Formal Approaches to Identify Cadet Fatigue Factors by Means of Marine Navigation Simulators

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Abstract. Contemporary marine education tends to have been using navigation simulators enabling cadets to be trained for any unlikely event. These issues are sure to be in the sector with high demand focusing on safety. Thus, they would be extremely beneficial for marine industry. The proposed study aims to identify seafarer fatigue during the maneuver carrying out according to circumstantial evidence and, as a result, the influence of this phenomenon on the trajectory formation of transition or maneuver experiences. In addition to it, the method of cadet posture identification is generally revealed. To summarize all this information exo – back spine and an automated system are proposed to be used. The study provides the mechanism formation of spatial trajectory taking into account the identification of fatigue indicators. This issue will, eventually, benefit into reducing risks of accidents. Besides, a formal description of perception and decision-making processes being performed by the cadet by means of modal logic and algebra of events are introduced in the preceding article. It is a basis for determining the stages and individual preferences in the formation of the trajectory transition (maneuver). To make ground, the experiment within the framework of analyses of the mooring operation carrying out is sure to be named an effective one. This article proposes comprehensive approaches and provides the possibility to classify models for the formation of the trajectory of the cadet in conditions of fatigue crack factors.

Keywords: human factor, fatigue factor, support decision making, trajectory cadet behavior

1 Introduction

It goes without saying that fatigue indicator (both among cadets and professional navigators [1-4]) are named to be one of the most significant causes of negative human factor influence in maritime transport. Contemporary studies have been trying to contribute to finding the appropriate way out focusing mainly on the control of robot modes while having a navigational watchkeeping practice [5-6]. However, there are no inquiries embracing direct fatigue indicators of cadets while watchkeeping carrying out in real time mode. Meanwhile, a number of psychological and medical investigations implemented in this field has turned out to be reflecting the heterogeneity of the fatigue manifestation during a certain period of time [7-8]. These issues are highly likely to be contributing to the significant augmentation of the uncertainty degree in scientific search.

This following article would like to introduce an alternative method of cadet fatigue identification during the complex navigation tasks performing on the captain's bridge. They would be mostly based on circumstantial pieces of evidence [9-11]. In the course of the experimental analysis of the behavior of the cadets – navigators, reported to have been carried out for four years, several issues had been drawn attention to, such as the posture when working with navigation devices, the reaction rate when performing primary actions etc. Furthermore, the sensors applying (i.e. accelerometers in the form of exo – back spine) have triggered in significant facilitation of cadet posture identification in space in real time mode [12]. The particular details must be added to the fact regarding the accomplished automated analysis of micro-reactions which enormously simplified the implementation of an individual approach to result interpretation.

2 Materials and method

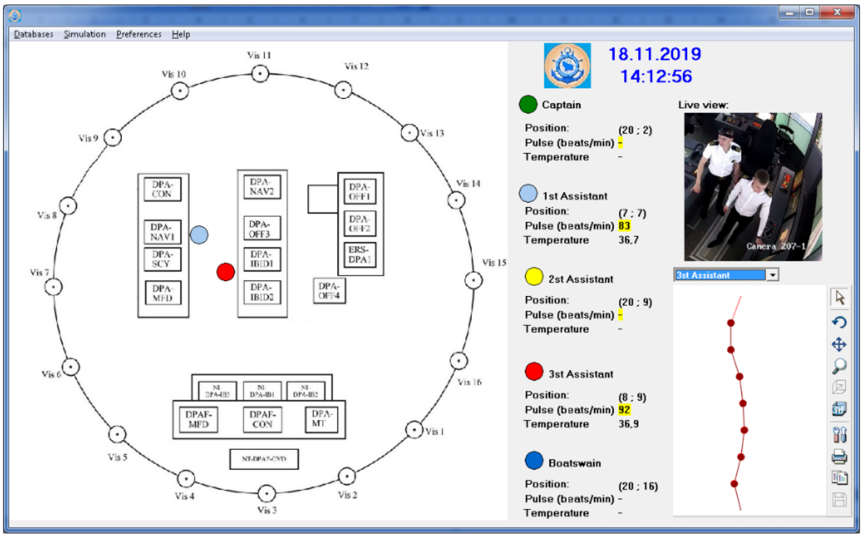
In this context, the exo – back spine is said to be a dynamic system being defined in accordance to a number of parameters. Data parameters can be represented as system limiters. Considering this approach to exist within the framework of formal research [13], the most significant components of the system can be named as: l the angle of distortion between adjacent shoulders relative to the exo – vertebra cadet during the maneuver; m is the complexity of the maneuver; H is the fatigue coefficient at a given time *i*.

Then this set of components, $\xi = \{l_i, m_i, H_i\} \in \Xi \subseteq E_N, i = 1, \ldots, n$ could possibly occur in the presence of a circumstantial factor model of the $\omega = q^0 \in Q | q = (q_1, \ldots, q_n) \in Q_n$ representing the initial position of the exo – back spine of a cadet in space [14]. However, unlike artificial spine systems the dynamic one of a cadet is noticed to be unable to correspond to a formal gradient model such that: $g(\omega) = (q^0, 0) \in E_{2n}$, $\Phi^0(\xi, z) = C\|z\|^2$ phase system vector, $z = (q, \dot{q}) \in Q_n \times \dot{Q}_n$, $z = Z \subseteq E_{2n}$ and penalty constant *C*.

