UDC 656.61.052

INFLUENCE HUMAN FACTOR ON SAFETY'S PLANNING ROUTE OF WATER TRANSPORT

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The study is aimed at conducting a formal analysis of algorithms for captains to apply when planning routes in difficult navigation situations. Formal and algorithmic analysis based on decision trees made it possible to improve ergatic navigation safety systems and to predict potential risks of maritime accidents in a timely manner.

The article discusses approaches enabling algorithmisization of processes of navigational situations perception by captains. A formal description of the most essential elements of captains' human factor affecting the route planning processes is provided. Also, the issues related to perception of difficult navigation situations by captains are considered, dependences on volume and multithreading of input information are given.

In order to confirm actual influence of captains' human factor elements on safe route planning, a number of experiments have been carried out using the Navi Trainer 5000 navigation simulator and subsequent modeling by means of Data Mining. As a result of modeling, standard designs for planning water transport routes have been obtained together with the confirmation of constructed models adequacy exemplified by the factor Fs 3 - «weather conditions». The proposed approaches will further expand the capabilities of predictive possible maritime accidents models due to human factor.

Keywords: *water transport, human factor, planning a safe route, ergatic systems.*

DOI: 10.33815/2313-4763.2021.1.24.057–070

Introduction. When carrying out route planning, the captain of vessel is guided by a wide rules range, directions and factors that allow building a safe trajectory for vessel's movement. Route *Z*, simultaneuosuly, as a decision-making task, is based on $x \in X$ captain's initial information about the situation, in form of which the initial stage is formed $z \in Z$ [1].

Captain's experience plays a significant role, for example, when captain's entropy is low, action plan is precisely defined z / Z, which entails detailing – $B_t(x)$ and leads to plan $X_t^{\wedge}$, otherwise the captain relies on experience of similar tasks *Z*, generalizing – $C_t(x)$ for $x \in X_t$, what $X_t \to X_{t+1}$ forms $C_t : X_t \to 2X_t$ and $B_t : X_t \to 2X_t$.

Extension of actions by generality $C_t(x)$ forms $\{Ind\}Z$ relatively domains D_j affecting focus: $D_1\ \{Ind\}\, D_1 \to D_2\ \{Ind\}\, D_2 \to \ldots \to D_n\ \{Ind\}\, D_n$.

Detailing and generalization determine: $\forall x \in X_t\ C_t(x) \cap B_t(x) = x$, within the framework of the task *Z*, in this case: $x' \in C_t(x) \Leftrightarrow x \in B_t(x')$ where *x′* is a planning feature. In this case, the activity of the captain is important: $\forall x \in X_t\ e(x) \to e(C_t(x))$.

Captains act consciously, which means planning will be determined by a predicate $P(x,z)$ such that: $\forall x \in X \; \exists z \in Z \; P(x,z)$. Decisions made will be: $\forall x \in X \; z \in A(x) \; P(x,z)$ and $\forall x \in X \; z \notin A(x) \neg P(x,z)$, where $A : X \to 2Z$. In a critical situation, captain must accurately plan the next stage *H*, in relation to criterion Ω_t, $H_t = \{x \mid x \in X_t, \; B_t(x) \equiv x\}$.

Captain's intuitive actions are also possible, when: $\exists x, \; x' \in H_t$ what $C_t(x) \cap C_t(x') = \varnothing$, $U_t = \varnothing$ and $\forall x \in X_t^{\wedge} \exists! zx \, P(x, zx)$, then a situation arises: $\forall x' \in C_t(x) \cap X_t^{\wedge} \; P(x', zx)$.

In order to ensure proper planning, it is necessary to determine trajectory of vessel $\{x_n\} \, x \equiv \{x = x_0 < x_1 < \ldots < x_n\} \subset X_t^{\wedge}$ without critical situation: $X_t^* = \{x^* \mid x^* \in X_t \; \exists! z \in Z \; P(x^*, z)\}$. Proceeding from this, it becomes necessary to determine model for captain's decision making [2], taking into account the planning phases that ensure safe navigation.

The purpose of the article is to formally analyze the algorithms for planning safe routes by captain in difficult navigation situations. Formal and algorithmic analysis based on decision trees will improve ergatic navigation safety systems and predict probable risks of accidents in advance.

Main research material. In order to formally describe planning process, we will define the time «codes» of captains $\forall x \in X_t^* \; \exists! z \in Z \; P(x,z)$. Three time phases of planning are considered, $X_t^{\wedge} = \bigcup z \in Z \left(X_t^{\wedge}\right) z$; $X_t^* = \bigcup z \in Z \left(X_t^*\right) z$; $\forall z \in Z \left(X_t^{\wedge}\right) z \to e\left(X_t^*\right) z$, taking into account the conditions and risks of sailing: $V = (x \to zx)$. This is specific to each captain, so any additional information $x \in X_t^{\wedge}$ may affect the planning strategy.

When planning, a priori information is formed: $\Omega_t = \{\alpha = \langle x\alpha, z\alpha \rangle \mid x\alpha \in H_t\}_t$ which does not imply changes in strategy. When factors arise $\left(X_t^*\right)\alpha$, preliminary route plan is changed by set rebuilding of rules-actions: $\{S^*\}\alpha = \{x^* \to z\alpha \mid x^* \in \left(X_t^*\right)\alpha\}$.

