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Identification of distortion of the navigator's time in model experiment

This article discusses a formal analysis of time perception made by sea transport navigators being in critical situations while performing vessel navigation. The carried out analysis of experimental data and investigations of marine accidents provided us with valuable insights of having wide range of cases in which navigators, while performing complex maneuvers (i.e. mooring operation), are highly likely to be involved into facing challenges of getting poor time comprehension during template implementation process. It is worth mentioning that while having it this very issue is being influenced on by external and internal factors. It, for its part, is noticed to considerably contribute into the increased likelihood of accidents. The main goal of this study is reported to be the development of a concept of having formal and automated means and methods for the identification distortion of the navigator's time (DNT) as being an indicator of negative manifestation of human factor in critical situations. For the sake of having been able to accomplish this goal a generalized model for the formation of t DNT was proposed as well as mathematical models and automated tools were introduced to be used for DNT intervals identification when analyzing the physical trajectory of the vessel's movement. Besides, the generating individual time codes in emergency situations system is managed to be successfully revealed. Moreover, the carried out experiments using the certified navigation simulator Navi Trainer 5000 are said to have confirmed the convincing cogency and to have made clear evidences of providing practical value of the proposed approaches. It goes without saying that these issues are sure to significantly improve the safety-driven process of keeping a navigational watch while navigating a vessel.

Keywords: experimental data, navigator's time distortion, ergatic and automated systems.

Introduction

Contemporary being used tools for the analysis of experimental data of physical processes, getting impact on the trajectory of the ship are encountering the need of having certain amount of ambiguity with regard to the human- navigator fault [1]. This very circumstance is able to directly affect the accuracy of predicting the vessel movement [2]. As a result, it turns out not to provide any possibilities to determine the valid reasons for the deviation of the trajectories from the optimal ones calculated by the onboard information and intelligent systems (Fig. 1).

Figure 1. Deviation from the optimal trajectory due to the influence of uncertain factors

Consequently, the calculation of the full range of physical parameters does not authorise the on-board computer to be using the autopilot due to the peculiarities of the port waters locations and international legislation [3].

As it is vividly seen, the initial analysis of the trajectory of the maneuver on the right in Figure 1 is noticed to provide significant difference from the optimal one for no apparent reason. The analysis delivers us the opportunity to single out one of the key reasons for the following navigator's behavior happening to be due to the perception of the situation regarding the time range of the operation [4–7]. The parameter of time perception by the navigator is considered to be an uncertainty $a \in A$ in the situation $s \in S$ with having the situation identifier presented in the form $\pi(s) = \varphi(s, A) = \bigcup_{a \in A} \varphi(s,a)$, whereas the optimality ε is reported to take into account uncertainties in the following form:

$$\widetilde{\mathrm{Max}}(S,\varepsilon) = \left\{s \in S \mid \pi(s) \subset \mathrm{Max}\left(\pi(s),\varepsilon\right)\right\} = \left\{s \in S \forall x \in \pi(s), f(x)\right\} \geq \sup\left\{f(y) \mid y \in \pi(S)\right\} - \varepsilon =$$

$$= \left\{s \in S \mid \inf\left\{f(x) \mid x \in \pi(s)\right\} + \varepsilon \geq \sup\left\{f(y) \mid y \in \pi(S)\right\}\right\},$$

where: a — is a set of uncertainties in the form of metadata belonging to *A*; S — is a set of navigator strategies; s — is a strategy that determines the current situation; $\pi(s)$ — is a situation determined by the strategy; φ — is a mapping that determines the situation on the pair (s,a); ε — is a set of optimal situations for some admissible subset of situations *X*, $R(X,\varepsilon) \subset X$; f — is a vector performance criterion; x, y — is an element of an admissible subset of situations *X* defined by the dominance relation "$\succ$".

The research data and the indicated dependencies are empowered to determine the degree of influence on the situation of information signals from the physical environment with the data of navigation sensors and devices being used. However, the central tendency of having time recognised only as a discrete component in the proposed above models is highly likely not to present possibilities of finding out factors of its perception [8].

Other models are certain to submit the situation as a descriptive one basing on empirical experiments of getting clear and convincing evidences of the hypothesis of the change in the navigator's time perception in emergency situations. Nevertheless, these issues happen not to implement an understandable patterns of the dependences of time perception when performing tasks in a formal form. The only obvious item to be paid attention to is having the subjective up-to-individual time calculation being significantly different from the devices' readings [9, 10]. This process directly affects the navigator's behavior making an inevitable contribution to uncertainty in decision making [11]. Hence, in its turn, it can affect the physical trajectory of the vessel. It would be beneficially taken into account that the time factor *a* should be introduced as being the difference between the real perception according to the *i*-th parameter of the navigation system $a_r(t)_i$ and the distorted one $a_d(\Delta t)_i$ in the form: $D(i)_t = \left|a_d(\Delta t)_i - a_r(t)_i\right|$

These all mentioned above issues seem to cause contradictions between the need of getting explicit identification of the distortion or «distortion of the navigator's time» (DNT) when performing maneuvers and the capabilities of contemporary electronic and automated navigation systems.

Thus, the relevance of this study is said to be the necessity to determine the formal models of ship control performed by the navigator with due regard for DNT basing on experimental navigation data.

The aim of the study targeting to be fulfilled is having formal and automated means developed and methods for determining DNT as an indicator of the negative human factor manifestation of the navigator in emergency situations on sea transport identified.

Research objectives:

1. To develop a generalized model for the formation of DNT in order to determine the level of its individual distortion.

2. To build mathematical models and automated means for identifying the DNT intervals on the physical trajectory of the vessel.

3. To elaborate a formal system for the shaping of individual time codes and identify the conditions for their operation in critical emergency situations.

