УПРАВЛІННЯ У ТЕХНІЧНИХ СИСТЕМАХ

CONTROL IN TECHNICAL SYSTEMS

УПРАВЛЕНИЕ В ТЕХНИЧЕСКИХ СИСТЕМАХ

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IDENTIFICATION OF MARINE EMERGENCY RESPONSE OF ELECTRONIC NAVIGATION OPERATOR

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ABSTRACT

Context. The article introduces an approach for analyzing the reactions of a marine electronic navigation operator as well as automated identification of the likelihood of the negative impact of the human factors in ergatic control systems for sea transport. To meet the target algorithms for providing information referring to the results of human-machine interaction of an operator in marine emergency response situations while managing increasing complexity of navigation operations' carrying out are put forward.

Objective. The approach delivers conversion of the operator's actions feature space into a logical-geometric one of *p*-adic systems making the level of the operator's intellectual activity by using automated means highly likely to be identified. It is sure to contribute to its dynamic prediction for the sake of further marine emergency situations lessening.

Method. Within the framework of the mentioned above approach attaining objective as automated identification of the segmented results of human-machine interactions a method for transforming deterministic fragments of an operator's intellectual activity in terms of *p*-adic structures is proposed to be used. To cope with such principles as specification, generalization as well as transitions to different perception spaces of the navigation situation by the operator are said to be formally specified. Having been carried out of simulation modeling has turned out to confirm the feasibility of the proposed above approach causing, on the grounds of temporary identifiers, the individual structure of the operator's reactions to be determined. As a result, the data obtained has delivered the possibility of having typical situations forecasted by using automated multicriteria methods and tools. This issue for its part is said to be spotted as identification of individual indicators of the operator's reaction dynamics in complex man-machine interaction.

Results. In order to have the proposed formal-algorithmic approach approved an experiment was performed using the navigation simulator Navi Trainer 5000 (NTPRO 5000). Automated analysis of experimental server and video data have furnished the means of deterministic operator actions identification in the form of metadata of the trajectory of his reactions within the space of *p*-adic structures. Thus, the results of modeling involving automated neural networks are sure to facilitate the time series of the intellectual activity of the electronic marine navigation operator to be identified and, therefore, to predict further reactions with a high degree of reliability.

Conclusions. The proposed formal research approaches combined with the developed automated means as well as algorithmic and methodological suggestions brought closer to the objectives for solving the problem of automated identification of the negative impact of the human factors of the electronic navigation operator on a whole new level. The efficiency of the proposed approach is noticed to have been approved by the results of automated processing of experimental data and built forecasts.

KEYWORDS: reaction identification systems, automated data processing systems, simulation of operator reactions, computer navigation simulators, analysis of the human factor, automated control systems.

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ABBREVIATIONS

ECDIS is the Electronic Chart Display and Information System;

ARPA is an Automatic Radar Plotting Aid;

AIS is the Automatic Identification System;

GPS is the Global Positioning System;

NTPRO 5000 is the navigation simulator “Navi Trainer 5000”;

UTC is the Universal Time Coordinated;

ETA is the Estimated Time of Arrival;

MAICS is a module for automated identification of critical situations.

NOMENCLATURE

$\tilde{\psi}$ is a navigation signal;

r_1 is a dimension of an l-dimensional vector;

ψ is a signal parameters;

k is a correlation functions;

A is the “Subjective” identification system;

B is the “Ideal” identification system;

$\mathbf{X}_1$ is the difference between “ideal” and “subjective” navigation signal identification system

$\Delta\psi$ is a stochastic uncertainty of the identification process;

β_ε is an emotionally reactive activity of the operator;

σ_i, η_i is an alternatives to reactions;

x_i is a points of space of perception;

k is a correlation functions;

Q is the effectiveness of decision making by the operator

$X_{(p=2)}$ is a perception space with $p = 2$;

$Y_{(p=3)}$ is a perception space with $p = 3$;

$Z_{(p=4)}$ is a perception space with $p = 4$;

A , V is an operator skill levels;

R, R^{-1} is a strategies of operators U, V ;

f is a payoff function;

S_a is a set alternatives;

j is an accompanied emotion;

μ^+ is a normalization factor;

U, L is a positive and negative decision-making strategy;

ε^+ is an emotion level;

$\tilde{x}^S$ is a random strategy;

y is an uncertainty factor;

Z_p is a set of nodal points x;

x_0 is an initial situation of the cycle γ ;

$\mathbf{U}(\tau)$ is a graph vertices;

$\{a\}, \{b\}$ is a threshold values of perception;

Gv is a directions of transition to systems of perception on the basis of p-adicity;

P is the probability of a transition to systems of perception with respect to p-adicity;

a, b is a detailing and generalization;

ρ_p the distance between the situations-nodes of the p-adicity system graph;

H_π is a subjective operator entropy;

N is a number of reaction alternatives;

π is a performance index of alternatives;

ζ_i is a density of situation identification;

Δ_t is a response time range.

INTRODUCTION

The cause analysis of catastrophic situations in maritime transport is definitely to uncover the problems associated with the accuracy of identification of navigation situations by operators with increasing frequency [1–2]. In most cases, deficiency of data and metadata for effective decision-making associated with the critical situation occurrence during navigation is to be mentioned as being first-ranked one [3–4]. It goes without saying that the decisive factor settling it is highly likely to be the skill level of the operators. Taking into consideration the fact of most maneuvers and tasks being typical in navigation the skipper gets used to identifying the current situation relatively to several, the most significant, universal criteria. Due to the fact that the navigation situation at each moment of time is said to be having a set of incoming information signals (visual observation; sound commands (walkie-talkie); radar; ECDIS; ARPA; AIS; GPS, etc.), the operator gets used to reacting to these signals by classifying them according to their skill level and experience.

Thus, a process with two systems functioning simultaneously for the sake of identifying the navigation situation: “subjective”, depending on the level of the operator, and “ideal”, accommodating all significant information signals, is eventuating.

The formal description of the process is believed to be that the navigation signal $\tilde{\psi}$ in the form of an l-dimensional vector of dimension r_1 with regard to the parameters ψ and the correlation function k is about to have the following form:

$$\tilde{\psi}(k) = \psi(k) + \Delta\psi(k) = \psi(k) + B_1(k)\mathbf{X}_1(k).$$

Meanwhile, the vector $\mathbf{X}_1$ is to be characterised as the difference between the “ideal” and “subjective” navigation signal identification system in the following form:

$$\mathbf{X}_1(k) = A_1\left[\mathbf{X}_1(k-1), k\right] + W_1(k),$$
$$B_1 = \left[l \times r_1\right],\ \Delta\psi = B_1 X_1.$$

Consequently, the efficiency of decision-making by operator Q can be reflected as:

$$Q(k) = F\left[\Delta\psi(k), k\right] + n(k).$$

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In this formal description the vector $\Delta\psi$ is noticed to be a random one being able to represent the stochastic uncertainty of the given process. However, the formulation of the question needs to be taken into account with a high degree of accuracy attempting to determine the distortion when identifying the situation by the operator. This issue is to be coped with to construct predictive models driving to the accident and disaster risks lessening. At the same time, the analysis of statistical data fails in being able to define $\Delta\psi$ as well as the questionnaires of experienced sea captains [5].

All these items are certain to highlight the objective problem of constructing mathematical, simulation models as well as automated systems for having "subjective" navigation situations analysed with a view to preventing dangerous cognitive biases as a negative human factor manifestation.

Hence, the **object of research** is said to be human-machine interaction in information systems of maritime navigation.

The **subject of the research** is supposed to be models and algorithms for automated analysis and identification of operator reactions occurring in critical situations.

The **purpose of the study** is defined as implementing formal and algorithmic approaches to transform data of the intellectual activity of an electronic navigation operator with an aim to identify and predict his reactions in tight situations.

The purpose of the article is chosen to be the applying special purpose solution method embracing the following problems:

1. To analyze the existing approaches with an eye toward determining the principles of formal description of the operator's emotional-reactive activity β_ε in the space of alternatives σ_i.
2. To propose the principle of data transformation of individual operator's reactions in the process of decision-makings based on *p*-adic systems in the form of points-situations $f_s(x) = x^s$ on a geometrically defined space of perception.
3. To introduce attribute perception spaces of the navigation situation by operators $X_{(p=2)}$, $Y_{(p=3)}$ and $Z_{(p=4)}$ within the framework of *p*-adicity to sketch the level of reactions and time fragments of their operation on the grounds of the analysis of server data.
4. To carry out the experiment using the navigation simulator Transas navigation simulator NTPRO 5000 targeting to establish terminal data of the operators reactions during typical navigation operations.
5. To analyse the time series of operator reactions using automated neural networks setting the focus to getting the proposed approach validated. Over and above, to train the most effective neural networks, to deal with ahead of the operator's reactions for 5 cycles as well as to determine the stability of the forecast data over time.