In many situations, captain does not intuitively change original itinerary plan unless it endangers safety of vessel. To change strategy W_t, *Z*, a precedent X_{t+1}^* must arise that changes safety of navigation:

$$\Omega_t = \{V\}0 \to W_t, Z(\{V\}0) \to W_t, Z \circ n(\{V\}0) \to W_t, Z \circ n(\{V\}0) = \{S^*\}_t, \text{ Full}, \{V\}_t, \text{ Full} = \bigcup k =$$
$$= 0,1,2,\ldots,n \;\; W_t, \; Z \circ k(\{V\}0), \; EZ \geq 0, \text{ it happens } \mathrm{H}_t \to W_t, \; Z(H_t) \to W_t, \; Z \circ n(H_t) = X_t^*, \; EZ \geq 0,$$

where *EZ* is captain's energy and motivation.

In turn, an element of uncertainty can lead to formulation of the following formal problems class [3–6]:

$$\frac{ds}{dt} = f(s(t), s(t-\tau_1), \ldots, s(t-\tau_s), d(t)) \tag{1}$$

where $s(t) = (s_1(t), \ldots, s_n(t)), d(t) = (d_1(t), \ldots, d_m(t)), \tau_i > 0, i = \overline{1,z}$ is boatmaster's reaction to occurrence of uncertain factors in *z*, where $d = d(t)$ and replanning [7].

Then system (1) can be strategically changed:

$$s(t_0)=s_0,\ s(t)=\varphi(t), t\in\left[t_0-\max_{1\le i\le z}\ \tau_i, t_0\right] \qquad (2)$$

where t_0 is the moment of strategy change.

Considering planning process, we may define class of functions [8, 9] that affect range of *D*, which can be subject to additional restrictions related to the specifics of the route. These restrictions may encompass location, maneuverability of vessel and its characteristics, weather conditions, environmental conditions, etc. [10]. Then, in general case, condition is considered:

$$d(t)\in D\subset Y^m \qquad (3)$$

where D is a set in Y^m. Considering that the main goal of planning is formalized within framework of (1), it is necessary to fulfill a number of conditions:

$$\eta_{q-i+1}(d)\ge\eta,\ i=\overline{1,y},\ \ y\le q \qquad (4)$$

Here are $\eta_{q-i+1}=\eta_{q-i+1}(d), i=\overline{1,y}$ the lengths of the scheduling time intervals:

$$c(s(t))\le 0,\ \ t\in\left[t_1^i-\eta_i, t_1^i\right],\ i=\overline{1,q} \qquad (5)$$

where $t_0^i=t_1^i-\eta_i, t_1^i$ are the boundary points of stages $[t_0,T]$ at which inequality is satisfied $c(s(t))\le 0$. The size $\eta>0$ and number of stages $y\ge 1$ for which the planning conditions must be met (4). The interval at which inequality (5) is fulfilled is interpreted as a stage of disaster risk reduction on route sections [11-14], relative to condition $m(t)\le\overline{m},\ t\in\left[t_1^i-\eta_i,\ t_1^i\right],\ i=\overline{1,q}$, where m*(t)* is an indicator of the cartographic situation complexity.

It is important to take into account that with a cyclical repetition of the critical situation signs, the loss of control over vessel is possible [15]. The *q*, y values depend on maneuverability of vessel and its parameters. Inequalities affecting the state of navigation safety system at the moment t_1^q degree characterize the situation complexity:

$$J_i(d)=g_i\left(s\left(t_1^q\right)\right)\le 0,\ \ i=\overline{y+1,\ y+\eta} \qquad (6)$$

The time to reach safe state for transition to manual control $t_1(d)=t_1^q-t_0$ determines the complexity of navigation situation: $J_j(d)\le 0, i=\overline{1,y+\eta}$.

Considering the complex navigation situation as represented by a plan with directions in the form of making managerial decisions, we will compare the position of vessel with the waypoints of route [16]. At the same time, floating targets and hazardous isobaths build the interaction field, considered in the vessel model interaction with hazardous objects.

In the case of standard Mercator cartographic projection [17], the state of frame-vessel changes depending on interaction. Interaction frame is transformed according to vector of vessel's movement relative to the cartographic location [18].

In difficult situations, planning the movement of a vessel in space can be conditionally expressed in one direction for four directions (fig. 1). It is possible that the vessel is not capable of moving in the preferred direction. This occurs when there are insurmountable cartographic obstacles on its way, constraint by vessel's draft. In these cases, the boatmaster tries to change the direction of a vessel, by choosing the way where there are minimum obstacles.

Marine transport navigators scan the situation using radar and ECDIS at a distance location *r* and choose direction of movement. They then observe the least amount of maritime transport, favorable weather conditions and nonavailability of cartographic obstacles [19].

Taking into account that considered decision-making processes have a complex formalization, we can present their description in terms of the group theory mathematical system. In this case, the elements of the system will be: an alphabet or a set of objects; many words or combinations of objects, a finite set of relationships; theorems or rules of inference. As already noted, in view of the need to present the results of mathematical modeling, the theory of geometric groups is close to the description of the above principles. This theory is presented as an independent one, originating from group theory and determining the balance of the formal system [20], which is very important for streamlining the structural principles of captain's decision-making model formation.