4. To carry out experiments evaluating the viability of the proposed means of experimental detection of DNT when navigating a vessel by having the navigation simulator Navi Trainer 5000 involved.

Problem statement

Research methods. To illustrate the ideas let us consider the trajectory of the navigators‘ decision-making by way of a Markov homogeneous chain of the form:

$$\sum_{j=1}^{n} p_{ij} = \sum_{j=1}^{n} p_v \zeta_{ij}^1 + \sum_{j=1}^{n} q_v \zeta_{ij}^0 = p_v + q_v = 1,$$

where p_{ij} — is a probability of transition from state a_i to state a_j; p_v — is a probability of DVN manifestation, at $q_v = 1 - p_v$; n — is a border of possible typical states; ζ_{ij}^0, ζ_{ij}^1 — is an stochastic matrices, where indices 1 — penalty, and 0 — not penalty.

Then in this case the mathematical expectation of the occurrence of DNT on the trajectory will be presented in the form of the following equation:

$$M(A,C) = \sum_{j=1}^{n} Q_j p_{vj},$$

where M — is a mathematical expectation; Q_j — is a final probability of the state a_i; A — is a state automaton; C — is an environ.

Nonetheless, it must be emphasised that the actual observed occurrence of DNT can be treated as being extremely intricate to be uncovered in the form of the matrix of transition states. The reason for not being capable of dealing with it is considered to be randomness of DNT manifestation meeting the eye. Contemporary tendency of explaining it is based on the affairs of having this phenomenon dependable on the number of information factors perceived simultaneously by the navigator. It must be especially taken into account if he occurs to find them self in critical or emergency situations [13].

It must be added that the analysis of decision-making processes by navigators is possible to be described by the mathematical apparatus of fuzzy systems withal. So, the reference to source [14] is providing us with the definition of mutually mini-related quantities $\xi_1,...,\xi_n$ as being introduced as follows:

$$\mu_{\xi_1,...,\xi_n}(x_1,...,x_n) = \varsigma\{\gamma \in \Gamma : \xi_1(\gamma) = x_1,...,\xi_n(\gamma) = x_n\} = \varsigma\{\xi_1^{-1}(x_1) \cap ... \cap \xi_n^{-1}(x_n)\}, \forall (x_1,...,x_n) \in R^n,$$

where $x_1,...,x_n$ — is an observed sample values; ς — is the measure of the possibility; Γ — is set of the system elements; γ — is an atomic element of the system; R — is the modal value of the capability of the magnitude; $\xi_1,...,\xi_n$ — is a fuzzy values.

Simultaneously, for the sake of rationing $\xi_1,...,\xi_n$ a criterion α is welcomed as the level of risk of erroneous distributions of the estimate. In addition, the form of distribution of possible polar values H in terms of the coefficient ambiguity with regard to b' the investigated parameter ρ' (DTN) is described by the following dependencies [14]:

$$b' = \frac{\max\limits_{1\le i\le n} x_i - \min\limits_{1\le i\le n} x_i}{H_+^{-1}(\alpha) - H_-^{-1}(\alpha)}, \ \rho' = \frac{1}{2}\left(\max_{1\le i\le n} x_i - \min_{1\le i\le n} x_i\right) + \frac{b'}{2}\left(H_+^{-1}(\alpha) - H_-^{-1}(\alpha)\right),$$

where b' — is a fuzzy factor; ρ' — is an the investigated parameter DVN; α' — is a standardization criterion of $\xi_1,...,\xi_n$; H — is a distribution of possible polar values.

From these mentioned above descriptions it is vividly seen that the distribution of quantities may generally be having «normal» behaviour pattern in the form of an ellipsoid and within the framework of problem solving $\xi_\alpha^+ - \xi_\alpha^- \to \min; \mu_{\xi_1,...,\xi_n}(x_1,...,x_n,\rho',b') = \alpha$. However, the latter approach happens to be complicated enough to be appealed to in the aforementioned problem since having DNT factor poorly correlated with the concept of normal distribution. It is worth noticing that this issue mostly depends on inhomogeneous spectrum of parameters (Fig. 2).

So, for the aim of getting more accurate determination of the nature of this uncertainty experimental data of navigation devices and sensors during maneuver operations in the Bosphorus is said to have been performed. To meet this desired outcome the certified navigation simulator Navi Trainer 5000 located at the Kherson State Maritime Academy had been made use of.

The peculiarity of the location can have troublesome air due to the fact of maneuvering with multiple controlled targets [15, 16].

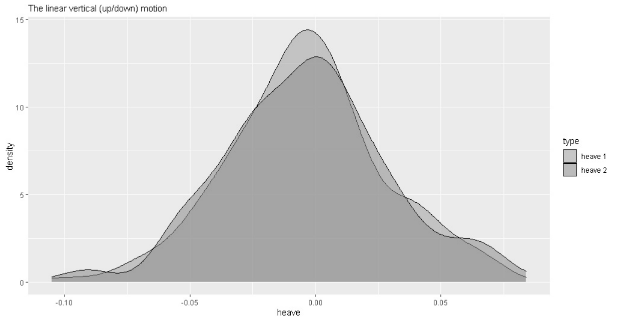

Figure 2. Ratios of natural factors of wind «wind 1,2» and waves «heave 1,2»

With regard to the spoken above circumstances the condition of the location as well as similar natural factors, time of day (season) and location of the port had been welcomed to pay attention to.

Despite observing similar initial conditions and high level of qualifications of navigators the graphic of the longitudinal movement of the **surge** vessel is noticed to be different significantly. Besides, it was uncovered that the navigator get used to choosing a maneuver being untypical for this location (Fig. 3).