The obtained predictive models based on neural networks as well as the cyclic correction of the models built on subsequent experiments are supposed to be on the point of having a whole class of operators' reactions in the main navigation situations identified. The foretold options are definitely to provide fair contribution into enhancement of sea transportation safety.

1 PROBLEM STATEMENT

Consider the evolution of the perception of the situation depending on the levels of operators *A* and *V* within the framework of game theory [6]. To begin with, let us assume an existing set of navigation situations requiring the operator to make decisions based on individual strategies in the system being finite: $\Gamma = \left\langle A, V, X, R, f \right\rangle$. In this case, the set of decision making *X* should be taken as being the same for each of the operators counting on the ship's control capabilities, location, weather conditions and traffic intensity. On the premises of $A \times V \to X$ we are able to come to the conclusion that the values of strategies *R* and R^{-1} are noticed to be normalized having a general framework of gain (efficiency) of the type $R \cap R^{-1}$. Nevertheless, this issue does not seem to be fitted to the criteria for the evolution of the subject's consciousness [7] and, therefore, has to be mentioned as inappropriate in being used in work.

Consecutively, the approaches based on the theory of subjective entropy [8] and the theory of preferences [9] are likely to be treated as challenging tasks being consistent to our study. Then, the formal description of these processes is depicted to be founded on the preference of functions $\pi(\sigma_i)$, $\sum_{i=1}^{N} \pi(\sigma_i) = 1$. In addition, within the framework of this theory interrelated values are certain to be described: $A(\sigma_i) \to A_{ij}$ is a positive decision-making strategy and $L(\sigma_i) \to L_{ij}$ is considered as a negative one. This theory is up to succeed in dealing with analyzing the impact of the human factor in aviation. Nevertheless, the formal apparatus is noticed to be incapable of implying levels of discretization welcoming a qualitative change in the structure of the perception of the situation. To a greater extent, the theory is doomed to gear forward determining the situational emotion by the subject as a whole based on the positive effect of decision-making:

$$\varepsilon^{+}\left(\eta_{jt}^{+} \mid \sigma_{it-1}\right) = \mu^{+} \frac{\varepsilon^{+}\left(\eta_{jt-1}^{+}\right) \cdot U_{jt-1} \cdot e^{\beta_\varepsilon U_{jt-1}}}{\sum_{q=1}^{M} \varepsilon^{+}\left(\eta_{qt-1}^{+}\right) \cdot U_{qt-1} \cdot e^{\beta_\varepsilon U_{qt-1}}}.$$

It should be mentioned that a formal description is said to be involving the use of a parameter of the emotion β_ε accompanying the decision taking. However, in this study there is surely an evitable necessity to be faced in

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expanding this concept into the form of a discrete, class-forming quantity leveraging the effects of the operator's decision-making process qualitatively.

2 LITERATURE REVIEW

In [10] the problem of automating the construction of models of quantitative dependencies by precedents was managed to have been solved. To settle it a tree-like cluster-regression approximation method was proposed to be used entrenching in the construction of a hierarchical clustering tree of instances. This approach needs to be drawing attention to as being considered as a worthwhile one by the hierarchical manner in which the cluster areas are presented. Subsequently, this item delivers a great possibility to have them classified as separate elements (nodes) of the tree. One more proposed method worth speaking about is neural networks usage heading for constructing a cluster-regression model.

Furthermore, in the theory of operations research [11] in situations with inhomogeneous strategies set splitting into families of non-empty subsets that form subclasses of strategies happens to have been effectively described. The criterion for this partition is named as the evaluation of the effectiveness of the random strategy $\tilde{x}^S$: $\inf\limits_{y \in N} F\left(\tilde{x}^S, y\right)$. In this way, the subsets are to be treated as parts of the universal set despite their being the formed subclasses of strategies. However, we are striving to pursue the goal of finding an evolutionary formal principle to describe a qualitative transition to another level of perception of the navigation situation.

The theory of p-adic numbers rooting out from the theory of numbers is grounded on the principle of partitioning of sets superior to Archimedes' axiom [12] being highly likely close enough for possible application.Besides, the foretold above approaches considered in the theory are said to be mostly about the construction and formal description of tree-like class-forming structures leading to the process of approximating the mental functions of the subject in the form of a fundamentally new structural composition [13, 14].

Analysis of the literature has definitely revealed the dominating tendency to have been having a search for processes similar to our research in related areas of knowledge for a long time. [15–18]. It is quite vividly seen the problem presented in the study has necessitated an enhancement in the approach on the grounds of p-adic systems with a target to formally describe the qualitative transient processes of situation identification for its subsequent automation to be reached.

Approximating the approach of p-adic systems [19] to the objectives of the study the existence of an objective information space of situations identified and classified by the operator within the framework of the subject area regarding decision-making processes might be hypothesised. Let us suppose that the subject area is to be the navigation problem [20, 21] and the space of situations is to be treated as a finite set Z_p of nodal points x on a graph with a tree-like hierarchical structure. Consequently, the evolutionary dynamics of identification on a graph node will be the following: $f: Z_p \to Z_p,\ x \to f(x)$, as for the node points on the graph it would be true to express the dependency as the following: $x_n = f^n(x_0)$, $\gamma = (x_0, x_1, \ldots, x_{n-1})$.

Taking into account the nature of the perception of objective reality, the operator tends to be generalizing the identified points-situations with concurrent reducing the range of input information parameters to an image close to the image from his own experience.

Thus, the identified point-situation is noticed to contain a lot of close associations – parameters: $\lim\limits_{n \to \infty} y_n = x_0 = \left\{ y \in Z_p : y_n \to x_0 \right\}$. Therewith, each subsequent point turns out to be generated by the function $f_s(x) = x^s$, $s = 2, 3, \ldots, n$ and, therefore, it is sure to be acquiring the previous experience of the operator with regard to the class of the situation according to the principle of perception evolution.

It must be noted that its p-adicity is changing being conditioned by the level of the operator .

Thence, for example, it is true to say that for cadets-trainees $p = 2$. Therefore, cadets tend to react to the parameters of the situation by means of coding in the form: "yes" – "no"; "exists" – "does not exist"; "significant" – "not significant", etc. In its turn, for the third and second mates it is sure enough to have it as $p = 3$ in the form: "weak" – "medium" – "strong"; "ignore" – "keep in mind" – "react"; "do not include into account" – "fall-back" – "main option", etc. Considering the p-adicity of the chief mates and the captains themselves it certainly expands significantly highly likely to have $p = 4, 5, 6$, etc.

There from, the raised question worth speaking about is: how can the evolution of decision-making during the transitions from the lowest p-adicity to the highest for operators of electronic marine navigation be identified and demonstrated?

3 MATERIALS AND METHODS

It goes without saying that there is the classification – coding inheritance to be observed, i.e. the operator, passing, for example, from $p = 2$ to $p = 3$, appears to add a linguistic variable to the already adopted system for identifying incoming information signals. This process should be processed as a completely natural one owing to the fact that knowledge is being expanded consistently not having psyche drastically changed during life-being.

Taking into consideration this very issue, the quite logical conclusion to be drawn is that in the system $p = 2$: "yes" – "no" with a high degree of probability for $p = 3$ the items tend to appear as: "yes" – "I do not know" – "no", etc.

Thus, the task to be spoken about is to determine the trajectories of the individual development of the perception of situations by operators of electronic maritime navigation during the transition to $p = n + 1$.

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In addition, there is certainly a need in paying regard to the fact that the *p*-adicity of operators according to the full range of navigation situations is biased to be evolving equitably since being dependable not so much on qualifications as on the frequency of occurrence of typical situations. Thereupon, in some cases, the situation, due to its simplicity, is noticed to be less likely to require high *p*-adicity despite the experience of the captain. This issue becomes obvious enough resting on the principle of preserving emotional energy and strength. Consequently, the map of mental states relative to the spectrum of navigation situations seems to be heterogeneous getting different *p* - adicity.

On this subject it causes the dependence in the construction of a tree-like hierarchical structure to be existing: an increase in *p*-adicity gives rise to an increase in detail and, in its turn, a decrease contributes to generalization. Based on the formal theory of creativity and the theory of systems development [22] conclusion is about to be made that it is sure to occur within the set of internal nodes of the graph $\mathbf{U}(\tau)$, between the threshold values $\{a\}$ and $\{b\}$. This item is supposed to generate the possibility to move to the nearest systems of *p*-adicity upward and downward being conditioned by the situation $\mathbf{U}(\tau)=\left[\cap_{j=1,\ldots,n} Gv^{\uparrow}\left(\tau|a_j\right)\right]$.

In this case, the transition process appears to be symmetric regardless of the direction:

$$Gv^{\downarrow}\left(\tau|b\right)=Gv^{\uparrow}\left(\tau|a\right)\Rightarrow\left\langle\underline{\tau},P\right\rangle_W$$

at $Gv^{\uparrow}\left(\tau|a_i\right)\cap Gv^{\uparrow}\left(\tau|b_i\right)=\varnothing$.

