditions based on the predispositions of the navigator are described. A method for predicting the time ranges of navigator states in the conditions of navigational watch and ship control. Using discrete Markov chains, prognostic models based on Kalmagorov differential equations for five states were selected. In order to implement these approaches in real time, software has been developed that provides automated prediction of the cycle of navigation tasks, $t + 1$. Thus, the goal of the article has been fulfilled. Further research will be aimed at developing an information model of the navigator that allows with a sufficient degree of accuracy to carry out forecasting of catastrophic situations related to sea transport.

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Носов П. С., Бень А. П., Носова Г. В., Новиков В. И. МОДЕЛЬ РАСПРЕДЕЛЕНИЯ ВНИМАНИЯ СУДОВОДИТЕЛЯ ВО ВРЕМЯ НЕСЕНИЯ НАВИГАЦИОННОЙ ВАХТЫ

Целью статьи является разработка формальной модели и ее геометрической аппроксимации позволяющей описать логику распределения внимания старшим помощникам капитана во время выполнения маневров с возможностью дискретного прогнозирования. Для построения данной модели проведен анализ международных морских правил и ситуаций, что позволило определить формальную структуру и логические принципы модели приближенные к реальным ситуациям при решении навигационных задач.

В статье приводятся формальные подходы учитывающие индивидуальные факторы предрасположенности судоводителя к восприятию навигационных ситуаций и связанных с ними опасностей. Предложена геометрическая апроксимация модели в виде декартового куба разделенного на восемь квадрантов с локальными системами координат что позволило объединить данные по распределению внимания относительно восьми объектам согласно ПДМНВ-78. Разработаны формально-логические конструкции позволяющие отделить состояния модели распределения внимания в зависимости от этапа выполнения навигационной задачи в рамках цикла. В связи с этим, предложены подходы для прогнозирования состояний модели с помощью Марковских дискретных цепей в условиях непрерывного времени. Автоматизация прогноза позволила в режиме реального времени получать данные о скорости восприятия и обработки навигационных данных для

перехода в последующие состояния с целью снижения вероятности возникновения катастрофических ситуаций на морском транспорте.
Ключевые слова: *модель распределения внимания, человеческий фактор, штурман, пронозирование катастроф, безопасность на морском транспорте.*

Носов П. С., Бень А. П., Носова Г. В., Новиков В. І. МОДЕЛЬ РОЗПОДІЛУ УВАГИ СУДНОВОДІЯ ПІД ЧАС НЕСЕННЯ НАВІГАЦІЙНОЇ ВАХТИ

Метою статті є розробка формальної моделі і її геометричної апроксимації, що дозволяє описати логіку розподілу уваги старшим помічникам капітана під час виконання маневрів з можливістю дискретного прогнозування. Аналіз експериментальних та статистичних навігаційних даний дозволяє стверджувати що існує ряд факторів що негативно впливає на результативність виконання маневрів судноводієм у складних умовах. Втрата контролю судноводія визначено фактом як випадковою зміною керуючих впливів при управлінні судном так і траєкторією виконання складних маневрів. Таким чином у статті розглянуто особливості поведінки судноводія із врахуванням макрорівня що відображає індивідуальні стратегії формування його моделі.

Для побудови даної моделі проведено аналіз міжнародних морських правил та ситуацій, що дозволило визначити формальну структуру і логічні принципи моделі, що наближені до реальних ситуацій при вирішенні навігаційних завдань. Зазначено ряд навігаційного обладнання у якості джерел інформації які дозволяють визначити геометричну метрику запропонованої моделі.

Наводяться формальні підходи, що враховують чинники індивідуальної схильності судноводія до сприйняття навігаційних ситуацій і пов'язаних з ними небезпек. Запропоновано просторову апроксимацію моделі у вигляді декартового куба розділеного на вісім квадрантів з локальними системами координат що дозволило об'єднати дані з розподілу уваги щодо восьми об'єктів згідно ПДМНВ-78. Таким чином з'являється можливість визначення центру уваги та частки уваги судноводія відповідно до кожного з квадрантів що значно спростить аналіз його поведінки експертом під час аналізу складних навігаційних обставин на морському транспорті.

Також, розроблені формально-логічні конструкції дозволяють відокремити стани моделі розподілу уваги в залежності від етапу виконання навігаційного завдання в рамках циклу. У зв'язку з цим, запропоновані підходи для прогнозування станів моделі за допомогою Марковських дискретних ланцюгів в умовах безперервного часу. Автоматизація прогнозу дозволила в режимі реального часу отримувати дані про швидкість сприйняття і обробки навігаційних даних для переходу у наступні стани з метою максимального зменшення можливості виникнення катастрофічних ситуацій на морському транспорті.
Ключові слова: *модель розподілу уваги, людський фактор, штурман, пронозування катастроф, безпека на морському транспорті.*

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