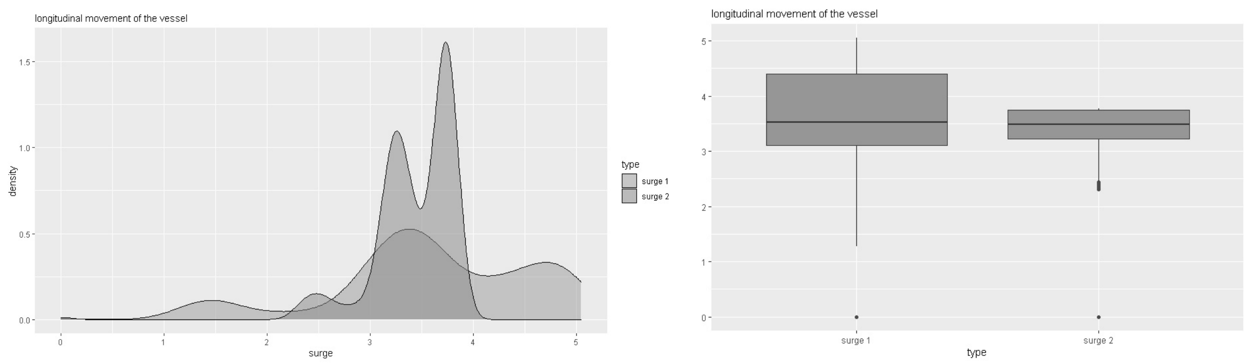

Figure 3. Graphs of density distribution and median of the vessel's longitudinal movement «surge».
Surge 1 with autopilot and Surge 2 with manual captain control

Thus, this situation was successfully dealt with having the accident avoided. Nevertheless, the navigator was highly likely not to consider his actions to be erroneous ones. Therefore, a precedent associated with the expectations of the navigator personality in emergency situations is on the point of resurfacing. It goes without saying that this manner could directly be delivering huge impact on his behavior pattern when navigating the ship [17]. So, the certain complexity of the indicated experiments and a number of having happened typical situations found out during the investigation of accidents at marine transport are leading to a real challenge and necessity in having a detailed analysis and mathematical description of these processes and phenomena.

Material and method

For the sake of getting a visual determination of the individual distortion level of DNT the generalized model is proposed to be introduced being built on the basis of a Cartesian coordinate system. Its axes are about to be factors possible to be divided into three groups with polar coordinates (Fig. 4).

The generalized model of the formation of DNT in three-dimensional space is reported to be represented by the following coordinates: $(x;-x)$ — environment: day/night; $(y;-y)$ — navigation systems and sensors: full/partial watch; $(z;-z)$ — voice commands: native language / foreign.

It is clearly seen that points *A*, *B*, *C* are displayed along each axis at nominal distance in the form of certain informational factors being able to be covered simultaneously by the navigator [18]. Meanwhile, it must be brought up that the maximum of factors with zero DTN, t_{ij} is specified according to navigator's experience: 7 — inexperienced operator (1 time in the current position); 8 — average operator in experience (2–3 times in the current position); 9 — experienced operator (4 or more times in the current position).

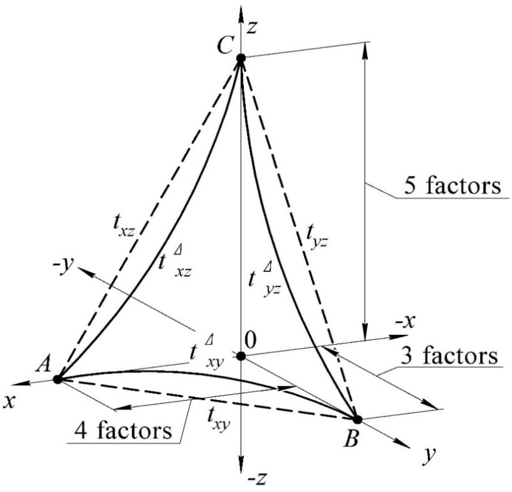

Figure 4. Model with 12 factors determining DTN, t_{ij}^{Δ} — being depicted

The critical sum of the parameters are noticed to simultaneously affect each segment of the ABC triangle and, as a consequence, the level of DNT is being increased. This interpretation of the model of the formation of DNT seems close to the terms of the geometric group theory [19, 20]. Proceeding from similarities metric and space for more specified description of the model for the formation of DNT seems highly likely to be constructed not speaking about further provided research tasks.

Nevertheless, according to the geometric theory of groups the definition of the metric, space and generator system should be stated as being an important step. Thus, the specifics of the subject field as well as the research tasks are making us give objectives that include engaging with determining the conditions of the formal system process.

Appropriately, at each certain moment of watchkeeping the navigator objectively carries out only one set of forming axes of the geometric system: (x, $-x$; y, $-y$; z, $-z$). It is sure to be meant that all possible actions of the navigator are about to be performed within one of the eight quadrants of the Cartesian coordinate system. Therefore, the formal system of navigator actions of the navigator in the form of the Cayley graph seems possible to be represented as following (Fig. 5).

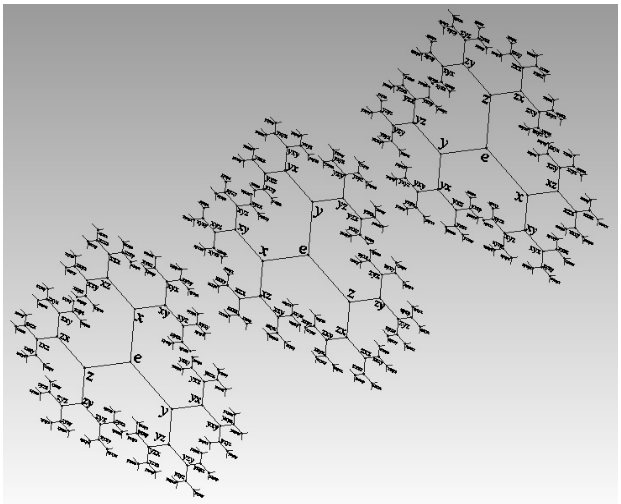

Figure 5. Formations of the Cayley graph

Basing on the evidence of having this graph $Cay\left\langle x, y, z \mid x^2 = y^2 = z^2 = e \right\rangle$, built in the system of generators x, y, z there are substantial grounds for believing in its being a subject to affine transformations on the flat, in particular, relatively to the centre e.