Based on the proposed dependencies we are on the point of summing up of having a certain kind of balance of *p*-adicities for which it is considered to be equally true:

$$\forall x\in\left[Gv(\tau)\right]\Rightarrow\exists a\in\{a\},$$
$$x\in\left[Gv^{\uparrow}\left(\tau|a\right)\right]\&\,\exists b\in\{b\},x\in\left[Gv^{\downarrow}\left(\tau|b\right)\right].$$

Thus, the observed balance of transition in *p*-adic structures can definitely be contingent upon both factors: the level of complexity of the navigation situation (necessity) and the skill level of the operator (possibility):

$$Gv(\tau)=\cup_{a\in\{a\}}Gv^{\uparrow}\left(\tau|a\right)=\cup_{b\in\{b\}}Gv^{\uparrow}\left(\tau|b\right).$$

Being aware of spoken above approaches and formal descriptions a method containing the following sequence of actions is assumed to be used:

1. To add, setting on the accepted theory of *p*-adic systems a metric is possible to be defined in the following way: $\rho_p\left(x,y\right)=\left|x-y\right|_p, x\to\left|x\right|_p$ [23]. Simultaneously, the assumption is sure to be proposed that *p*-adicity is to be nothing but a perception criterion delivering the opportunity to evaluate the navigation situation at a qualitatively new level as well as to make management decisions. It should be highlighted that the last one happens to be of great benefit at the time of making decisions being in conditions of a navigational hazard identified as a critical situation. So, the complexity of the situation requires the operator to be having an appropriate and meaningful level of perception possible to be expressed by spaces $\left(X,\rho\right)\&\left(Y,\rho'\right)$. For example, decision making in binary logic (p = 2) is seen to be the most consistent with monosyllabic tasks driving to switching on or off with respect to a given indicator of the operator. In its turn, (p = 3) is noticed to be adding a linguistic variable according to the principle: $\rho'\left(j\left(x_{1_{p=2}}\right),j\left|x_{2_{p=2}}\right|\right)=\rho\left(x_{1_{p=3}},x_{2_{p=3}}\right)$ directing it to a higher level. This is likely to come up to the sense that problems being able to be solved in space *Y* cannot be settled in space *X*. Thus, metric spaces determined by the adicity level might be represented in the form of graphs. So,to confirm the hypothesis of the study, let us consider the levels of perception of a critical navigation situation within the framework of p = 2, p = 3, p = 4 – adicity on the example having representation of the problem of crossing the separation lines in the Singapore Strait (Fig. 1). In the figure, using the module for predicting the time trajectories of ships in the TRANSAS Navi Trainer 5000 system, two groups I and II are capable of being clearly distinguished.It has to be beared in mind that they are supposed to be different from each other only according to the decision-making experience. Alongside with it, the group I is following a parallel course relative to the separation lines but group II deviated from group I by 31º– 33º. Therefore, the conclusion might be drawn that the decision-making of the group of vessels I and II is supposed to have been bounded up by different sets of information signals. This means that groups I and II were likely to assess navigation situation in a different system of *p* – adicity shaping spaces *X* and *Y* as the following: $X\subseteq Y \mid X\setminus Y=\varnothing$.

So, targeting to compare two systems of perception let us build a graph describing the isometric essence of the spaces *X* and *Y* (Fig. 2).

When considering the graphs *X* and *Y* eventual conclusion being able to be made is that, for example, identification of the navigation situation No. 25 in space $X_{(p=2)}$ can be probably done with the help of going through 5 steps. Besides, there is a need to define the values of 5 parameters, respectively, in binary coding. Nevertheless, as for identifying the same situation in space $Y_{(p=3)}$ three steps are definitely to be required with a ternary coding system. However, it should be taken into account that the lower the *p*-adicity is more brutal the decision-making results are about to be. Wherefore, two approaches are supposed to be compared when laying the route of the vessel's movement (Fig. 3).

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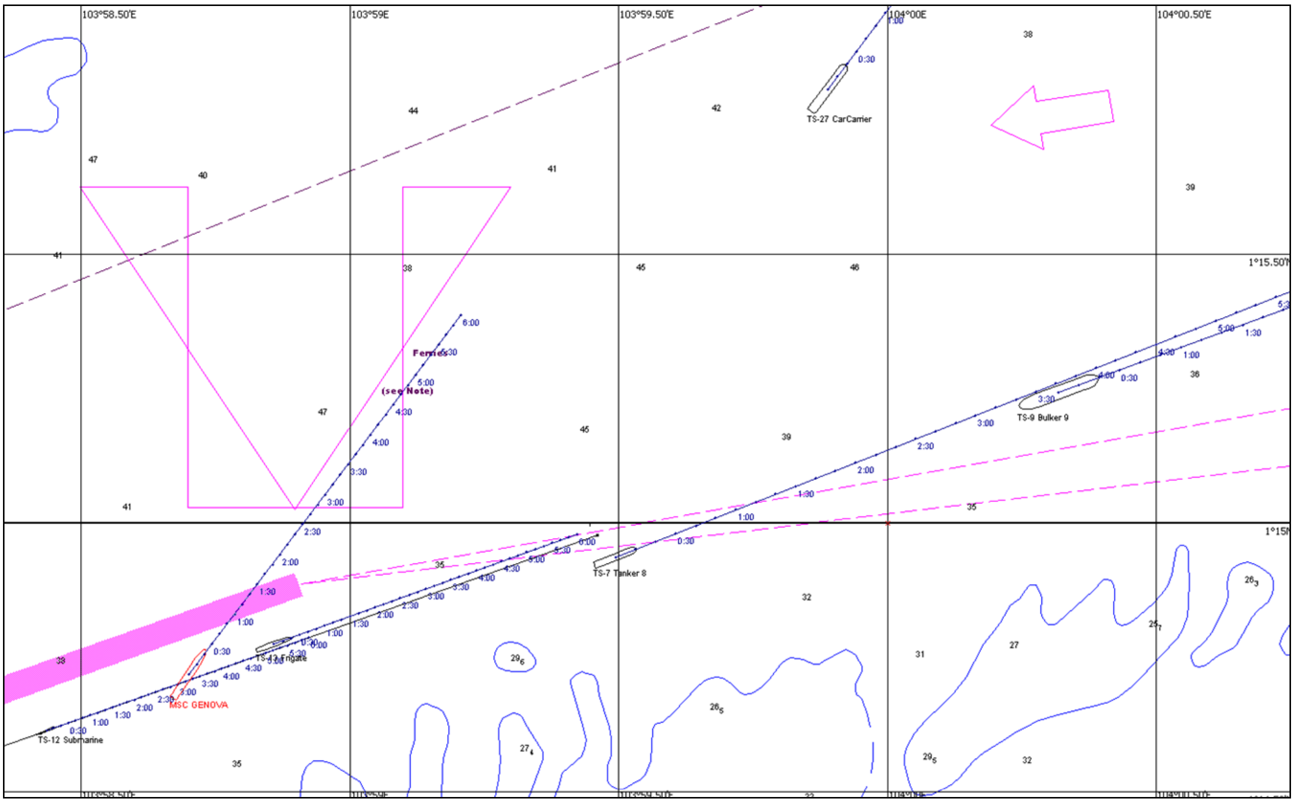

Figure 1 – The beginning of the maneuver of crossing the lines of separation in the Singapore Strait

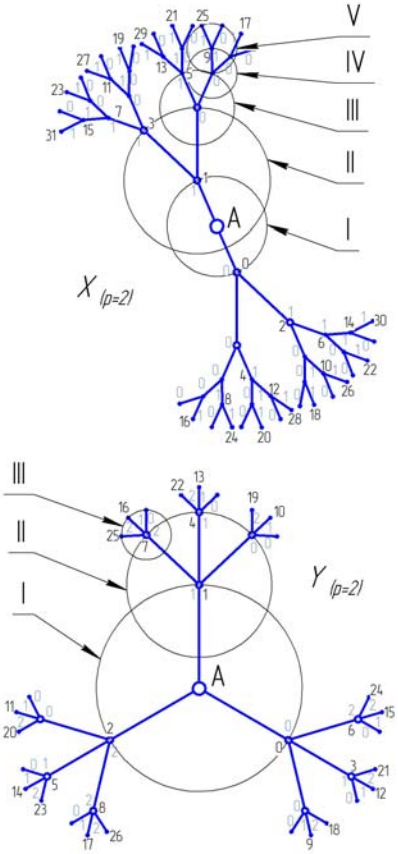

Figure 2 – Spaces of identification of the navigation situation *X* and *Y*

As can be clearly seen from Figure 3, in case a, the operator gets used to making a decision in space $X_{(p=2)}$ with no regard to the parameter (the value of the safe depth) acting mostly according to the principle: the water surface can be treated as "yes" or "no". For its part, the operator making decisions in space $Y_{(p=3)}$ is noticed to have a different classification of the water surface: "shallow water", "safe depth", "open sea / ocean". Nonetheless, $Y_{(p=3)}$ is already characterized by values in meters of depth and knowledge of the ship's draft to determine the boundaries of each linguistic variable. The most dangerous option of the given example does not only concern the fact that there is the operator's tendency to make decisions within the framework of the space $X_{(p=2)}$ but the most challenging aspect which is to be faced is that this space is sure to be considered unsuitable for this task carrying out. Despite this, in the course of empirical analysis it was noticed that 32% of operators happened to have made a decision in the framework of $X_{(p=2)}$ even in situations with modeling being about the space $Z_{(p=4)}$. It all boils down to embracing the fact that operators are mostly about keeping to simplification of identification forms that causes an increase in the probability of critical situations in maritime transport. This process is highly likely to be described formally using the term "subjective entropy" H_π: $H_\pi = -\sum_{i=1}^{N} \pi(\sigma_i)\cdot \ln \pi(\sigma_i)$.