It can vividly be observed that within each definite time span system parameters may vary nonlinearly in accordance to having physiological characteristics of the cadet. He is being influenced by a number of external and internal factors. So, to be precise, the position of the cadet is engaged in providing a great possibility for an automated system to detect and to deliver the information about what type of a navigation device is being operated with.

Therefore, when a number of similar situations happens to be, it is reasonable to state that one or another posture deviation has a high likelihood of being looked at as normal but only for a short period of time. It is mostly due to the dashboard which is being located underneath.

At the same time, there are other factors sure to be noticed directly influencing on psycho-emotional state of the cadet (i.e. pulse and temperature of body combined with the speed of performing manipulations with joysticks, buttons and touch panels ECDIS, ARPA, GPS and others) [15] (Fig. 1).



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Captain
Position: (20 ; 2)
Pulse (beats/min) -
Temperature -

1st Assistant
Position: (7 ; 7)
Pulse (beats/min) 83
Temperature 36,7

2st Assistant
Position: (20 ; 9)
Pulse (beats/min) -
Temperature -

3st Assistant
Position: (8 ; 9)
Pulse (beats/min) 92
Temperature 36,9

Boatswain
Position: (20 ; 16)
Pulse (beats/min) -
Temperature -

Fig. 1. Identification interface psycho-emotional state of the cadet

Furthermore, according to [16, 17] a plan constituting a number of stages of the impact of $u = \{u \in E_n | |u_i| \le u_i^{'}, i = 1, \ldots, n\}$ on ship specific control objects $u(t) \in V$ let the cadet be aware of every action afterwards. So, defining the set of the valid running impact made by the cadet in the form of $X \times Y, x \in X$such that $Y(x) \subseteq Y \subset E_m$ the model of $q(x) = \max\limits_{y \in Y(x)} f^0(x, y) \to \min\limits_{x \in X}$is possible to be taken as being the true one, where y represents the vertical axis of the exoskeleton, and x does the horizontal one (Fig. 1).

Suppose, that a cadet is performing a maneuver and trying to make a use of navigation devices and controls. It goes without saying that he defines for himself the trajectory and sequence of transitions due to his having had experience and acquired behavior patterns in similar situations. So, it is worth emphasizing that this is the predominant way of action plan shaping recognized as being the most productive and valuable one in a particular situation [18].

By all means, there are several other approaches allowing transition paths to be identified and individual sequence of actions to be checked [19]. Notwithstanding, there is another challenge to make a stand against that is noticed to be a problem of comparison and classification of such trajectories. As well as this item the performance measurement at the early stages of the maneuver is to be spoken about.

The following article presumes that a solution has been reached through the idea of taking the main factor allowing to identify trajectories causing risk as a time indicator of interaction with navigation devices or controls. It must be noticed that attention switching from one to the next in the chain trajectory objects is highly likely to take no more than 1 second. It depends mostly on the complexity of the maneuver and qualifications of a navigator.

Conducted experiments of TRANSAS NAVIGATIONAL SIMULATOR NTPRO 5000 of Kherson State Marine Academy (Ukraine) provided substantial opportunity to come up to the conclusion that skippers' behavior patterns turned out to have been inherited and transformed rarely into new forms. These issues depend mostly on location and weather conditions. It must be noticed that only experienced sailors were involved into the spoken above experiment. So, therewith, at the same time, the fatigue factor must be taken into consideration as being the main and significant contributor of any changes in cadet behavior. It is due to the fact that it is completely different from other factors from the point of view of applied strength and degree of influence upon the final result.

A proper formal description of events and trajectories of transitions between ship management facilities and navigation data sources is proposed to apply the logical-event algebra of events. It happens to have approaches which can properly describe the behavior of the cadet under severe conditions [20].

Let's consider this approach applying basing on this experimental data by means of analyzing log files from the server of the English channel simulator location. So, the transition trajectory can be characterized by 9 stages, each of which is precisely determined either by fixing awareness time or by time spent on controlling manipulations (i.e. steering, machine telegraph, thrusters, navigation signals, etc.).

It must be reported that the number of trajectories of carrying out of the typical maneuver actions performed with an aim to determine the cadet behavior model is to be approximately a minimum from 5 to 9. To meet the spoken above requirements 11 trajectories were taken to be analyzed. In addition, we are to underline that one and the same navigator was chosen to be experimented upon with an issue to perform a typical maneuver action in various locations.

Maneuver from mooring operation was paid attention. To a certain degree, the figure provides the opportunity to watch the time ranges of work with objects of the trajectory having 2-3 levels of deceleration. This fact is said to be the index of having nonrandom contributing factor affecting the transitional indicator of the maneuver performance.

Besides, the convenience of having this trajectory visualization in the form of a graph should be additionally italicized and, so, let's describe the exact peculiarities of its construction. Graph variables represent an integral index of being ready for the stage maneuver s_i implementation depending on the identified fatigue. This data is based on indications of exoskeleton curvature and individual threshold perception of navigational danger:

α is the reaction of a quick transition to the next element of the trajectory;

β is an indicator of fatigue during posture curvature;

γ is an indicator of fatigue when the reaction is getting to slow down.