Therefore, the possible rotations (displacements) of the graph are supposed to be multiples of 120º shaping three varieties of the graph G_1, G_2 and G_3 in the way that: $G_2 = f(G_1)$, $G_3 = g(G_2) = g(f(G_1))$. This means that the graphs are obviously congruent with each other $G_1 \cong G_2 \Rightarrow G_2 \cong G_3$.

Imagine a situation when a navigator is involved into performing actions along a pre-planned trajectory of events [21]. Primarily, the navigator miscounts his actions having in mind his own experience. At the same time, on the basis of already acquired skills an individual time frame is formed delivering the possibility to judge if it is the acceptable course of events or unable to be endured one.

Having been obtained in 2 years period data of the navigation tasks and vessel control maneuver carryings out using ECDIS, ARPA and other devices let the database with an accuracy from 1 to 4 seconds track the navigator's actions (Fig. 6).

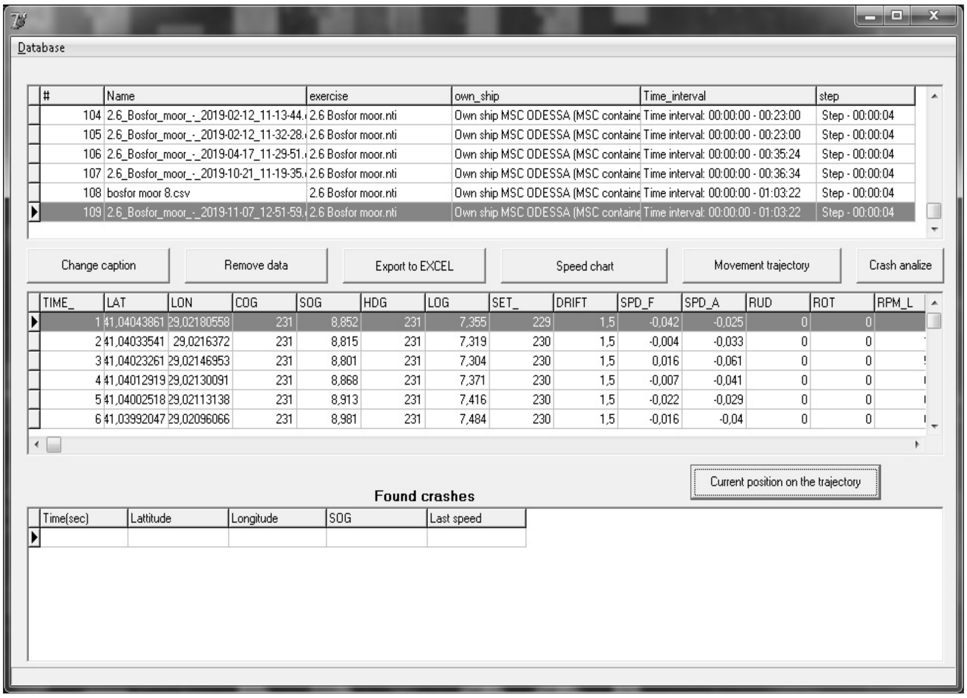

Figure 6. Database of navigation events

The analysis of the data provided the opportunity to determine the temporal environs for a wide class of actions being carried out during a navigational watch with regard to to each navigator. It is said to have been succeeded by means of the Navi Trainer 5000 navigation simulator. In addition, the developed classification scheme enhances having unacceptable increases or decreases in time frames. Further psychological research has revealed that an increase in time frames can be treated as key indicator of the restructuring of strategy. In contrast to aforementioned one, decrease indicates an increase in functional entropy, loss of control over the situation [18].

Thus, the shaping of mathematical models, software and hardware for identifying the DNT intervals on the physical trajectory of the ship's movement within the framework of the proposed approaches has been highly likely to happen.

Suppose a situation when the navigator has already defined the trajectory of actions in the form of yxyzyx. Then each point-node of the trajectory is sure to be involved into work and interaction with a finite number of devices and objects of perception (i.e. RADAR, ARPA, AIS, ECDIS, GPS and whatever).

As previously indicated, the excess amount of perception objects on the captain's bridge would definitely be leading to a loss of control, uncertainty and, as a consequence, would cause to an excess of time for the navigation task carrying out. Thus, let the trajectory in each of its nodes have the possibility of triggering DNT constituting to be a movable structure on flat (Fig. 7).