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Thus, it is vividly seen that the operator is sometimes involved into choosing an ineffective alternative $\pi^{-}(\sigma_i)$ intentionally because of either lacking of confidence in his abilities or of embarking to the habitual experience [24]:

$$\pi^{-}(\sigma_i)=\left(e^{-\beta L(\sigma_i)}\Big/\sum_{j=1}^{N}e^{-\beta L(\sigma_j)}\right).$$

Therewith, the first case appears to be typical for novice operators, who, due to their having poor qualifications, are biased to avoid difficulties. Nevertheless, over time they are to go-getting to a higher level of perception. The second case is regarded as typical one for experienced seafarers who are likely to be accustomed to get their work carried out in an established regime. Therefore, this very issue is considered to be the most dangerous one owing to their having less inclination to deviate from habitual behavior pattern strategies. Based on this, the density of the situation identification ζ_i directly depends on the p-adicity: $\zeta_{2\ldots n}=\left(\frac{1}{2};\frac{1}{3};\frac{1}{4},\ldots,\frac{1}{n}\right)$. The more accurate and multi-parameter solution an operator needs to be making the higher the p-adicity is to appear. However, it is worth bearing in mind that the mentioned above balance of issues is able to be adjustable from situation to situation. The sequence of decisions made by the operator at a certain discrete moment in time has to be relied on very p-adicity at each stage. It could be regarded as problematic as, on the one hand, is on the point of driving to the desired result but on the other hand, of the strength and emotional energy keeping.

Thus, it is obvious enough that the operator is inclined to initially plan p-adicity transitions to the foreseeable distance of the chain of consecutive actions. For each part, as studies are sure to have shown, characteristics corresponding to mental states and directions of anticipation are typical ones [25, 26].

00:00 05 - 11 - 18
Ship's time 04 : 00 : 00
Prim DGPS 1 01° 10.090 N 104° 11.265 E
Sec: NONE
3q5qqc02 ON
Last upd.: 28-02-2012
Updated to:
System information

Drift	000.0° - 0.0 kn
Current	171.5° - 0.5 kn
Sf.contour	15 m
True wind	002.3° - 2.6 m/s
Rel. wind	073.0°(P) - 2.6 m/s
Water t °	7.2 °C

WPT	Name	Position	Leg type	Leg	Total distance	XTD port/stbd	Turn radius
3		104° 18.448 E		3.10 NM		0.10 NM	
4		01° 12.879 N 104° 20.297 E	RL	097.3° 1.86 NM	10.82 NM	0.10 NM 0.10 NM	0.10 NM
5		01° 13.173 N 104° 22.133 E	RL	081.0° 1.88 NM	12.69 NM	0.10 NM 0.10 NM	0.10 NM

Edit route
Latitude 01°12.917' N
Longitude 104°20.527' E
Ship position: Bearing true 073.1, relative 002.2 °; Opp. Bearing true 253.1, relative 177.8 °; Range 9.69 NM, 17954 m

From WPT 0
To WPT 5
Distance 12.69 NM

a

WPT	Name	Remarks	Draught	UKC	Ref. point	BRG/Dist	Safety contour	Safety depth
3			Undefined	Undefined			30 m	30 m
4			Undefined	Undefined			30 m	30 m
5			Undefined	Undefined			30 m	30 m
6			Undefined	Undefined			30 m	30 m

Select waypoint
Latitude 01°12.655' N
Longitude 104°22.302' E
Ship position: Bearing true 077.6, relative 002.5 °; Opp. Bearing true 257.6, relative 177.5 °; Range 11.33 NM, 20953 m

From WPT 0
To WPT 7
Distance 12.73 NM

b

Figure 3 – Navigation system of electronic cartography

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4 EXPERIMENTS

Based on the foregoing, let us conduct simulation modeling of operator's decision-making during a critical navigation situation using a three-dimensional model of the graphs of the spaces $X_{(p=2)}$, $Y_{(p=3)}$ and $Z_{(p=4)}$. As depicted in Figure 4 the spatial model is about to assume the combination of three space-planes in the form of graphs to display the intellectual activity of the operator in the form of trajectories of dimension in accordance with the selected p-adicity.

Let us build the trajectory of the operator of electronic navigation intellectual activity at the time of performing complex maneuvers. Identification of operators' attention [27], automated analysis of electronic logbooks as well as psychological techniques [28] provided fair ground to determine time series and trajectories of their reactions (Fig. 5).

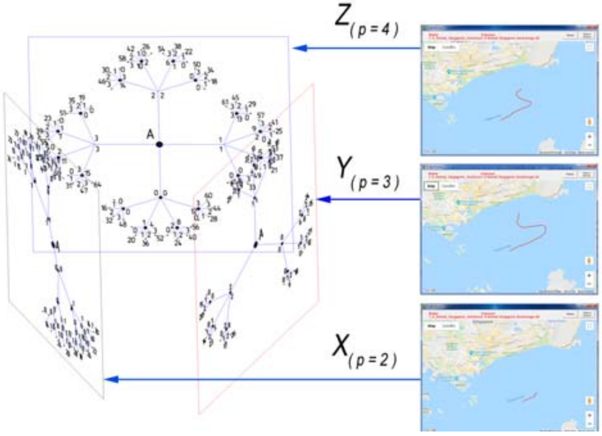
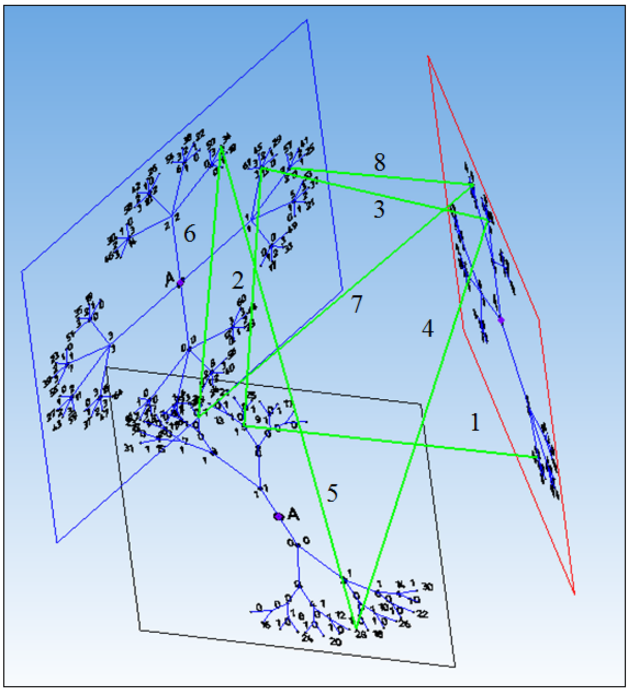
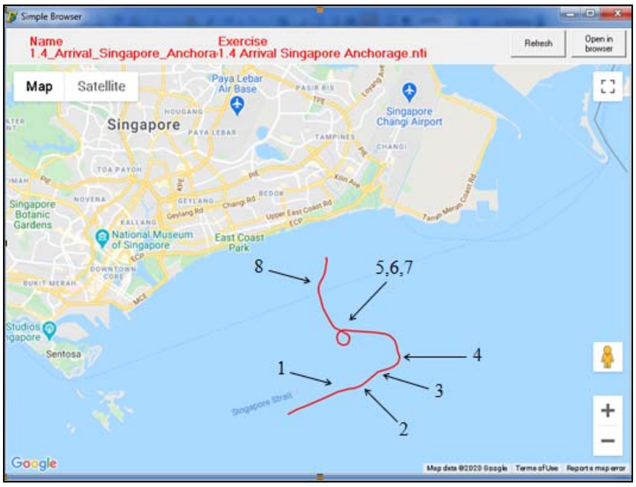