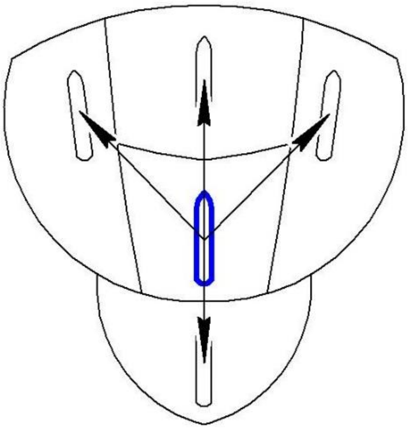


Figure 1 – Frame for moving the vessel

1. Closedness of the group. For any two elements of the group, there is a third one, which is their product, such that (7):

$$\forall a,b \in g:\ \exists c \in g,\quad a \circ b = g \tag{7}$$

The axiom describes the integrity, complexity and hierarchy of constructing a vessel's trajectory, consisting of vessel control operations.

2. Group associativity for product operations. The order of operations is insignificant (8):

$$\forall a,b,c \in g:\quad a \circ (b \circ c) = (a \circ b) \circ c = a \circ b \circ c \tag{8}$$

Axiom defines the cycle of homogeneous elements, which is aimed at achieving the ultimate goal of navigation.

3. The existence of a single element. In group there is some element e, the product of which with any element *a* of the group gives the same element *a* (9):

$$\exists e \in g:\quad \forall a \in g,\quad a \circ e = e \circ a = a \tag{9}$$

The axiom assumes the influence on all structural elements that have all the features of system, and comes from initial stage of route planning in form of an initial operation that determines the vessel trajectory. That is, initial strategy chosen by captain predetermines its effectiveness.

4. Existence of inverse element. For any element *a* of the group, there is an element a^{-1} such that their product gives the unit element *e*, such that (10):

$$\forall a \in g:\ \exists a^{-1} \in g:\ a \circ a^{-1} = a^{-1} \circ a = e \tag{10}$$

Axiom presupposes the repetition of vessel control operations, i.e., their reverse functions, which provides for a return to beginning of the first stage of the decision-making model.

In this context, it becomes possible to present route planning by captain in terms of geometric group theory.

In this case, we will call alphabet the finite set of planned route stages:
$A=\begin{Bmatrix} a, & b, & c \\ a^{-1}, & b^{-1}, & c^{-1} \end{Bmatrix}$, где a^{-1}, b^{-1}, c^{-1} – reverse alphabet according to clause 4.

The group will be represented as $\langle A \mid R \rangle$, in which R is relationship between sets of operations leading to a single route element: $\langle a,b,c \mid a^2=b=c^4=e \rangle$ [21].

The set of elements a^x will have its own focus when planning a route, b^y and c^z therefore – alternatives. Aggregates of these sets can be represented as fragments of routes, for example a^4b^6, but operating with combinations based on captain experience. By means of this formal description, two variants of groups are formed: commutative and free. Formed words represent independent decision-making trajectories that can be formed from basic elements of captain's experience. A visual display of decision-making trajectories is possible in the form of a tree that includes all actions characteristic of a given captain, thus unifying the properties of the formal system considered above [22].

Thus, it becomes possible to form an attribute space for planning and decision-making by captain in situations close to context. Connecting points in a given space makes it possible to obtain a graph, while it should be assumed that formation of graph edges is possible if next element is obtained from previous one by multiplying by one group set letters. This is logical from the position that each new element takes into account the informational component of previous one. For example, g_1 and g_2 are connected by an edge if in the alphabet $\exists a \in A;\ g_1 = g_2 \cdot a \Leftrightarrow g_1 \cdot a$. Thus, it becomes necessary to construct a metric space within the framework of identification the route planning models by the captain, for subsequent predictive analysis of probable critical situations.

However, it should be taken into account that formation of such a graph may be limited in terms of elements number due to increasing complexity of navigation situations perception. For example, when planning a complex route, consisting of a chain elements in form of waypoints, there is a danger of increasing information overload. This feature can be expressed in terms of *p*-adic systems.

Therefore, an increase in *p*-adicity leads to an increase in detail, and a decrease leads to generalization. Based on [1], we can conclude that the route planning process is considered within the set of internal vertices of graph $\mathbf{U}(\tau)$, between the threshold values $\{a\}$ and $\{b\}$. This makes it possible to move to nearest systems of *p*-adicity in ascending and descending directions, depending on situation, $\mathbf{U}(\tau)=\left[\cap_{j=1,\dots,n} Gv^{\uparrow}(\tau|a_j)\right]$.

Each route planning strategy depends on final set of situation parameters that determine the navigation conditions and possible risks:

$$Gv^{\downarrow}(\tau|b)=Gv^{\uparrow}(\tau|a)\Rightarrow\langle\underline{\tau},P\rangle_W \text{ at } Gv^{\uparrow}(\tau|a_i)\cap Gv^{\uparrow}(\tau|b_i)=\varnothing.$$

Then the transition to alternative route planning strategies is possible under conditions of the interaction balanced system between external factors and navigation experience:

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

The observed balance of transition between situations in p - adic structures can depend on both: the level of complexity of navigation situation (necessity) and the operator (possibility) skill level:

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

Based on these formal descriptions, a route planning algorithm is proposed, which is based on the navigation perception situation in the framework of *p*-adic systems. Let's define the metric of situation: $\rho_p(x,y)=|x-y|_p, x\rightarrow|x|_p$ [23]. At the same time, it is appropriate to assume that *p*-adicity is a criterion for perception of navigation situation that allows planning a route. The main planning factor is risk of navigation hazard, which increases the risk of critical situation occurrence. Considering the complexity of the situation, captain requires to have an appropriate level of experience, each of which can be expressed in spaces $(X,\rho)\&(Y,\rho')$. Route planning for ($p = 2$) is most consistent with simple tasks requiring switching on or off according to a given operator attribute. In turn, at ($p = 3$), a factor is added according to principle: $\rho'\left(j\left(x_{1_{p=2}}\right), j\left|x_{2_{p=2}}\right|\right)=\rho\left(x_{1_{p=3}}, x_{2_{p=3}}\right)$ and transfers planning to a higher level. Thus, the problems solved in the situation space *Y* cannot be solved in situation space *X* due to changed metric (fig. 2 a, b).