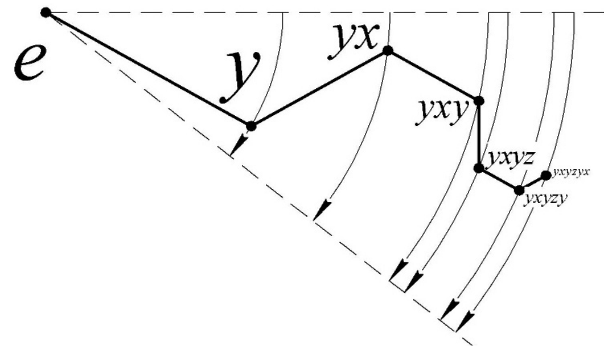

Figure 7. The process of displacement of nod-points

Furthermore, initially the graph is about to correspond to the *xyz* scheme, an offset by an angle $2\pi/3$ would provide the *zxy* scheme, and $4\pi/3$ the *yzx* one. The zero displacement or 2π would be denoted as a_0, respectively $2\pi/3$ as a_1 and $4\pi/3$ as a_2:

$$a_0 \cdot a_0 = a_0,\ a_0 \cdot a_1 = a_1 \cdot a_0 = a_1,$$
$$a_0 \cdot a_2 = a_2 \cdot a_0 = a_2,\ a_1 \cdot a_1 = a_2,$$
$$a_1 \cdot a_2 = a_2 \cdot a_1 = a_0,\ a_2 \cdot a_2 = a_1.$$

For instance, let us example a typical case from the analyzed data, to be exactly shift of a_1 along the trajectory yxyz**y**x with regard to the scheme *xyz*. The transition along the fifth point of the trajectory in the form of: yxyzyx $\to$ zyzxzx turns out to be observed. So, according to having been provided trajectory additional time had been spent by the navigator for the aim of having visual analysis of the environment beyond the time frame. In this case the identification of DNT is said to be obvious: yxy**zz**x.

The proposed model for DNT identification lets you process any possible trajectory of the navigator's behavior within the framework of the selected system of generators of the group *G*.

Besides, an opportunity of getting the auto DNT identification is said to be launched. The only question to be paid attention to is availability of experimental database of tasks performed by navigators in more than three years period. Hence, as a result of the analysis, the individual peculiarity of the navigators' graph shift was said to be successfully noted. Conversely, the probabilistic options of the transition from a trajectory node a_i to the node a_j in typical situations [22] were certain to be detected. It must be emphasised that the navigator's connections having been built on the basis of prior experience are sure to contribute to the probability of such a transition ζ_{ij}^l. One more essential element is the consolidation of the input parameters of the situation taking place with probability of positive outcome highly likely to be practically guaranteed. Thus, the navigator at each nodal point with an input probability $(\zeta_{ij}^l; 1-\zeta_{ij}^l)$ is sure to carry out whatever is necessary for him to be done: do not change the planned trajectory a_1 or perform a shift within the graph a_2 with the corresponding probabilities $Q_1(t)$ and $Q_2(t)$ at time *t*.

Positive consequences tend to be forming a row of the matrix of transition probabilities in the form $\left((1-a)+a\zeta_{ij}^l;\ a\left(1-\zeta_{ij}^l\right)\right)$, negative consequences succeed in having a probability row $\left(a\zeta_{ij}^l;\ 1-a\zeta_{ij}^l\right)$, then in this case (1):

$$\begin{aligned}
&\overline{\zeta_{11}^0(t+1)} = \zeta_{11}^0(t) - Q_1(t)(1-p_1)(1-a)\left[\zeta_{11}^0(t)(p_1+p_2)-p_2\right],\\
&\overline{\zeta_{11}^1(t+1)} = \zeta_{11}^1(t) - Q_1(t)(1-a)p_1\left[\zeta_{11}^1(t)(p_1+p_2)-p_2\right],\\
&\overline{\zeta_{22}^0(t+1)} = \zeta_{22}^0(t) - Q_2(t)(1-p_2)(1-a)\left[\zeta_{22}^0(t)(p_1+p_2)-p_1\right],\\
&\overline{\zeta_{22}^1(t+1)} = \zeta_{22}^1(t) - Q_2(t)p_2(1-a)\left[\zeta_{22}^1(t)(p_1+p_2)-p_1\right],
\end{aligned}
\quad \text{for } A(t+1) = \left\| \begin{matrix} \overline{\zeta_{11}^0(t+1)} & \overline{\zeta_{11}^1(t+1)} \\ \overline{\zeta_{22}^0(t+1)} & \overline{\zeta_{22}^1(t+1)} \end{matrix} \right\|, \quad (1)$$

where p_{ij} — is a transition state probability.

It must be underlined that the matrix of navigator transition probabilities is being normalized and refined with each location being passed through while tasks and maneuvers performing. Furthermore, the experimental data provided in the course «The Ship's Captain and the Pilot» [23] clearly illustrate the idea that navigators beyond the age of 45 have already had a formed matrix of transition probabilities for the most amount of typical situations making entanglement possibly influence to introduce changes in their behavior. For example, one of the significant factors influencing the transitions described above can be brought out by Professor V.A. Kasyanov. [24], «subjective entropy» which represents the mental state of the navigator being in a problem situation. Indirectly, the manifestation of subjective entropy can be judged basing on the analysis of the curves of the speed and course of the vessel (Fig. 8). Its symbolizing the scale of navigator's having confidence in the actions performed.

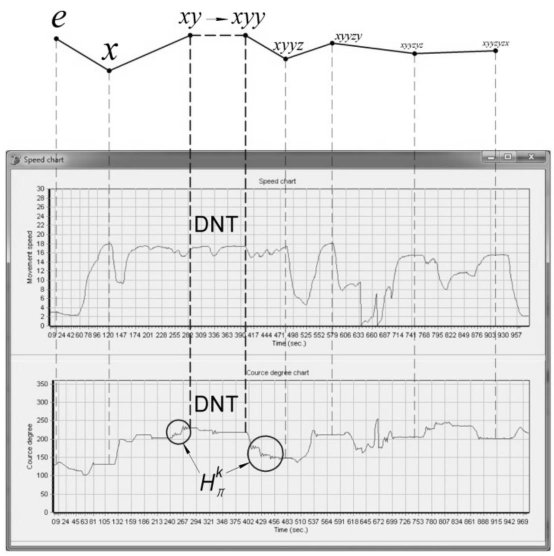

Figure 8. Model for the identification of DNT intervals on the physical trajectory of the vessel movement

Experimental data have highlighted that the navigator is used to control the machine telegraph and the rudder of the vessel confusedly even in straight areas of the Bosphorus. It is noticed to be a clear evidence issued from fluctuations in the curves. Hence, it allows to have the formal perception defined as well as software and hardware for the DNT intervals identification on the physical trajectory of the vessel's movement drawn up.