Figure 4 – Spatial model of the operator's intellectual activity

The foundation of the time series creation happened to be the results of an experiment with the help of operators' attention recorders which contributed to the identification of the time intervals between the spaces $X_{(p=2)}$, $Y_{(p=3)}$ and $Z_{(p=4)}$. The time measuring for the transition from one system of perception of the situation to another one facilitated assessing to what extent the operator is confident in the logic of his actions. Besides, depending on specific sources of navigation information the operator gets used to paying attention to the approximation of these data in the form of objects of a particular p-adic space became possible to be done. So, for example, let us consider a fragment of the sequence of the operator's actions at the stage of assessing the situation when approaching the port. It is likely to include the following: analysis of ECDIC data ($Y^{t1}_{(p=3)}$); visual observation, one target ($X^{t2}_{(p=2)}$); ECDIC data analysis ($Y^{t3}_{(p=3)}$); visual observation, many targets, instrument readings ($Z^{t4}_{(p=4)}$). Analysis of the experimental data welcomed the opportunity to have the moments of time on the route of the maneuver with the transition from one space of perception to another one determined. Besides, having analyzed the typical trajectories of maneuvers in the same navigational and weather conditions, the chains of events forming the perception of the situation in the time frame appeared to have been singled out (Fig. 5 a, b).



a transitions between spaces of perception



b transition points on the chart

Figure 5 – Chains of events on the trajectory of the ship's maneuver

Analysis of trajectories, as well as the time spent on transitions, forwarded to determine the stages of this or that space of perception of the navigation situation being used by an operator.

Above and beyond, the involvement of experienced sea captains as experts bestowed us to deal with thorough determination of the spots of the ship's trajectory where the space $X_{(p=2)}$, $Y_{(p=3)}$ or $Z_{(p=4)}$ are regarded to be appropriate.

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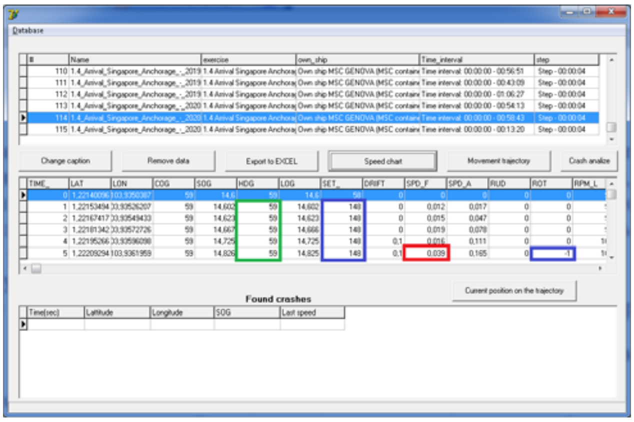
However, this fact can not be treated as enough to predict likely critical situations for each operator. Experiments have revealed the fact of each operator having his own plan of expected actions and his own sequence of transitions to the spaces of perception necessary for the situation to be identified. This is leaving a lasting imprint on the situation of both uncertainty and complexity in building predictive models. Consequently, expert judgment and accepted reference reaction models recommended by experts are unable to bring a solution to the problem requiring a fundamentally different approach to be pursued.

Taking into consideration these circumstances, an individually oriented one is highly likely to be proposed for both analyzing and predicting the reactions of a single operator purposes using time intervals or time codes of reactions. This is a very important issue definitely proving the hypothesis and research objectives.

It should be noted that the time ranges of transitions between spaces are said to have been taken as atomic elements for building a model of operator reactions. Data is regarded to have been collected within the 8 months period. It concerned the question of typical maneuvers carrying out happening in various locations from 76 operators by means of the certified navigation simulator NTPRO 5000. The collected data from the ECDIS server made the great opportunity to fragment and decompose the transition trajectories for each operator to be delivered. Thus, individual reaction models for three typical situations-maneuvers are considered as follows: turn of the ship by 90º, mooring and anchoring. Being aware of the difficulty of anchoring operation in confined waters and harsh density of traffic in Singapore the study was chosen to be focusing on this maneuver. Automated analysis of data in the form of log-files of maneuvers performed by dozens of operators contributed to getting micro-frame situations of interconnected navigation parameters identified causing a specific operator's action to be exactly determined (Fig. 6).



#	Name	exercise	own_ship	Time_interval	step
110	1.4_Arrival_Singapore_Anchorage_-_2019	1.4 Arrival Singapore Anchora	Own ship MSC GENOVA (MSC contain	Time interval: 00:00:00 - 00:56:51	Step - 00:00:04
111	1.4_Arrival_Singapore_Anchorage_-_2019	1.4 Arrival Singapore Anchora	Own ship MSC GENOVA (MSC contain	Time interval: 00:00:00 - 00:43:09	Step - 00:00:04
112	1.4_Arrival_Singapore_Anchorage_-_2019	1.4 Arrival Singapore Anchora	Own ship MSC GENOVA (MSC contain	Time interval: 00:00:00 - 01:06:27	Step - 00:00:04
113	1.4_Arrival_Singapore_Anchorage_-_2020	1.4 Arrival Singapore Anchora	Own ship MSC GENOVA (MSC contain	Time interval: 00:00:00 - 00:54:13	Step - 00:00:04
114	1.4_Arrival_Singapore_Anchorage_-_2020	1.4 Arrival Singapore Anchora	Own ship MSC GENOVA (MSC contain	Time interval: 00:00:00 - 00:58:43	Step - 00:00:04
115	1.4_Arrival_Singapore_Anchorage_-_2020	1.4 Arrival Singapore Anchora	Own ship MSC GENOVA (MSC contain	Time interval: 00:00:00 - 00:13:20	Step - 00:00:04

TIME_	LAT	LON	COG	SOG	HDG	LOG	SET_	DRIFT	SPD_F	SPD_A	RUD	ROT	RPM_L
0	1,22140096	103,9350387	59	14,6	59	14,6	58	0	0	0	0	0	
1	1,22153494	03,93526207	59	14,602	59	14,602	148	0	0,012	0,017	0	0	
2	1,22167417	03,93549433	59	14,623	59	14,623	148	0	0,015	0,047	0	0	
3	1,22181342	03,93572726	59	14,667	59	14,666	148	0	0,019	0,078	0	0	
4	1,22195266	03,93596098	59	14,725	59	14,725	148	0,1	0,016	0,111	0	0	
5	1,22209294	103,9361959	59	14,826	59	14,825	148	0,1	0,039	0,165	0	-1	

Found crashes

Time(sec)	Latitude	Longitude	SOG	Last speed

Figure 6 – Micro frame-situation identified as a maneuver – turn of the ship

The graph is being built in accordance with the preferences for the perception of the situation. These preferences are different for each operator. So, for instance, for one operator, the first place is occupied by an information signal in the form of visual observation of target vessels and navigational obstacles meaning that his tree begins its functioning from visual perception in a certain *p*-adicity system. For another operator, the graph is able to start its construction with an auditory one, for example, a request to coastal services by radio, etc.

Hence, a certain even the same type of action might be preceded by an unalike perception of the situation at a particular stage. According to the carried out analysis of experimental data the operators get used to applying the most accepted elements of perception at the very beginning of the maneuver. Simultaneously, it was further noted that the speed of assessing the situation differs being conditioned by the nature of perception. Consequently, the time ranges of each action aimed at assessing perception are somewhere near with regard to each individual operator enabling it to act as a kind of time code of the action.

5 RESULTS

Thus, in this way, there is obviously a need both for the construction of a scheme of individual perception of the navigation situation corresponding to the time range and the position on the graph tree. Trying to disguise the navigation situation perception we will be on the point of taking a lot of atomic actions while having the operation performed [29] during the conducting an experiment by means of the TRANSAS Navigational simulator NTPRO 5000. On the grounds of this, the defragmentation of the ship's anchoring operation was managed to be done in the form of a life cycle taking into account the full range of information signals and human-machine interaction.While having the experiment the 18 th team of navigational operators was noticed to be showing the following time ranges during the assessment of the navigation situation (Fig. 7).

In addition, the analysis of the video series and the data of the psychological questionnaire provoked the dominant alternatives being identified for each operator. Thereby, the experimental data required for modeling the trajectory of decision-making by the operator and, accordingly, individual classifications amalgamated with the time series succeeded in being obtained. Consequently, it has driven into the possibility of applying approaches based on automated neural networks in attempt to identify transitions between spaces of perception [30].

The basic approach is considered to be as follows:

1. The classification data and time intervals at each stage of decision-making relating to a specific subtask (anchoring) is about to concede to correlating the simulation results to the entrenched algorithms of the reactions of a particular operator.

2. Comparative analysis of the operator's actions with respect to the formed deterministic model of his reactions makes the prediction of the events likely to occur in real time while a maneuver carrying out.

3. Automated analysis enabled the boundaries of transitions to other spaces of perception , an increase in time at stages, during transitions to the upper spaces of percep-

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tion, and, accordingly, its decrease, during transitions to lower ones to be defined.