The transitions between the stages of the trajectory s_i can be one directional in the case of α reaction and the reverse ones in case of having β or / and γ.

Having experimented permitted to identify several types of situations to speak about as the cadet returning to the element of trajectory. It is mostly due to having lacked of perceived information or due to the changes in management strategies. We are sure to underline the idea of demonstrating of the mentioned above behavior pattern as being typical or distinctive one in the conditions of implicit action plan formation for a certain period of time [21].

The aim of the study is stated to introduce the automated identification process scheme of such types of phenomena that will provide the ability to determine the human factor influence with the help of implicit indicators. For the implementation of more detailed analysis we wanted to find out and offer the levels of stage characterizing the cadet interaction with navigation devices and objects of location. These levels will be varied according to complexity starting from the least difficult l_1 to the most time-consuming ones l_4: l_1 which is visual perception of the situation; l_2 is analysis of current data of navigation devices; l_3 is performing maneuvers (steering, machine telegraph, thrusters, navigation signals, etc.), l_4 is discrepancy with goals, mooring, computation of complex maneuvers (Fig. 2).

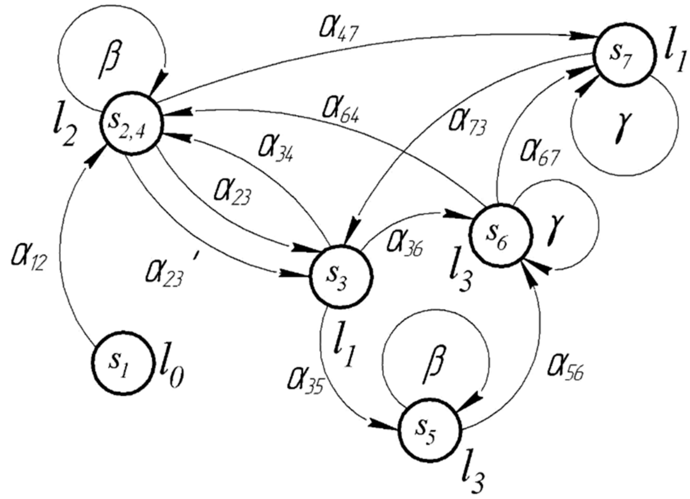


Fig. 2. Difficulties in defining variables in a classical graph

The metric for representing a graph on the flat is limited by discrete axis l_i and continuous axis t_i which determines the time Δt gaps between the steps of the trajectory s_i (Fig. 3). Let's have a quick look at what kind of issues can be described by the direct transition matrix.

$$S_{ij} = \begin{array}{ccccccc} \emptyset & \alpha_{12} & \emptyset & \emptyset & \emptyset & \emptyset & \emptyset \\ \emptyset & \beta & \alpha_{23} & \emptyset & \emptyset & \emptyset & \emptyset \\ \emptyset & \emptyset & \emptyset & \alpha_{34} & \alpha_{45} & \alpha_{36} & \emptyset \\ \emptyset & \emptyset & \alpha_{23}' & \emptyset & \emptyset & \emptyset & \alpha_{47} \\ \emptyset & \emptyset & \emptyset & \emptyset & \beta \vee \gamma & \alpha_{56} & \emptyset \\ \emptyset & \emptyset & \emptyset & \alpha_{64} & \emptyset & \gamma & \alpha_{67} \\ \emptyset & \emptyset & \alpha_{73} & \emptyset & \emptyset & \emptyset & \gamma \end{array}$$

Constructing transitions in the trajectory due to the introduction of β and γ as well as mandatory circumstantial indexes are unable to succeed in this problem solving. A similar problem highly likely to be found out is that the system of equations of the form does not reflect the trajectory in the whole way:

$$\begin{aligned} X_1 &= X_1 S_{11} \vee X_2 S_{21} \vee \ldots \vee X_n S_{n1} \vee R_1, \\ X_2 &= X_1 S_{12} \vee X_2 S_{22} \vee \ldots \vee X_n S_{n2} \vee R_2, \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ X_n &= X_1 S_{1n} \vee X_2 S_{2n} \vee \ldots \vee X_n S_{nn} \vee R_n. \end{aligned}$$

where X is an event with reference to the trajectory element, S is a i-th component.