The research problem being deemed to be the most appropriate for our purposes to be reached is the distribution entropy $\pi(\sigma_i)$ in the Shannon form. Suppose, that at the very beginning of the trajectory the navigator is facing the difficulty of choosing a class from *k* ones for the aim of the problem being solved that is included in the set $S_a|_{\sigma_0}$. There is a finite number of alternatives L_s and, accordingly, the value of the function of their preferences π_{L_s} being in each s-class. So, taking into consideration that $\pi_s = L_s\pi_{L_s}$ the navigator's entropy would be represented in the form:

$$H_\pi^k = -\sum_{s=1}^{k}\pi_s \ln\pi_s + \sum_{s=1}^{k}\pi_s \ln L_s; \left(k \in \overline{1,N}\right). \tag{2}$$

In this case, entropy seems to reach a maximum at: $\pi_s = \frac{1}{k},\ \sum_{i=1}^{N}\pi(\sigma_i) = \sum_{s=1}^{k}\pi_{L_s}L_s = 1 \Rightarrow \sum_{s=1}^{k}\pi_s = 1$.

$$H_\pi^k = \ln k + \ln\sqrt[k]{L_1L_2\cdot\ldots\cdot L_k} \tag{3}$$

Having been delivered formulas successfully demonstrate that experimental connections are sure to occur for only one class of problems causing significant entropy reduction. Thereby this process is involved into defining a model of behavior in the form of the graph displacement. To a certain point, the correlation to be mentioned is less amount of the experiential connections are bigger t_{ij}^{Δ} and more critical the manifestation of DNT is. Having this issue in mind we are sure to emphasise the growing focus on delivering high-quality trainings to navigators in the educational process course being aware and using modern innovative technologies and methods [25].

For the sake of revealing the principles of individual time codes formation as well as of identifying the trigger conditions for their functioning in critical situations the concept of «subjective time» is said to be considered. As a component of the systemopaterna *f*, this concept is noticed to possess a fractal structure being able to be directly represented by information and by the energy spent on achieving the certain goal $\underline{e}_f$ or actions $F = \{f/\mu\}_t$ [26, 27]. This item is completely justified in our study. Furthermore, the analysis of experimental data is helpful enough with illustrating that more than 47 % of navigators get used to having the same sequence of actions/operations when performing typical maneuvers (i.e. mooring, diverging from the vessel and whatever) [28, 29]. Although, despite mentioned above, the time intervals between the stages of actions (nodes of trajectories) as well as the total available energy $E(t)$ are expressed in an individual capacity. For example, the energetic concept of carrying out the trajectory of actions of a fractal graph by a navigator with an aim to achieve the intended target is possible to be represented in the following way (4):

$$\forall t \ \sum_{f\in\{f\}} e_f(t) \le E(t), \ \ \forall f \in \{f\} \int e_f(t)\,\mathrm{d}t \le \underline{e}_f \tag{4}$$

Experienced connections of the navigator and the individual manner of the carryings out of trajectories of actions are able to be managed by the developed system of stimuli $x(t)$ and reactions $r(t)$. The precise information about them can be expressed statistically and, therefore, their probabilistic nature is to be spoken about in the way that (5):

$$\forall t,\ \forall x(t)\in X,\ \Sigma_r p(r/x)\cdot\log\left[p(r/x)/p(r)\right]\to \max,\ \Sigma_r p(r/x)\cdot e(x,r) = \Sigma_{f/\mu\in F} e_{f/\mu}(t) \le E(t) \tag{5}$$

Thus, while having planning and anticipation the navigator is engaged into impact assessment of internal factors as well as external ones defining the trajectory to be an implementation mechanism $\mu(\{d/D\})$ regarding the criteria K in the form: $\forall f/\mu \ \ opt\mu : \{\underline{d}/D\}_f^* = \arg opt_{\{d/D\}} K(\mu(\{d/D\}))$.

Consequently, the Cayley graph for identifying DNT enables to be represented as a set of system patterns (operations) k in the form of points or nodes of the trajectory whereabouts the estimation of the situation J is performed, identification of enough energy e/E for the implementation purposes of the plan is discharged and the formation of the image (sketch) $Gs\ \alpha$ of the situation is fulfilled. Therewith, the evaluation of the set of associations a/A and situational identifiers c/C for having events achieved can be expressed in the way b/B (6):

$$k = \left\{ f/\mu\{J_c\ c/C\} : \{J_a\ a/A\},\ J_e\ e/E \to \{J_b\ b/B\},\ \mu\in\{\mu\}_f \right\} \cup P_k,\ \{Gs(f/\mu)\} \subset k . \tag{6}$$

Thus, at each point of the graph trajectory a situation seems to appear α and its conditions revaluation $U(\{\underline{c}/C\})$ is turning out to be done having dependable position of subjective entropy of the navigator on satisfaction issues $\alpha\triangledown$. In this case anticipation $\phi^{t/\Lambda}$ is possible to be presented in the form (7):

$$\phi^{t/\Lambda}\left(\{a/A\} | U(\{\underline{c}/C\})\right) = \cup_{\alpha\in\Omega}\left\{ f/\mu : \underline{t}/\Lambda, \{\langle J_\tau \underline{\tau}/T,\ J_t \underline{t}'/\Lambda\rangle\} \xrightarrow[\alpha,\,k]{} \{J_a \underline{a}/A\}_\alpha \,|\, \alpha\triangledown U(\{\underline{c}/C\}) \right\}. \tag{7}$$

The precedents mentioned above are involved into the shaping of the manifestation of DNT by the critical impulse building Imp_{kr} being a result of revealing inconsistencies between the set of associations $\{J_a\, a/A\}$ of an event α and energy consumption $\underline{e}/E$ due to hard boosting process of information factors which could be represented in the form: $\{Imp_{kr} : \{J_a\, a/A\},\ \underline{e}/E \to \{b/B\}\}_t,\ \Sigma_{\{Imp\}} \underline{e}/E > E$.