4. According to the carried out experiment, in typical (standard) situations, there is a distinct possibility of the time being distorted with regard to the complexity of the locations. Nevertheless, the reaction algorithm itself is practically deemed to be unchanged.

5. While having unforeseen actions of the operator the module of automated identification of critical situations (MAIKS) has let out the formation of an unpredictable branch of his reactions-actions in 4 situations. Having been shown by means of experiment, this phenomenon was preceded by a long time pause exceeding the threshold by 3–5 times.

6. While facing such a phenomenon MAIKS is about to begin comparing the trajectories from the base containing the operator's reactions data with the newly formed branch of reactions-actions ones. If MAIKS encounters every chance of trajectories being compatible with this task the alarm tends not to be functioning. On the contrary, in the opposite situation, a signal is bound to be sent to the captain to have the navigational watch harden. Hence, this approach is totally described by *p*-adicity models.

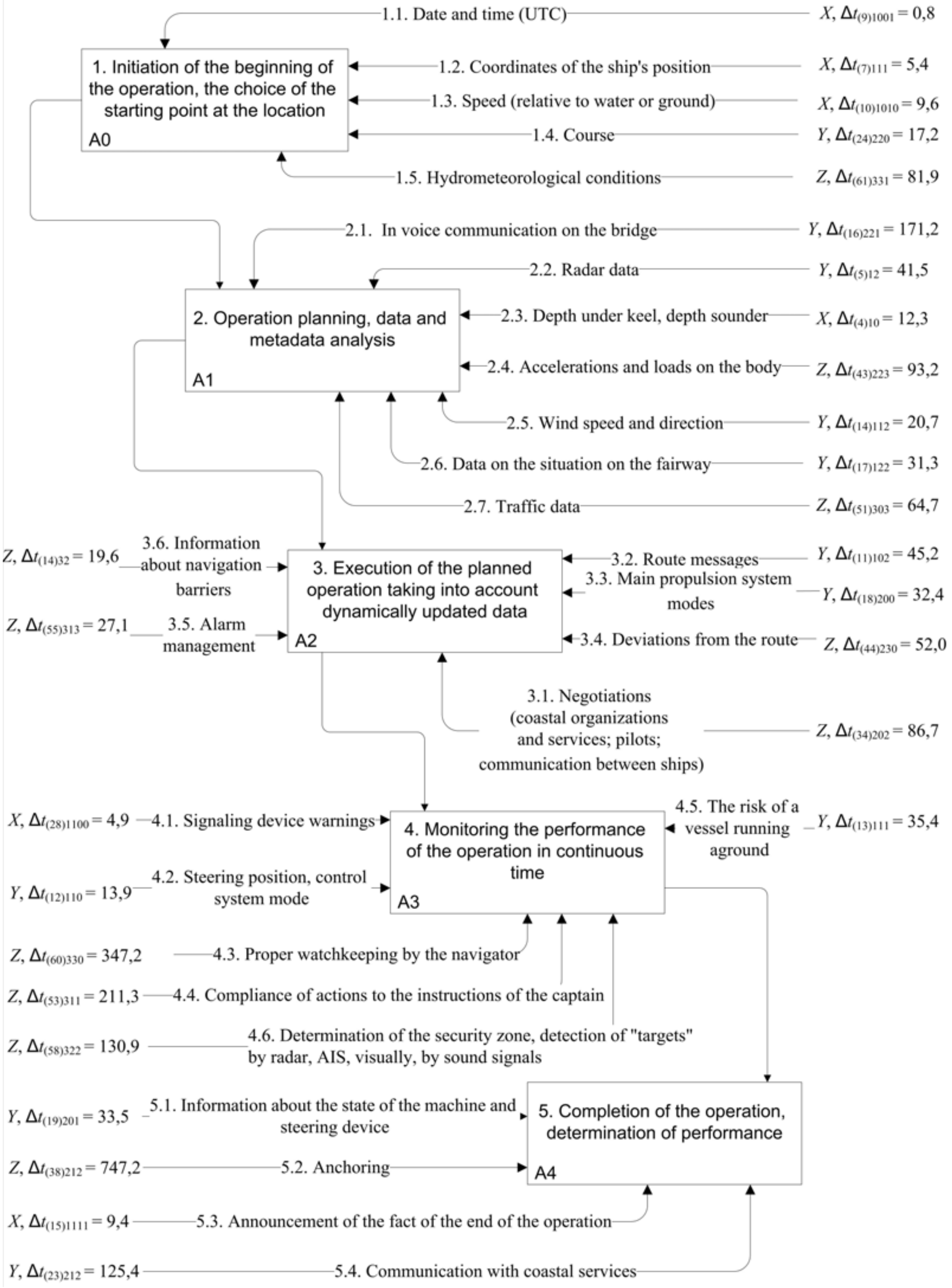

Figure 7 – Analysis of the operation in relation to $X_{(p=2)}$, $Y_{(p=3)}$ and $Z_{(p=4)}$ time.

The obtained experimental data came out with the possibility of detecting points on the graph in the form of the beginning of critical situations. For that reason in all probability an essential and final stage of the study is to be presented in the form of the construction of sensitive predictive models to identify the onset of critical situations going on in real time. It must be highlighted that setting up on the specifics and nature of the research data the most promising summing up to be made is that the most obvious and possible to be measured parameter is certainly the indicator of time in intervals related to specific stages and relative to a single operator.

It is worth speaking about being important to distinguish the time interval associated with the transition to a new space of perception from the time interval. This marker doubtlessly gave the high sign of indicating a change in the strategy of reactions, the so-called "break in the decision-making trajectory" where the immediate change in the action plan occurs. Trying to cope with it data was proposed to be collected for implementing analysis by means of automated neural networks in the form of time series (Table 1).

Notwithstanding, it was not aptitude found to either increase or decrease in the extrema of the graph being an indicator of an already formed model of reactions regarding the carrying out of anchoring the vessel operation . Insignificant fluctuations presumably witnessed the fact of possible navigation situation in different seaports being able to differ .Simultaneously, it is not inclined to entirely affect the operator's reactions. The cycle of periodicity in the graph seems to consist of 28 measurements for each action. Each action contains its own time progress indicator. The obtained information about the experimental data gives us consent to go on to be dealing with the construction of a neural network regression model for performing an automated forecast of a time series for a further period. Having had training, seven most effective models are regarded to have been automatically obtained (Fig. 9). Further, we proceed to the analysis of the results choosing the best network No. 5 which embraces the lowest error rate. In addition, we are intending to construct a diagram of the residuals for both training and control samples (Fig. 10).

To analyze the dynamics of this series, let's build a line graph of ten tests from A to J (Fig. 8).

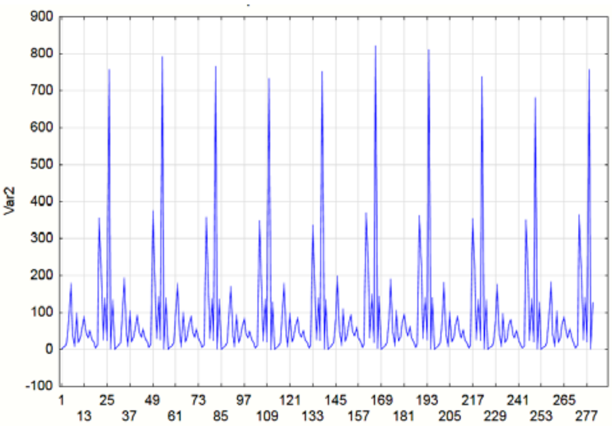

Figure 8 – Graph of the periodicity of the time series based on experimental data