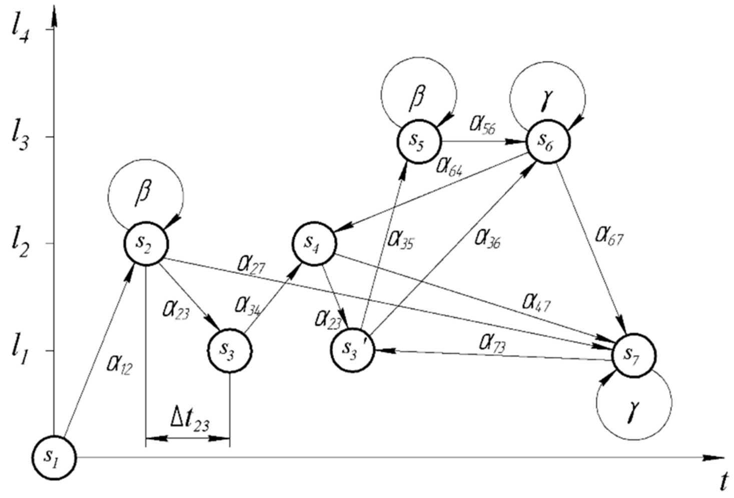
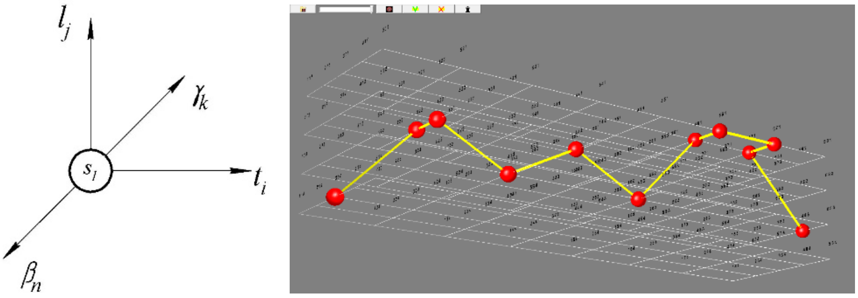


Fig. 3. A detailed graph on a flat in time approximation trajectories of elements in the state space

Thus, based on the spoken above information the study considers the use of the classical graph to be completely impractical due to the idea of being each element of the trajectory no longer the same one as it was being at the moment $t_{i\text{-}1}$. These issues are partially conditioned according to the fact that the cadet fatigue state and spent forces are to have been changing. Therefore, it is recommended to apply the interpretation of the proposed time-spent graph depicted in this figure. The new approach can be treated like worth taking particularly in the situations where the study is being involved in having temporary intervals for transition. This item is clearly evident in provided information from the article.

Moreover, ordinary interpretation is impossible to be used for indicating the determinant of time if the path element happens to be reversed.

In addition, one more situation to be taken into consideration is when there are one or two variables of priority and time range expressed implicitly. In this case accordingly it is convenient to use the third axis allowing to determine exactly all time intervals regarding active trajectory elements. So, then graphical interpretation will be described by the following geometric system (Fig. 4).



a b

Fig. 4. Three-axis geometric system for constructing a graph

As for a three-axis geometric system for constructing a graph, it could be problematic enough to be described by a graph on a flat not using designed visualization software. To deal with the point, software and tools for visualizing trajectories were created. They met the requirements of matching the implementation of such features as temporary indicators and indicators of fatigue (Fig. 4 a, b).

3 Results

To sum up, trying to find the way out, the automated geometric approximation of the trajectory is primarily proposed. This fact certainly grant you the possibility to control the transition speed between its elements in the form of thickness and time in the form of the diameter of the knot.

Besides, while the experiment was being performed there were several cases associated with increased exacerbation of navigation environment. They are rooting out of the negative influence of relevant factors. As a result, frequent returns to previous trajectory elements were noticed to be done confirming the information about cadet having lost of confidence in his own. Moreover, when the navigation situation is percepted in a much more confident way by a cadet and when he is perceiving the information with a high degree of reliability he comprehends the information peculiarities ψ parameters in node x have $B(x, \varphi)$.

Then at time t_x+1 the formation of connections between different items node x, will be developed basing on the following principles [22-27]:

$$\begin{aligned}
&L_S(x,\varphi) \land \circ\, B(x,\neg\varphi) \Rightarrow B(x,\varphi),\\
&L_S(x,\varphi) \land \neg \circ B(x,\neg\varphi) \Rightarrow B(x,\varphi),\\
&\neg L_S(x,\varphi) \land \neg \circ \big(B(x,\neg\varphi) \Rightarrow B(x,\varphi)\big) \Rightarrow B(x,\neg\varphi),\\
&L_S(x,\varphi) \land \circ\, B(x,\neg\varphi) \Rightarrow \neg B(x,\varphi).
\end{aligned}$$

Herewith, $K(x,\varphi)$ indicates that the cadet is aware of φ information on node x, i.e. $\circ\, B(x,\neg\varphi) \equiv \bot$, defining a number of knowledge formation rules.

Thus, to be more precise, the final goal of X is believed to be carrying out of a sequence of action – items of trajectory by cadet, while there are a number of conditions Ψ defining $\Box X$ and conditions Φ, defining $\Diamond X$. Besides, the passing's of the planned route could possibly be expressed with the intent of $\Box G(X,\Phi,\Psi)$:

$$\begin{gathered}
\Box G(X,\Phi,\Psi) \equiv B(X,\neg\Phi) \land G(X,\Diamond\Psi) \land\\
\land K(X,[(B(X,\Phi) \lor B(X,\neg\Box\Phi) \lor B(X,\neg\Psi))]).
\end{gathered}$$

So, in this case, the definite issue possible to be treated to as a successful one is to be said as being without repeated actions towards the elements of trajectory passing's:

$$\begin{gathered}
\Box G(X,\Phi,\Psi)' \equiv B(X,\neg\Phi) \land G(X,\Diamond\Psi) \land\\
\land K(X,[(B(X,\Phi) \lor B(X,\neg\Box\Phi) \lor B(X,\neg\Psi))\mathcal{U}\big(G(X,\Diamond\Psi)\big)]).
\end{gathered}$$