Thereby, the having been introduced of this formal system is catering for setting the mechanism for the formation of individual time codes goals and for establishment of trigger conditions for their operation in critical situations.

Experiments

Within the framework of the provided research an experiment managed to be carried out for the sake of evaluating effectiveness of the proposed means of experimental diagnostics of the DNT when navigating a vessel. It was successfully performed using the navigation simulator Navi Trainer 5000.

In order to ensure assessment of the influence of the human factor in the form of DNT an analysis of the trajectories of the vessel was conducted at the Bosphorus location. Taking mooring operation as a typical one 11 different watches and one type of the vessel to be used the experiment was performed. Besides, while having each experiment samples of readings are reported to have been obtained from the devices.

First of all, let us consider the influence of the autopilot (autopilot) mode on the following samples being built on numerous vessel readings: rpm_port (main rotor speed), distance (distance travelled by the vessel from the very beginning of the training according to the LAS data), surge (longitudinal movement of the vessel, sway (lateral movement of the vessel), pitch (up / down rotation of the vessel around its transverse axis), yaw (change in course in degrees), roll (roll, inclined rotation of the vessel along its longitudinal axis), heave (linear vertical up / down movement). Let's construct diagrams of averages for all parameters bearing in mind the autopilot factor (Fig. 9, 10).

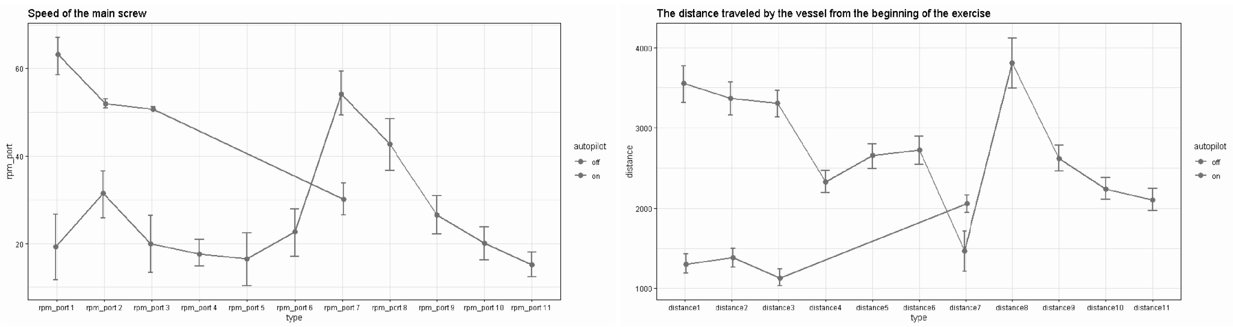

Figure 9. Diagram of confidence intervals for the rpm_port, distance parameter

Figure 10. Diagram of confidence intervals for the parameter pitch, yaw

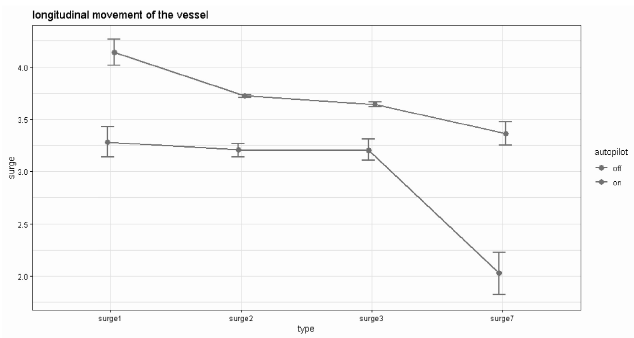

Figure 11. Plot of confidence intervals for the surge parameter for samples 1, 2, 3, 7

As it clearly seen from Figures 9–11 factor "autopilot" is considered to be important only for the first, second and seventh samples. So, for these issues we want separate diagrams to be built. Analysis of other parameters (i.e. surge, sway, roll, heave) are unable to make a difference as well. Necessary to check for homogeneity of variances using "Levene's test for homogeneity of variance across groups", also necessary to omit the check for normality as the sample sizes are noticed to be large enough. Lt's analyze on the surge parameter.

To analyze the experimental data, Levene's Test for Homo-geneity of Variance (center = median) was applied using RStudio.

Since F value = 47.758, $p < 0.05$, we are most likely to reject the null hypothesis of equality of variances. Consequently, in this case, the hypothesis of equality for ANOVA at $p < 0.01$.is to be denied.

Let's build a two-factor model with the interaction of factors based on ANOVA. Before coming to conclusions let's calculate the average table for this model and the summary results.

Since F value = 18.73, $p < 0.01$ the impact of collaboration between the factors is turning out to be statistically significant. Let's have Tukey's 'Honest Significant Difference' method carried out for delivering evidences which pairs are statistically significant difference.