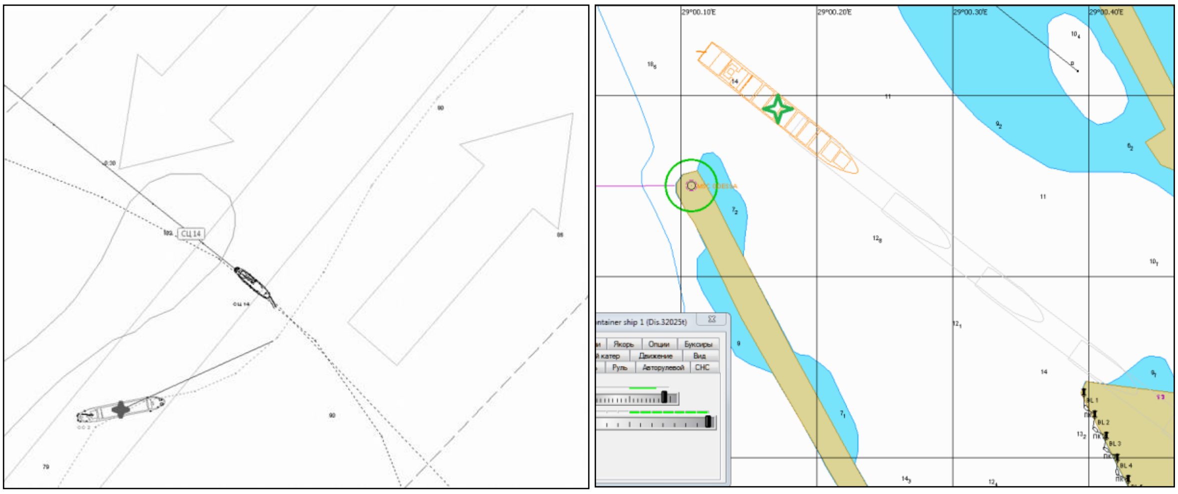

a *b*

Figure 2 – Spaces of perception of the navigation situation *Y* and *X* with different *p*-adicity metrics

Fig. 1 shows that route planning in the navigation situations *Y* and *X* was influenced by different sets of information signals. This means that captains evaluated the navigation situations in a different *p*-adicity system, forming spaces *X* and *Y*, such that: $X \subseteq Y \mid X \setminus Y = \varnothing$.

However, it should be borne in mind that in some cases, captains deliberately resort to a «weak» planning strategy, which leads to an increase in the likelihood to critical situations with maritime transport. It is possible to describe this process formally using the approaches of subjective entropy H_π [24]:

$$H_\pi=-\sum_{i=1}^{N}\pi(\sigma_i)\cdot\ln\pi(\sigma_i),\ \text{where}\ \pi^{-}(\sigma_i)\ \text{– is weak planning strategy.}$$

Inheritance of familiar route planning approaches increases the effect of uncertainty in decision making, $\pi^{-}(\sigma_i)=\left(e^{-\beta L(\sigma_i)}\Big/\sum_{j=1}^{N}e^{-\beta L(\sigma_j)}\right)$.

Experiment. Analyzing maritime accidents, one can come to the conclusion that one of the main reasons is neglect of significant navigation risks [25]. Among the significant navigation risks, the following should be noted [26]:

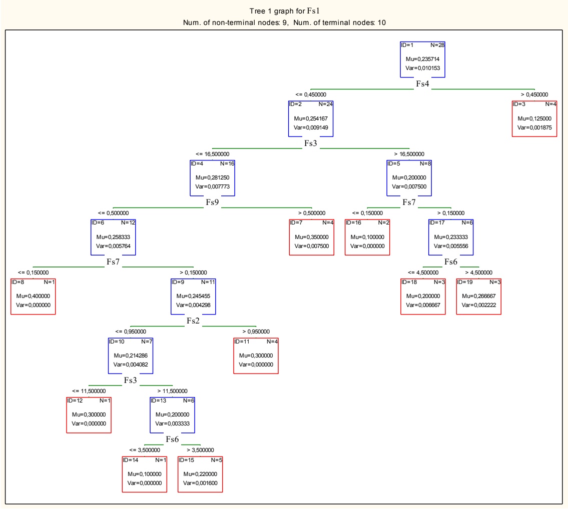
Fs 1 – vessel maneuverability;
Fs 2 – technogenic factors;
Fs 3 – weather conditions;
Fs 4 – team fatigue;
Fs 5 – the presence of a stressful situation;
Fs 6 – perception of the situation;
Fs 7 – special sailing areas;