Besides, it is worth speaking that in some situations to cope with a long trajectory it would be beneficial to divide it into homogeneous fragments. They are being characterized by high activity of taken decisions, each of which will be separated by the time interval $t_{(\Delta+m)}$, where m is the number of segments of the global trajectory. At the same time let's take that the primary fragments of the trajectory are supposed to have been overcome successfully. Consequently, the views of the cadet can be identified and described by the conditions in future $\circ\, G(x,\varphi)$:

$$\circ\, G(x,\varphi) \Leftrightarrow I(x,\varphi) \land K([Do(x,\alpha)],\varphi) \land \Box Do(x,e),$$

as well as by a specific fragment of trajectories:

$$G(x,\varphi)_{t_{(\Delta+m)}} \Leftrightarrow I(x,\varphi), G(x,\varphi \land \psi) \Rightarrow G(x,\varphi) \land G(x,\psi).$$

All these items contribute to increasing the level of information perception in the cases when fragments of the trajectory are characterized by the same set of actions of the cadet in the form of beliefs:

$$B\big(x,\Box(\varphi \land \psi)\big)_{t_{(\Delta+m)}} \land I(x,\varphi) \land I(x,\psi) \Rightarrow I(x,\varphi \land \psi)_{t_{(\Delta+(m+1))}}.$$

Then the created action plan at the time of $t_{(\Delta+m)}$, that is being expressed in the information model of behavior, $P(x,)$, where information about the performance of elements $I(x,\varphi)$ trajectory is presented as:

$$I(x,\varphi) \equiv \Box G\left(x, \exists e\left[B\left(x, \exists e'(\text{happ.}(x,e';\varphi))\right) \wedge G(x, \neg\text{happ.}(x,e,\varphi))\right]; e; \varphi\right).$$

Cadet perception forms a preference vector *P* under such conditions:
$\xi \in \{B(\varphi), I(\varphi), G(\varphi), \alpha\}, \varphi \in \mathscr{L}, \alpha \in \Theta_A$, so, that:

$$\begin{aligned}
&P(x, I(\varphi), I(\psi)) \Rightarrow I(x,\varphi) \wedge I(x,\psi),\\
&P(x, G(\varphi), G(\psi)) \Rightarrow G(x,\varphi) \wedge G(x,\psi),\\
&P(x, G(\varphi), G(\psi)) \Rightarrow P(x, I(\varphi), I(\psi)) \wedge G(x,\varphi) \wedge G(x,\psi),\\
&P(x, G(\varphi), I(\psi)) \Rightarrow P(x, I(\varphi), I(\psi)) \wedge G(x,\varphi),\\
&I(x,\varphi) \wedge \neg\exists\psi | P(x, I(\psi), I(\varphi)) \Rightarrow G(x,\varphi),\\
&I(x,\varphi) \wedge \neg\exists\psi | P(x, I(\psi), I(\varphi)) \Rightarrow I(x,\varphi) \Rightarrow G(x,\varphi),\\
&\neg\exists\psi\left[\left(P(x, I(\psi), I(\varphi)) \wedge B(x, \Box\varphi)\right) \Rightarrow I(x,\varphi)\right] \Leftrightarrow G(x,\varphi).
\end{aligned}$$

Meanwhile, in a way, it is obvious that its properties are determined by the following dependencies:

$$\begin{aligned}
&P(x,\varphi,\psi) \Leftrightarrow P(x, (\varphi \wedge \neg\psi), (\neg\varphi, \psi)), P(x,\varphi,\psi) \wedge P(x,\varphi,\psi)' \Leftrightarrow P(x,\varphi,\psi)''\\
&P(x,\varphi,\psi) \wedge P(x,\varphi,\psi)' \Leftrightarrow P(x, \varphi \vee \varphi), P(x,\varphi,\psi) \wedge P(x,\varphi,\psi)' \Leftrightarrow P(x,\varphi,\psi \vee \varphi).
\end{aligned}$$

Along with it, it should be taken into consideration that factors influencing on the carrying out of the fragment of the trajectory affects the execution of the element in the future – α_i, where α_1 is believed to be the most efficient item from the cadet's point of view then:

$$\begin{aligned}
&P(x,\alpha,\alpha_1) \equiv G(x, [Do(x,\alpha)]) \wedge B(x, [\![\alpha_1 \succ \alpha]\!]) \wedge B(x, [\![\alpha_2 \succ \alpha]\!]) \wedge \ldots\\
&\ldots \wedge B(x, [\![\alpha_n \succ \alpha]\!]) \wedge B(x, \alpha_1 \neq \alpha_2 \neq \ldots \neq \alpha_n) \Rightarrow G(x, [Do(x,\alpha)]) \wedge \ldots\\
&\ldots \wedge \left(\neg G(x, [Do(x,\alpha_2)]) \wedge \ldots \wedge \left(\neg G(x, [Do(x,\alpha_n)])\right)\right).
\end{aligned}$$

In this regard, initial information φ supposes the performance of ψ knowing *K* defines: $P(x,\alpha,\varphi) \equiv G(x, [Do(x,\alpha)]) \wedge K([Do(x,\alpha)], \varphi)$, such that:

$$G(x, \varphi\mathcal{U}\psi) \equiv P(x, G(\psi), I(\varphi)) \wedge \neg\exists\varphi\left[P(x, G(\psi), G(\varphi)) \wedge P(x, G(\varphi), I(\varphi))\right],$$

where $\mathcal{U}$ shapes the development of the trajectory in the future.