Basing on the results of R-Project program's carrying out a statistically significant difference was noticed to have been found out between 1 and 7, 2 and 7, as well as 3 and 7 samples with the autopilot off. Besides, it occured likewise between 1 and 2, 1 and 3, 1 and 7, 2 and 7 samples when autopilot was on. Hence, this issue is certain to be observed wherever in Figure 11 and in the table of averages. It must be made out that for the seventh sample averages for the «off» mode of the «autopilot» factor differ noteworthy from averages of all other samples as well as for the first sample averages for the «on» mode of the «autopilot» factor vary from all other samples). Thus, in experiment No. 7, DNT happened to be fixed twice. In addition, the automation process of the shaping of the trajectory of the vessel's route is shown in Figure 12.

Figure 12. Trajectory of movement of the vessel with the identification of DVN

Therefore, the effectiveness assessment of the proposed experimental diagnostics of DNT succeeded in having been delivered providing experimental confirmation when navigating a vessel. The Navi Trainer 5000 navigation simulator contributed into validation process. The developed automated tools enabled to identify at the initial steps the manifestation of DNT as well as to enhance the efficiency of cadets' trainings of the specialty "Sea and river transport. Navigation" while conducting such academic disciplines as: "Navigational Information Systems", "Ship Management" and whatever.

Result and Discussion

The proposed formal and algorithmic approaches as well as the developed automated tools for the sake of getting analysis of experimental data for DNT identification are sure to encourage and help along to bring the goal of reducing detrimental impact of the human factor in ship management field being persistent cause for concern in the contemporary world. Besides, in the course of the study a formal model of shaping and, as a consequence, DNT identification in the form of a model within the framework of the geometric theory of groups are reported to have been dealt with. This issue has turned out to open the door to visual representation of the phenomenon essence and to highlight the affecting factors of distortion level of the subjective time of the navigator. Being highly appreciated to be used in order to avoid this factor manifestation a formal-algorithmic system is reported to have been developed allowing to identify the intervals of the trajectory of the navigator's actions in the form of a fractal structure. The spoken above item concerned the possible ways of description the full set of options for the development of a critical situation in a formal form under the conditions of the entropy approach. Further establishment of the study is reported to be aimed at describing the principle of individual time codes shaping when performing tasks while maintaining a navigational watch.

Furthermore, the carried out experiments when performing the high complexity task — mooring operation in the Bosphorus Strait — enable to identify the fact of DNT manifestation by means of developed automated tools. As a result of the experiment, the effectiveness assessment of the proposed equipment of experimental diagnostics of DNT during ship control management using the navigation simulator Navi Trainer 5000 was contentedly performed. Beyond any doubt, the proposed approaches also are supposed to have been contributing to having process of navigators' training and retraining at much higher quality level during the course training and laboratory-practical course of disciplines "Navigation information systems" and "Ship management".

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П.С. Носов, В.В. Чернявский, С.М. Зинченко,
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Модельдік тәжірибеде навигатор уақытының бұрмалануын анықтау

Мақалада кемені басқару кезінде қиын жағдайларда теңіз көлігі навигаторларының уақытты қабылдауына формалды талдау жасалған. Эксперименттік деректердің талдауы және теңіз апаттарының зерттеуі көрсеткендей, көптеген жағдайларда навигаторлар күрделі маневр жасау кезінде, мысалы кемені арқандауда, сыртқы және ішкі факторлардың әсерінен типтік операцияларды орындау уақытын дұрыс қабылдамайды, бұл апариялардың ықтималдығын едәуір арттырады. Зерттеудің негізгі мақсаты сыни жағдайларда теріс адам факторының көрінісі көрсеткіші ретінде навигатор уақытының бұрмалануын (НУБ) анықтаудың ресми және автоматтандырылған құралдары мен әдістерін әзірлеу. Осы мақсатты орындау үшін НУБ қалыптастырудың жалпыланған моделі ұсынылды, кеменің физикалық траекториясын талдау кезінде НУБ-ның аралықтарын анықтауға арналған математикалық модельдер мен автоматтандырылған құралдар, сондай-ақ қиын жағдайларда жеке уақыт кодтарын қалыптастыру жүйесі жасалды. Navi Trainer 5000 сертификатталған навигациялық тренажерын қолдану арқылы эксперименттер жүргізілген, ұсынылған тәсілдердің тиімділігі мен практикалық құндылығын растады, бұл кемені басқару кезінде навигациялық вахтаны атқару қауіпсіздігін едәуір дәрежеде арттыруға мүмкіндік береді.

Кілт сөздер: эксперименттік деректер, навигатор уақытының бұрмалануы, эргатикалық және автоматтандырылған жүйелер.

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Идентификация дисторсии времени навигатора в модельном эксперименте

В статье проведен формальный анализ восприятия времени навигаторами морского транспорта в критических ситуациях при управлении судном. Анализ экспериментальных данных и расследования морских катастроф показал, что в широком ряде случаев навигаторы во время выполнения сложных маневров, на примере швартовки судна, неадекватно воспринимают время выполнения типовых операций в условиях влияния внешних и внутренних факторов, что значительно повышает вероятность возникновения аварий. В качестве основной цели исследования выступает разработка формальных и автоматизированных средств и методов определения дисторсии времени навигатора (ДВН) как показателя проявления негативного человеческого фактора в критических ситуациях. Для выполнения поставленной цели была предложена обобщенная модель формирования ДВН, разработаны математические модели и автоматизированные средства для идентификации интервалов ДВН при анализе физической траектории движения судна, а также система формирования индивидуальных временных кодов в критических ситуациях. Проведенные эксперименты с использованием сертифицированного навигационного тренажера Navi Trainer 5000 подтвердили результативность и практическую ценность предложенных подходов, что в значительной мере позволит повысить безопасность несения навигационной вахты при управлении судном.

Ключевые слова: экспериментальные данные, дисторсия времени навигатора, эргатические и автоматизированные системы.

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