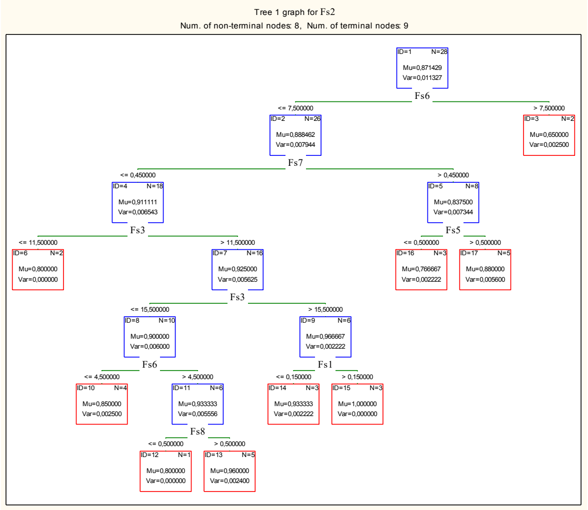
Fs 8 – quality of collaboration;

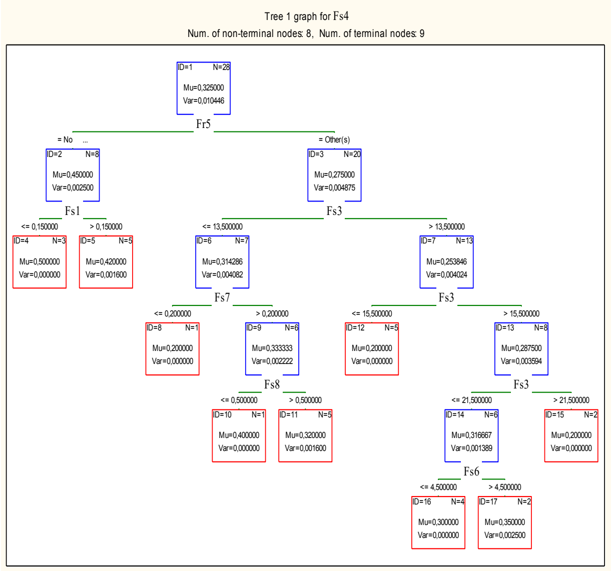
Fs 9 – automation and navigation information systems.

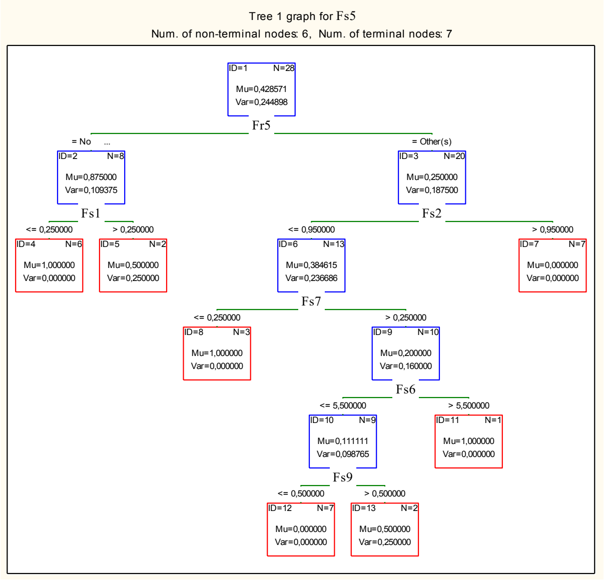
In order to carry out simulation modeling of possible navigation situations and manifestations of human factor, navigation simulator Navi Trainer 5000 (NTPRO 5000) and automated Data Mining tools were used.