In this case, φ as a prerequisite for the subsequent performance of a fragment of the trajectory is definitely determined by dependencies such type that:

$$G(x, \varphi S \top) \equiv \neg\exists\psi P(x, G(\psi), I(\varphi)),$$

$$G(x, \varphi S(\psi \wedge \varphi)) \equiv G(x, \varphi\mathcal{U}\psi) \wedge G(x, \psi S\varphi),$$

$$G(x,\varphi) \equiv I(x,\varphi) \wedge \forall\psi\left[P(x, \varphi S\psi) \Rightarrow B(x, \Box(\varphi \wedge \psi))\right].$$

This experience is leading to the functioning entrenched system of beliefs in the effective carrying out of the fragment of the trajectory [28]. It goes without saying that when the most challenging emergency situations arise the roles and strategies on the captain’s bridge can be greatly changed. They are causing the significant effect on the formation of the trajectory and become effort-consuming *I*:

$$G(x,\varphi)\wedge\neg Af\left(G(x,\varphi)\right)\Rightarrow\circ\ G(x,\varphi),$$

$$G(x,\varphi)\wedge\neg Af\left(G(x,\varphi)\right)\Rightarrow\neg\Psi(\psi)\left[P\left(x,I(\psi),I(\varphi)\right)\wedge Af\left(\Psi(\varphi)\right)\right]\Rightarrow\circ\ G(x,\varphi)$$

$$G(x,\varphi)\wedge\neg Af\left(G(x,\varphi)\right)\wedge$$

$$\wedge\forall\psi\left[P\left(x,I(\psi),I(\varphi)\right)\Rightarrow\neg Af\left(I(x,\psi)\right)\wedge B\left(x,\Box(\varphi\wedge\psi)\right)\right]\Rightarrow\circ\ G(x,\varphi)$$

Where $\Psi(\varphi), \varphi\subset\Psi$ is the formation of individual levels of cadet possible perception and his reaction to navigation circumstantial conditions [29].

4 Experiment

Taking into account the peculiarities of performing mooring operations, the most preferable to be used approach is said to be the SS one. The deterministic process of it is envisaged to take place.

Then, the mooring of the vessel s can be described by the following $(w, t|w\in W, t\in T)$, where $w=\langle\Theta_A^w, \Theta_O^w, \Theta_F^w, R_O^w\rangle$. Therewithal, variations of the mooring trajectory of the operations are able to be described by a variety of $S_w=\{(w,t)|t\in T\}$.

General number set of mooring situations are defined as $S=\cup_{w\in W} S_w$, where $s=\quad, s\in S$ and time can be reported by a sequence of actions in the path of trajectory $(t_0,\dots,t_k)$, $\forall u\in\{0,\dots,k-1\}$, $(t_u|u\in N)$, $(t_u,t_{u+1})\in R_w$ is considered to be a typical one in the initial stages. Nevertheless, an action plan is being formed at the time of t_{u+1}. As a rule, the initial plan of the development of the trajectory of actions has been formed. However, all possible factors forming its Δ_p are not taken into consideration.

To be precise, exactly these factors will make major contribution towards the supposition of the development of trajectories. We are to mention that it is the information-plan of its carrying out $\beta_1, \beta_2, \dots, \beta_n$ that is formed initially being fragmented as $\Delta_{\beta(t_u)}$. Situation identification $\delta\subseteq S\times S$ depends greatly on restrictions such as $\left((w,t),(w',t')\right)\in\delta$ and supposes $(s,s')\in\delta$ as a part of class-forming set Δ_δ.

So, hereby, the result of the variable formation of the trajectory can be described as being very different (Fig. 5 a and b).

In the Figure 5 the changes of strategies of maneuver carrying out $\beta_1\vee\beta_2$ are vividly reflected. They are being dependable on the limitations of $w', t'\in\delta$ when cadet is involved in choosing the direction and speed of the ship to prevent ship collision.

Let's describe the cadet action plan β aiming to keep the ship in the place while performing mooring operations and pulling it towards the pier using engines. It is given by the predicate $\circledast\ (\beta, p, u, v)$, where p is the way to the complete mooring operation and $[u,v]\in T$ is time intervals allotted for the maneuver carrying out. The time span is to be taken as no more than one hour as the overheating of the thruster is highly likely to happen [30-33]. Then the trajectory of the mooring task # will be described by the following dependencies:

$$\# \left(\alpha, p, u, v\right) \Leftrightarrow \left(v = u + 1\right) \wedge \left(Af\left(p\left(u\right), p\left(u+1\right) = \alpha\right)\right),\ \alpha \in \Theta_A;$$

$$\# \left(\beta;\beta', p, u, v\right) \Leftrightarrow \left(\exists n \in \left[u, \ldots, v\right]\right) \wedge \left(\# \left(\beta, p, u, v\right)\right) \wedge \left(\# \left(\beta', p, u, v\right)\right);$$

$$\# \left(\beta \mid \beta', p, u, v\right) \Leftrightarrow \left(\# \left(\beta, p, u, v\right)\right) \wedge \left(\# \left(\beta', p, u, v\right)\right);$$

$$\# \left(\beta \parallel \beta', p, u, v\right) \Leftrightarrow \left(\# \left(\beta, p, u, v\right)\right) \wedge \left(\# \left(\beta', p, u, v\right)\right);$$

$$\# \left(\beta^*, p, u, v\right) \Leftrightarrow \left(\left[u = v\right]\right) \vee \left(\# \left(\beta;\left(\beta^*\right) p, u, v\right)\right);$$

$$\# \left(s', p, u, v\right) \Leftrightarrow \left(s \in \left(w, p\left(u\right)\right)\right).$$