Table 1 – Experimental data of the operation

Identifier	Sample of experimental data of marine watch teams									
	A	B	C	D	E	F	G	H	I	J
1.1. X, $\Delta t_{(9)1001}$	0.8	1.0	0.9	0.7	0.8	1.2	1.1	0.8	0.7	0.9
1.2. X, $\Delta t_{(7)111}$	5.4	5.8	5.7	5.4	5.5	6.7	6.2	5.6	5.5	6.1
1.3. X, $\Delta t_{(10)1010}$	9.6	11.4	10.5	9.6	9.3	12.3	10.3	9.9	9.4	9.8
1.4. Y, $\Delta t_{(24)220}$	17.2	18.3	17.5	17.0	17.3	18.4	18.5	17.5	16.9	17.0
1.5. Z, $\Delta t_{(61)331}$	81.9	83.2	84.0	80.6	81.1	85.6	87.5	82.9	81.3	89.3
2.1. Y, $\Delta t_{(16)221}$	171.2	184.3	170.2	163.4	170.4	191.2	182.3	173.2	169.2	174.4
2.2. Y, $\Delta t_{(5)12}$	41.5	45.2	42.8	39.7	41.1	48.4	47.3	42.3	40.6	44.3
2.3. X, $\Delta t_{(4)10}$	12.3	13.1	12.4	12.0	12.4	15.2	13.9	12.2	11.9	12.0
2.4. Z, $\Delta t_{(43)223}$	93.2	96.3	94.9	89.2	91.4	101.5	98.2	94.3	91.3	96.8
2.5. Y, $\Delta t_{(14)112}$	20.7	22.6	21.5	19.3	21.0	24.2	23.6	21.1	19.2	20.9
2.6. Y, $\Delta t_{(17)122}$	31.3	33.0	32.4	29.3	30.2	33.2	32.7	31.3	29.8	32.1
2.7. Z, $\Delta t_{(51)303}$	64.7	67.2	66.9	63.3	64.7	69.7	70.4	65.3	65.4	67.3
3.1. Z, $\Delta t_{(34)202}$	86.7	90.3	89.0	83.3	85.4	93.1	94.7	88.2	81.3	86.9
3.2. Y, $\Delta t_{(11)102}$	45.2	44.7	48.2	43.6	44.8	50.1	49.2	46.2	42.1	47.2
3.3. Y, $\Delta t_{(18)200}$	32.4	34.2	33.9	31.2	32.7	38.2	38.5	32.1	30.8	32.6
3.4. Z, $\Delta t_{(44)230}$	52.0	55.3	54.7	50.0	51.5	59.3	61.3	52.3	52.1	54.7
3.5. Z, $\Delta t_{(55)313}$	27.1	30.1	29.3	26.8	27.4	32.1	31.4	28.3	26.1	28.9
3.6. Z, $\Delta t_{(14)32}$	19.6	21.2	20.5	18.3	19.5	23.1	21.4	18.3	16.3	19.9
4.1. X, $\Delta t_{(28)1100}$	4.9	5.3	5.2	4.6	4.5	6.1	5.9	5.1	3.9	4.3
4.2. Y, $\Delta t_{(12)110}$	13.9	15.6	14.5	12.4	13.6	15.2	16.0	13.7	11.0	13.8
4.3. Z, $\Delta t_{(60)330}$	347.2	367.4	349.2	338.7	327.5	361.9	352.2	344.8	341.2	354.2
4.4. Z, $\Delta t_{(53)311}$	211.3	219.4	216.3	209.1	207.6	227.9	218.2	210.7	207.1	213.0
4.5. Y, $\Delta t_{(13)111}$	35.4	37.1	38.4	31.3	34.5	39.1	37.2	35.7	33.2	36.1
4.6. Z, $\Delta t_{(58)322}$	130.9	135.2	130.4	127.2	130.8	141.3	133.9	128.5	129.3	134.2
5.1. Y, $\Delta t_{(19)201}$	33.5	36.2	34.1	30.2	33.3	27.3	35.7	32.8	29.9	30.6
5.2. Z, $\Delta t_{(38)212}$	747.2	782.1	756.2	724.1	743.1	812.4	801.3	729.4	673.3	748.0
5.3. X, $\Delta t_{(15)1111}$	9.4	10.3	9.7	8.9	9.2	11.7	10.5	9.7	9.1	10.1
5.4. Y, $\Delta t_{(23)212}$	125.4	131.8	127.8	120.2	126.3	134.9	132.5	125.0	118.9	127.3

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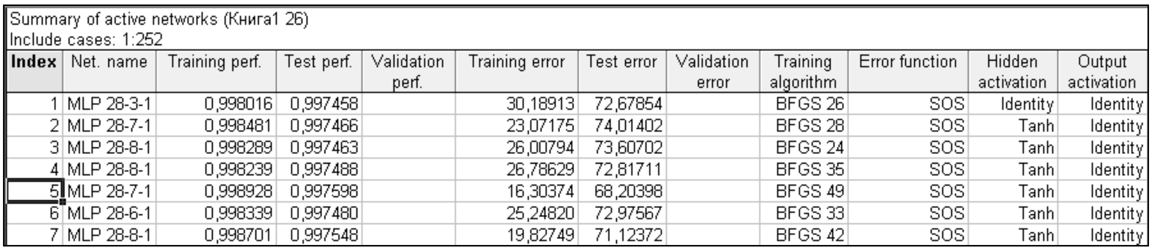

Summary of active networks (Книга1 26)
Include cases: 1:252

Index	Net. name	Training perf.	Test perf.	Validation perf.	Training error	Test error	Validation error	Training algorithm	Error function	Hidden activation	Output activation
1	MLP 28-3-1	0,998016	0,997458		30,18913	72,67854		BFGS 26	SOS	Identity	Identity
2	MLP 28-7-1	0,998481	0,997466		23,07175	74,01402		BFGS 28	SOS	Tanh	Identity
3	MLP 28-8-1	0,998289	0,997463		26,00794	73,60702		BFGS 24	SOS	Tanh	Identity
4	MLP 28-8-1	0,998239	0,997488		26,78629	72,81711		BFGS 35	SOS	Tanh	Identity
5	MLP 28-7-1	0,998928	0,997598		16,30374	68,20398		BFGS 49	SOS	Tanh	Identity
6	MLP 28-6-1	0,998339	0,997480		25,24820	72,97567		BFGS 33	SOS	Tanh	Identity
7	MLP 28-8-1	0,998701	0,997548		19,82749	71,12372		BFGS 42	SOS	Tanh	Identity

Figure 9 – Indicators of network performance

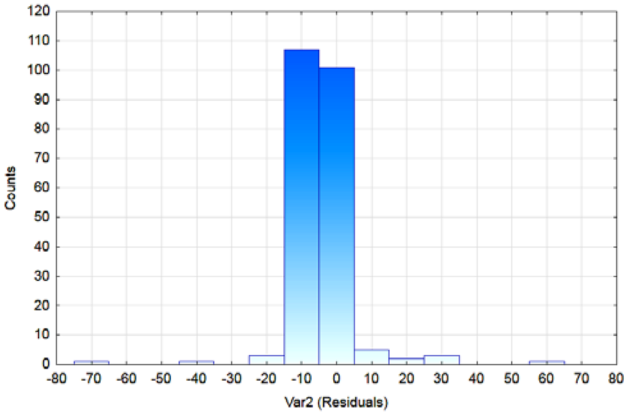

Figure 10 – Chart of residuals of the best network

As it clearly seen, the distribution might be considered almost close enough to standard delivering the evidence of the adequacy of the selected neural network model. Let us evaluate the quality of the model by building a scatter diagram of the target and output variables (Fig. 11).

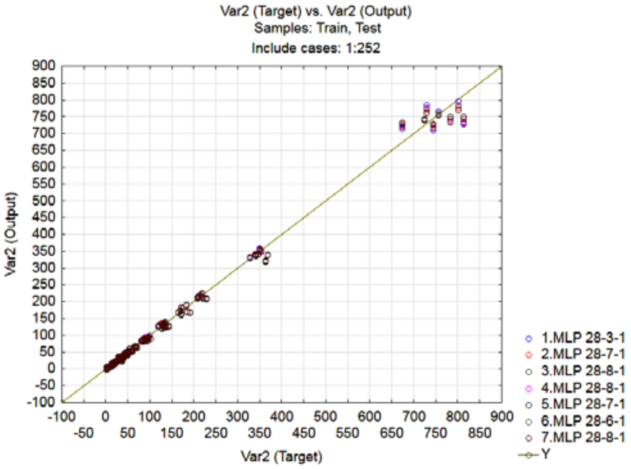

Figure 11 – Scatter diagram of target and output variables

The diagram depicts that the points of model No. 5 are bound to be the most structured ones with respect to the diagonal which is regarded to entirely confirm the advisability of its choice due to the high specifications of the constructed neural network.

Let's check the way the selected model will be on the point of performing prognoses of the initial series. It might be noticed that the constructed forecast graph tends to be copying a huge amount of similarity of values of the original data. (Fig. 12). This issue has become a true indicator letting precise prediction of the operator's actions to be revealed in various locations while performing typical habitual situations.

Besides, a projection of the graph targeting to analyze the accuracy of the neural network appears to have been built. Its correctness is deemed to be high enough due to the data presented in the resulting graph.