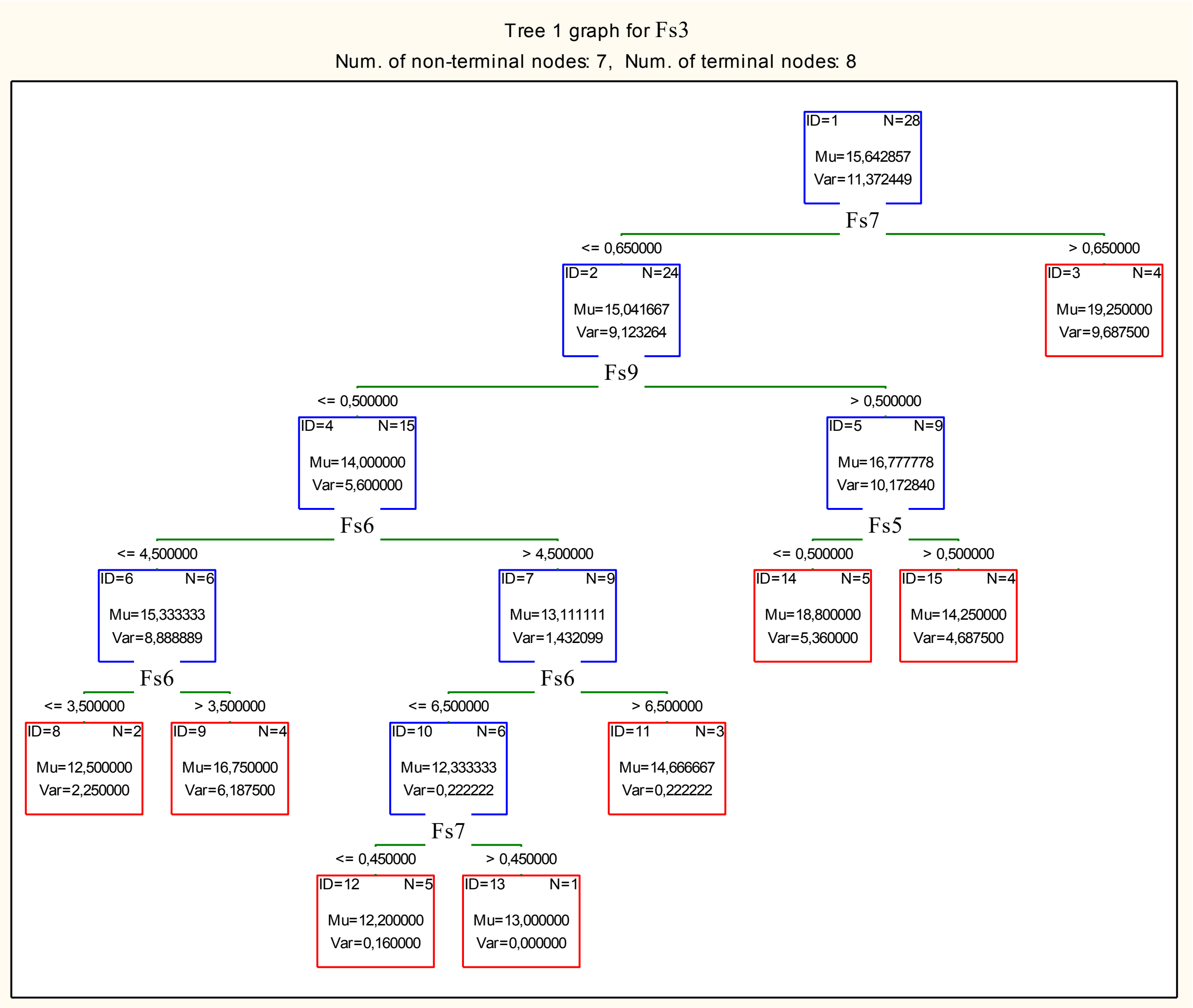
Based on results of experiments, typical route planning trees were identified by captains under the conditions of above factors priority. As a result, with help of automated modeling technologies, control algorithms have been built in form of tree structures (fig. 3).

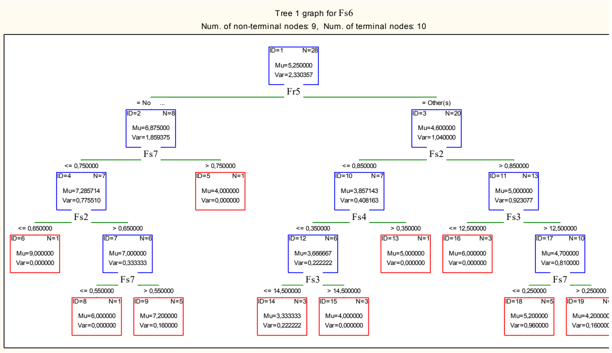


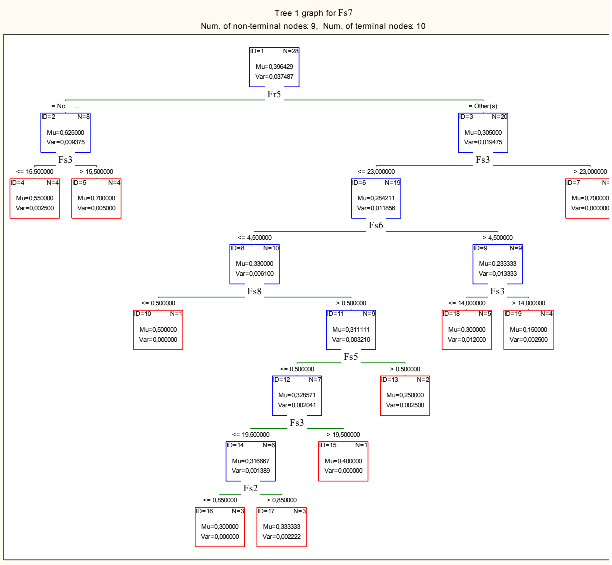







Tree 1 graph for Fs3
Num. of non-terminal nodes: 7, Num. of terminal nodes: 8
ID=1 N=28
Mu=15,642857
Var=11,372449
Fs7
<= 0,650000
> 0,650000
ID=2 N=24
Mu=15,041667
Var=9,123264
ID=3 N=4
Mu=19,250000
Var=9,687500
Fs9
<= 0,500000
> 0,500000
ID=4 N=15
Mu=14,000000
Var=5,600000
ID=5 N=9
Mu=16,777778
Var=10,172840
Fs6
<= 4,500000
> 4,500000
Fs5
<= 0,500000
> 0,500000
ID=6 N=6
Mu=15,333333
Var=8,888889
ID=7 N=9
Mu=13,111111
Var=1,432099
ID=14 N=5
Mu=18,800000
Var=5,360000
ID=15 N=4
Mu=14,250000
Var=4,687500
Fs6
<= 3,500000
> 3,500000
Fs6
<= 6,500000
> 6,500000
ID=8 N=2
Mu=12,500000
Var=2,250000
ID=9 N=4
Mu=16,750000
Var=6,187500
ID=10 N=6
Mu=12,333333
Var=0,222222
ID=11 N=3
Mu=14,666667
Var=0,222222
Fs7
<= 0,450000
> 0,450000
ID=12 N=5
Mu=12,200000
Var=0,160000
ID=13 N=1
Mu=13,000000
Var=0,000000