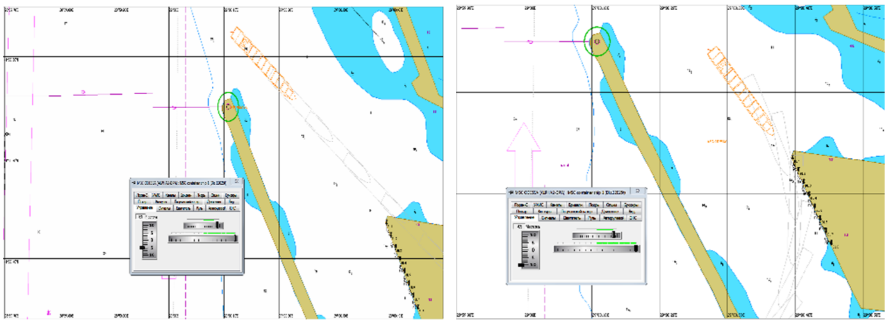

a b

Fig. 5. The variable formation of the trajectory

Thus, the experimental study of the mooring operation provides a sufficiently high possibility to identify the effectiveness of the action plan $\#(\beta, p, u, v)$ (Fig. 6-9):

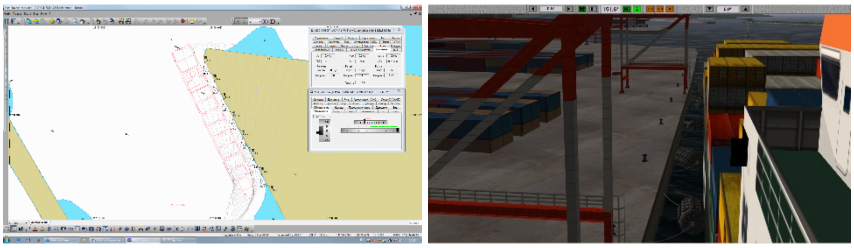


Fig. 6. Time: 07.33.30. When speed is getting to be decreased (reverse small stroke) fixed pitch right rotation rotor lets you shift the stern towards the berth. Having the bow thruster as an assistant bow is replacing to the pier

During the semester an experiment was conducted having 74 cadets involved in participating and performing the typical operation of vessel mooring and demonstrating various degrees of fatigue. The experiment confirmed the research hypothesis as being evident. This issue can easily be proved by the following scheme observation (Fig. 10).

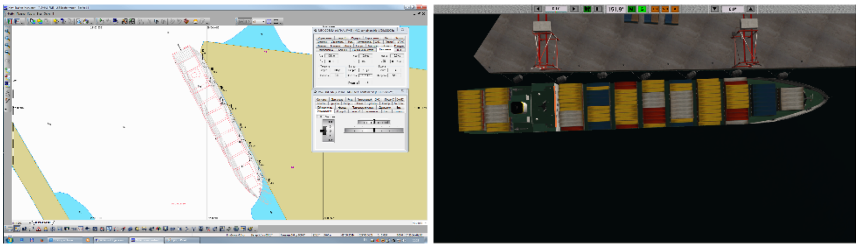


Fig. 7. Time: 07.36.30. The vessel is practically motionless and is located near the berth protection fender

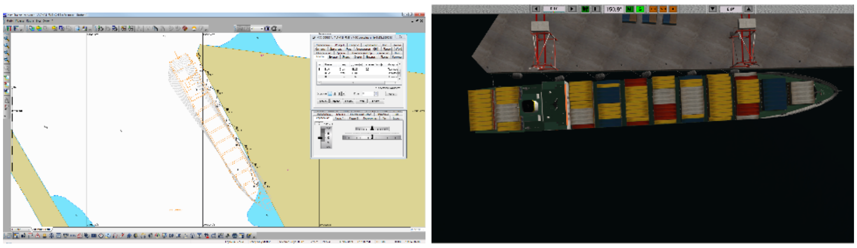


Fig. 8. Time: 07.38.50. Give the head and stern mooring lines

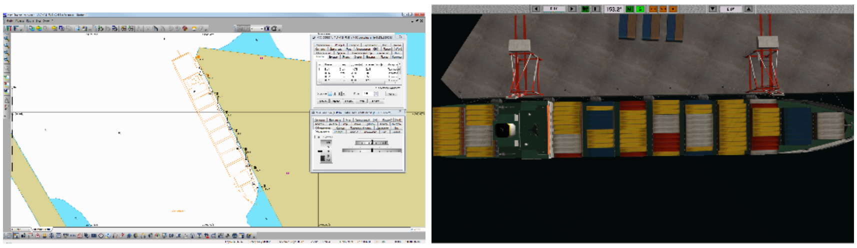


Fig. 9. Time: 07.46.00. Tighten up the head and stern mooring lines, make all fast

5 Conclusion

The experiments are noticed to demonstrate clear evidences of hypothesis confirmation of the formation of class-forming structures in the form of trajectories of transitions being under fatigue factor influence and circumstantial implicit evidences. They can be such as posture abnormalities, speed of movements, and physiological indicators of the cadet. It must be emphasized that proposed logical formal approaches enabled the stages of formation of action trajectories to be differentiated in the form of a plan as well as provided a beneficial possibility to describe an impact of individual behavioral strategies on the final result.