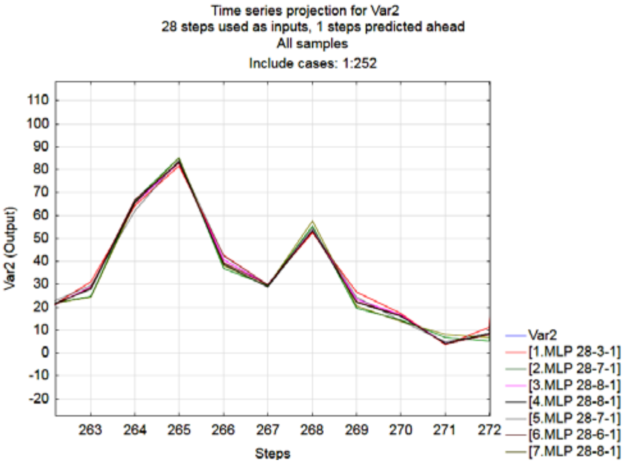

Figure 12 – Fragment of the obtained forecast graph

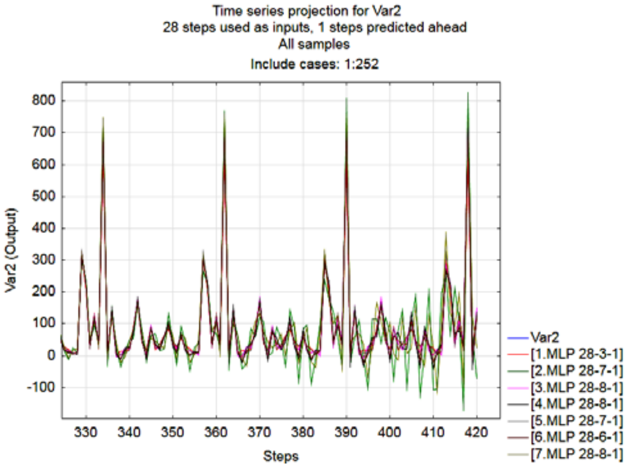

Figure 13 – Forecast for four cycles

As it can perceptibly be seen from Figure 1 having long-term forecasting, starting from 12 to 15 cycles, the graph might be distorted. This fact suggests that the safe use of the model is seen as workable just for two forecast cycles with having the neural network data periodically updated.

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CONCLUSIONS

Formal theories and logical-cognitive models are considered to have been analyzed based on game, decision, creativity theory, theory of subjective analysis and the theory of *p*-adic systems.It resulted in welcoming of the approaches being the closest ones to the research problem.

On the ground of the foretold approach, a mechanism for transforming the data of the ECDIS server, empirically obtained video series and time indicators were settled upon causing an individual map of the perception of navigation situations of operators on the graph of *p*-adic spaces to be identified.

In addition, it had delivered the opportunity to clearly define the transition points between the spaces of perception by means of using the module for the automated identification of critical situations and a change in the reaction time of operators in the course of human-machine interaction.

With an intention to achieve the main objective of the study an experiment is said to have been carried out as a consequence of which metadata concerning the reactions of operators during a vessel anchoring operation in the port of Singapore was thoroughly collected. The data was obtained during having had the automated analysis of the log files of the NTPRO 5000 navigation simulator.

It is to be underlined, in its turn, that automated analysis of the obtained data by means of using regression analysis of time series with applied automated neural networks acquiescence in the model training and further predict operator reaction cycles. As a result of modeling with a high degree of reliability it is possible to come to a conclusion that for 2–3 subsequent cycles the prediction of reactions is noticed to be satisfactory. Further settlement is about having the calibration of the models required not forgetting to take into account the dynamically changing data of individual time indicators relative to everyday reactions.

Thus, this study is regarded to have contributed to finding the solution of the problems of identifying the negative impact of the human factor of marine operators to enhance safety policy in maritime transport.

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ІДЕНТИФІКАЦІЯ РЕАКЦИЙ ОПЕРАТОРА МОРСЬКОЇ ЕЛЕКТРОННОЇ НАВІГАЦІЇ

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АНОТАЦІЯ

Актуальність. У статті запропоновано підхід аналізу реакцій оператора морської електронної навігації та автоматизованої ідентифікації негативного впливу його людського фактору в ергатичних системах управління морським транспортом. Запропоновано алгоритми зчитування інформації про результати людино-машинного взаємодії оператора у критичних ситуаціях при виконанні навігаційних операцій підвищеної складності.

Мета. Метою дослідження є розробка підходу що дозволяє перетворити простір ознак щодо дій оператора у вигляді логіко-геометричного простору p-адичних систем, в результаті якого з'являється можливість ідентифікації рівня інтелектуальної діяльності оператора за допомогою автоматизованих засобів і спрогнозувати його динаміку для нівелювання критичних ситуацій.

Метод. В рамках підходу і з метою автоматизованої ідентифікації сегментованих результатів людино-машинної взаємодії описано метод перетворення детермінованих фрагментів інтелектуальної діяльності оператора в термінах *p*-адічних структур. Формально описані принципи деталізації, узагальнення, а також переходів у різні простори сприйняття навігаційної ситуації оператором. Проведено імітаційне моделювання що підтверджує доцільність запропонованого підходу і дозволяє на основі часових ідентифікаторів визначити індивідуальну структуру реакцій оператора. Отримані дані дозволяють виконувати прогнозування для типових ситуацій із застосуванням автоматизованих багатокритеріальних методів і засобів, що у свою чергу дає можливість ідентифікувати індивідуальні показники динаміки реакцій оператора у складній людино-машинній взаємодії.

Результати. З метою підтвердження запропонованого формально-алгоритмічного підходу був проведений експеримент з використанням навігаційного симулятора Navi Trainer 5000 (NTPRO 5000). Автоматизований аналіз експериментальних серверних даних, даних відеоряду, дозволив ідентифікувати детерміновані дії оператора у вигляді метаданих траєкторії його реакцій в рамках просторів *p*-адичних структур. Результати моделювання із застосуванням автоматизованих нейронних мереж дозволили отримати часові ряди інтелектуальної діяльності оператора електронної морської навігації та з достатнім ступенем надійності виконувати прогноз подальших реакцій.

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Висновки. Запропоновані формальні підходи дослідження, в поєднанні із розробленими автоматизованими засобами, а також алгоритмічними і методологічними пропозиціями дозволили на новому рівні підійти до вирішення проблеми автоматизованої ідентифікації негативного прояву людського фактора оператора електронною навігації. Результативність запропонованого підходу була обґрунтована за результатами автоматизованої обробки експериментальних даних і побудованих прогнозів.

КЛЮЧОВІ СЛОВА: системи ідентифікації реакцій, системи автоматизованої обробки даних, моделювання реакцій оператора, комп'ютерні навігаційні симулятори, аналіз людського фактора, автоматизовані системи управління.

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ИДЕНТИФИКАЦИЯ РЕАКЦИЙ ОПЕРАТОРА МОРСКОЙ ЭЛЕКТРОННОЙ НАВИГАЦИИ

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АННОТАЦИЯ

Актуальность. В статье предложен подход анализа реакций оператора морской электронной навигации и автоматизированной идентификации негативного влияния его человеческого фактора в эргатических системах управления морским транспортом. Предложены алгоритмы считывания информации о результатах человеко-машинного взаимодействия оператора в критических ситуациях при выполнении навигационных операций повышенной сложности.

Цель. Целью исследования является разработка подхода позволяющего преобразовать признаковое пространство действий оператора в виде логико-геометрического пространства *p*-адических систем, в результате которого появляется возможность идентифицировать уровень интеллектуальной деятельности оператора с помощью автоматизированных средств и спрогнозировать его динамику для нивелирования критических ситуаций.

Метод. В рамках подхода и с целью автоматизированной идентификации сегментированных результатов человеко-машинные взаимодействия описан метод преобразования детерминированных фрагментов интеллектуальной деятельности оператора в терминах *p*-адических структур. Формально описаны принципы детализации, обобщения, а также переходов в различные пространства восприятия навигационной ситуации оператором. Проведено имитационное моделирование подтверждающее целесообразность предложенного подхода и позволяющее на основе временных идентификаторов определить индивидуальную структуру реакций оператора. Полученные данные позволяют выполнять прогнозирование для типовых ситуаций с применением автоматизированных многокритериальных методов и средств, что в свою очередь дает возможность идентифицировать индивидуальные показатели динамики реакций оператора в сложном человеко-машинном взаимодействии.

Результаты. С целью подтверждения предложенного формально-алгоритмического подхода был проведен эксперимент с использованием навигационного симулятора Navi Trainer 5000 (NTPRO 5000). Автоматизированный анализ экспериментальных серверных данных, данных видеоряда, позволил идентифицировать детерминированные действия оператора в виде метаданных траектории его реакций в рамках пространств *p*-адических структур. Результаты моделирования с применением автоматизированных нейронных сетей позволили получить временные ряды интеллектуальной деятельности оператора электронной морской навигации и с достаточной степенью надежности выполнять прогноз дальнейших реакций.

Выводы. Предложенные формальные подходы исследования, в сочетании с разработанными автоматизированными средствами, а также алгоритмическими и методологическими предложениями позволили на новом уровне подойти к решению проблемы автоматизированной идентификации негативного проявления человеческого фактора оператора электронной навигации. Результативность предложенного подхода была обоснована по результатам автоматизированной обработки экспериментальных данных и построенных прогнозов.

КЛЮЧЕВЫЕ СЛОВА: системы идентификации реакций, системы автоматизированной обработки данных, моделирование реакций оператора, компьютерные навигационные симуляторы, анализ человеческого фактора, автоматизированные системы управления.

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