Tree 1 graph for Fs6
Num. of non-terminal nodes: 9, Num. of terminal nodes: 10
ID=1 N=28
Mu=5,250000
Var=2,330357
Fr5
= No ...
= Other(s)
ID=2 N=8
Mu=6,875000
Var=1,859375
ID=3 N=20
Mu=4,600000
Var=1,040000
Fs7
<= 0,750000
> 0,750000
Fs2
<= 0,850000
> 0,850000
ID=4 N=7
Mu=7,285714
Var=0,775510
ID=5 N=1
Mu=4,000000
Var=0,000000
ID=10 N=7
Mu=3,857143
Var=0,408163
ID=11 N=13
Mu=5,000000
Var=0,923077
Fs2
<= 0,650000
> 0,650000
Fs4
<= 0,350000
> 0,350000
Fs3
<= 12,500000
> 12,500000
ID=6 N=1
Mu=9,000000
Var=0,000000
ID=7 N=6
Mu=7,000000
Var=0,333333
ID=12 N=6
Mu=3,666667
Var=0,222222
ID=13 N=1
Mu=5,000000
Var=0,000000
ID=16 N=3
Mu=6,000000
Var=0,000000
ID=17 N=10
Mu=4,700000
Var=0,810000
Fs7
<= 0,550000
> 0,550000
Fs3
<= 14,500000
> 14,500000
Fs7
<= 0,250000
> 0,250000
ID=8 N=1
Mu=6,000000
Var=0,000000
ID=9 N=5
Mu=7,200000
Var=0,160000
ID=14 N=3
Mu=3,333333
Var=0,222222
ID=15 N=3
Mu=4,000000
Var=0,000000
ID=18 N=5
Mu=5,200000
Var=0,960000
ID=19


Tree 1 graph for Fs7
Num. of non-terminal nodes: 9, Num. of terminal nodes: 10
ID=1 N=28
Mu=0,396429
Var=0,037487
Fr5
= No ...
= Other(s)
ID=2 N=8
Mu=0,625000
Var=0,009375
ID=3 N=20
Mu=0,305000
Var=0,019475
Fs3
<= 15,500000
> 15,500000
Fs3
<= 23,000000
> 23,000000
ID=4 N=4
Mu=0,550000
Var=0,002500
ID=5 N=4
Mu=0,700000
Var=0,005000
ID=6 N=19
Mu=0,284211
Var=0,011856
ID=7
Fs6
<= 4,500000
> 4,500000
ID=8 N=10
Mu=0,330000
Var=0,006100
ID=9 N=9
Mu=0,233333
Var=0,013333
Fs8
<= 0,500000
> 0,500000
Fs3
<= 14,000000
> 14,000000
ID=10 N=1
Mu=0,500000
Var=0,000000
ID=11 N=9
Mu=0,311111
Var=0,003210
ID=18 N=5
Mu=0,300000
Var=0,012000
ID=19 N=4
Mu=0,150000
Var=0,002500
Fs5
<= 0,500000
> 0,500000
ID=12 N=7
Mu=0,328571
Var=0,002041
ID=13 N=2
Mu=0,250000
Var=0,002500
Fs3
<= 19,500000
> 19,500000
ID=14 N=6
Mu=0,316667
Var=0,001389
ID=15 N=1
Mu=0,400000
Var=0,000000
Fs2
<= 0,850000
> 0,850000
ID=16 N=3
Mu=0,300000
Var=0,000000
ID=17 N=3
Mu=0,333333
Var=0,002222

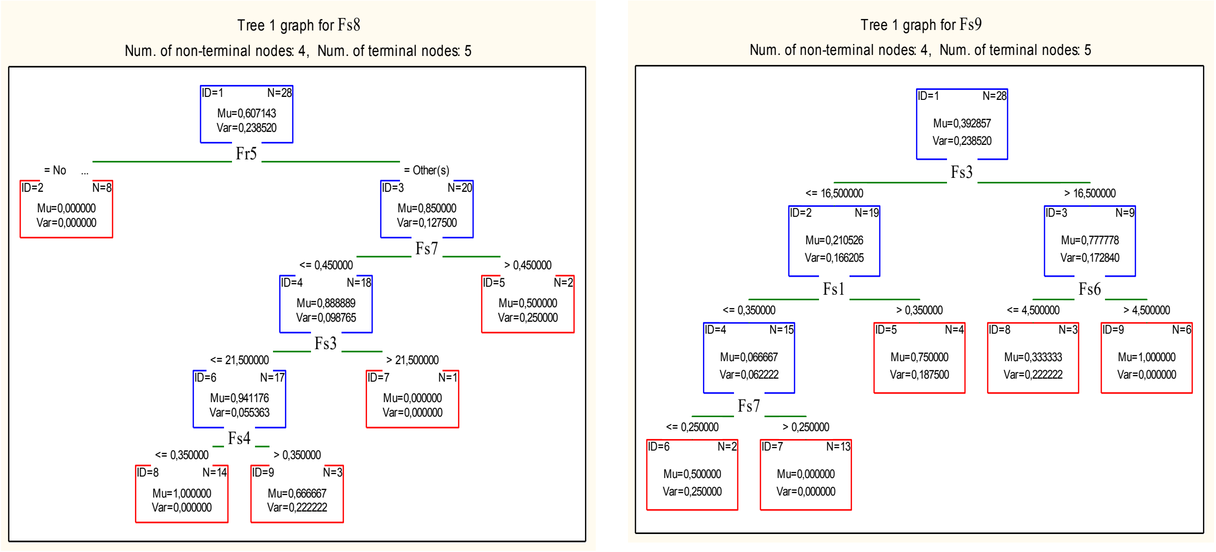


Figure 3 – Results of navigation situations simulation

In order to confirm the adequacy of the simulation, an additional experiment was carried out in which the factor **Fs 3 – weather conditions – became of special importance.** This experiment was carried out in the location of «Aegean Sea».