Thus, objective scientific results were obtained:

1. The co-dependency between the navigator's fatigue indices and the spatial position of its spine as a dynamic system determined by a number of parameters was

investigated, and, as a consequence, software identification of navigator posture deviations was proposed to be used.

2. The approaches for shaping the navigator’s trajectory of behavior by means of a 3D structured space during the maneuvering of the vessel were proposed. This fact delivered the possibility to take into account his fatigue factor.

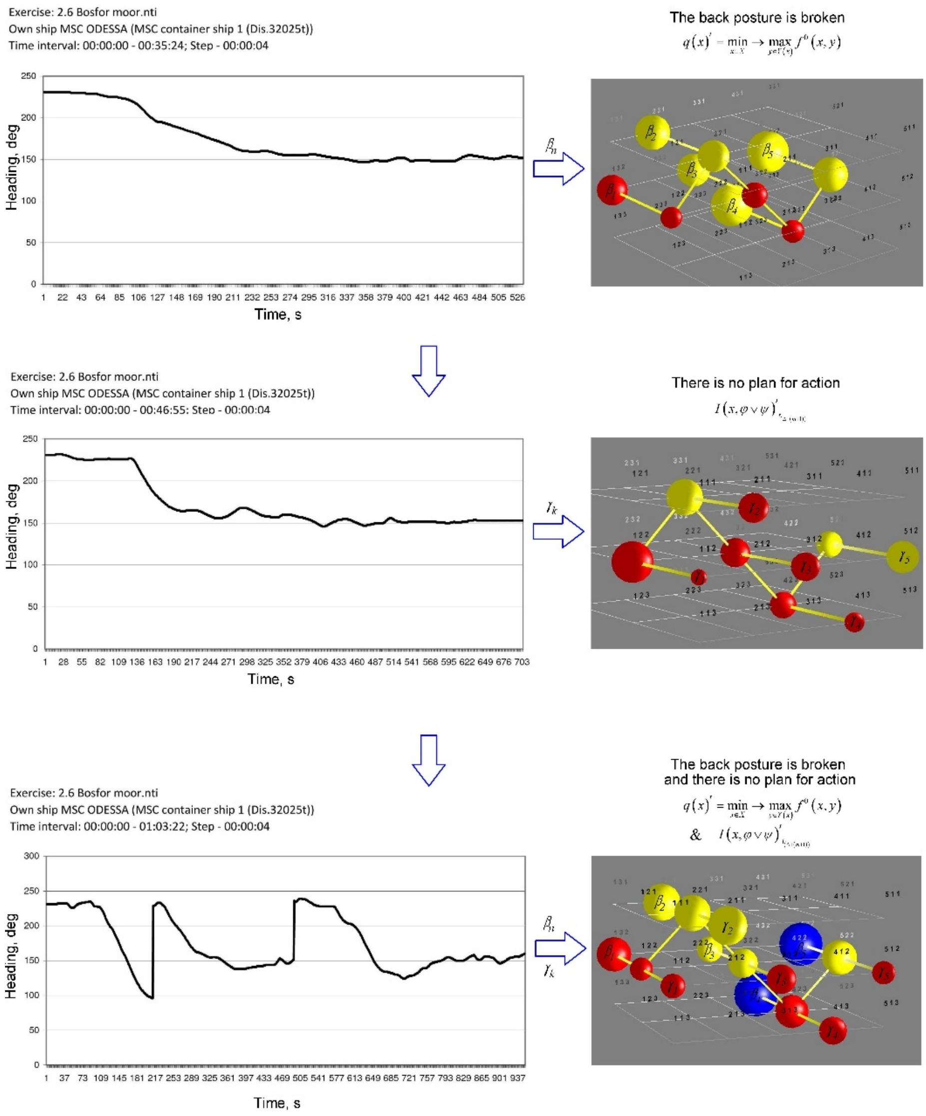


Fig. 10. Experimental confirmation of the hypothesis

3. The final obtained trajectories of the navigator’s behavior at the time of critical situations were analyzed. There was obviously a need of using modal logic,

arranging the possibility to distinguish the classes of temporal fragments of the trajectories. Besides, the factors affecting the performance of individual elements of the trajectory appeared to be determined. This fact allowed us to identify the behavior strategies of navigators on the captain's bridge. All this data is sure to provide the opportunity to describe the effect of individual navigator behavior strategies on the final result.

The obtained results give valuable grounds for quality retraining of navigators in cases of negative manifestations of behavior patterns and strategy shaping of action plans in the form of a spatial transition or maneuver.

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