Description of the navigation situation. The main route for ships in Aegean Sea to enter Dardanelles Strait from the side of Kaap Maleya is through Kafirefs Strait. Thas is the shortest route with the most intensive traffic in Aegean Sea in its northeastern part. In the winter, from November to February, the wind strength from NE reaches 7-8 points, and the sea state up to significant – 5-6 m. Particularly unfavorable section from the Kafirefs Strait to Bozcaada Island – waiting for entrance to Dardanelles Strait. The distance to the open sea is 122 miles. In stormy weather, the vessel loses speed, the deck, hold covers and deck cargo are flooded.

To avoid stormy weather in this section, the captain's recommendation was accepted to pave the way from Cape Maleya not to Kafirefs Strait, but to Mykonos Strait, between islands of Tinos and Mykonos, continue to the island of Chios. Thas is a 52-mile stretch where sea waves are much weaker during stormy weather. Moving north along the island Chios and Fr. Lesvos to about Bozcaada, the vessel will be protected from NE unrest.

The distance m. Maleya – Kafirefs – Bozcaada is 235 miles.

The distance from Malea – Mykonos – Bozcaada is 260 miles –by 25 miles more, but loss of transit time will be compensated by a smaller loss of speed from wave. By reference to meteorological situation, the ship's captain chose a safer route (fig. 4).

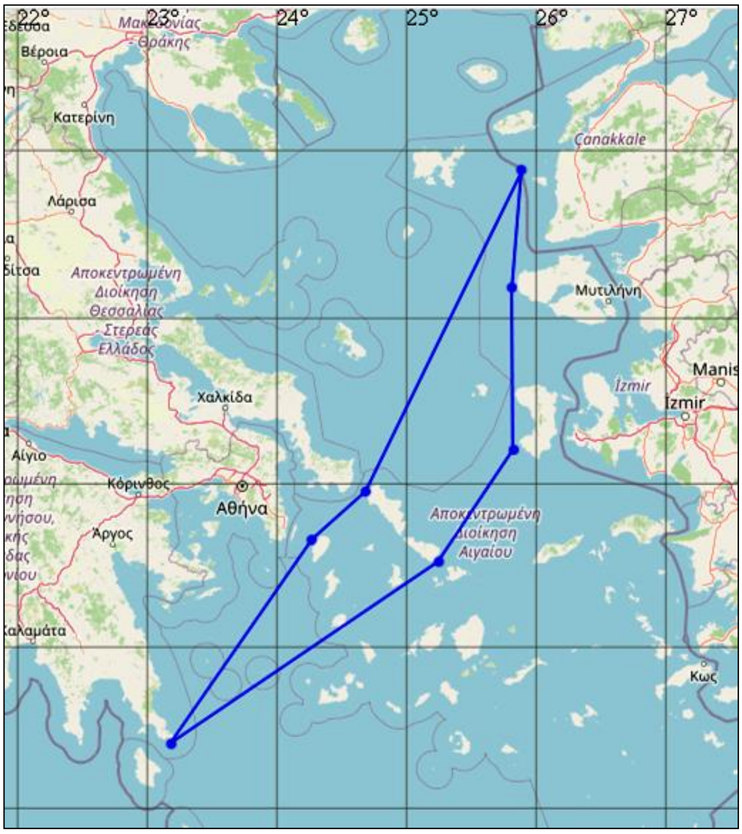


Figure 4 – The process of forming an alternative route by factor Fs 3

Conclusion. An analysis of the corresponding experimental model of route planning showed that the following became key factors for decision-making at main factor Fs 3 – "weather conditions»:

Fs 7 – «special navigation areas» → Fs 9 – «automation and navigation information systems» → Fs 6 – «perception of situation» & Fs 5 – «presence of a stressful situation» → Fs 6 – «perception of situation» → Fs 7 – «special sailing areas ».

As can be seen from the route planning algorithm, the most significant planning factors were Fs 6 – the perception of situation and Fs 7 – "special navigation areas», which appeared cyclically throughout the planning process.

In addition, an important role has been played by Fs 5 – «the presence of a stressful situation», which, with sufficient influence, can significantly affect course of events. However, the elimination of this factor in the short term is almost impossible and requires additional training at time of training [27].

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Носов П. С., Зинченко С. М., Прокопчук Ю. А., Попович И. С., Литовченко В. И. ВЛИЯНИЕ ЧЕЛОВЕЧЕСКОГО ФАКТОРА НА БЕЗОПАСНОСТЬ ПЛАНИРОВАНИЯ МАРШРУТА ВОДНОГО ТРАНСПОРТА

Целью статьи является формальный анализ алгоритмов планирования капитаном безопасных маршрутов в сложных навигационных ситуациях на водном транспорте. Формальный и алгоритмический анализы на основе деревьев принятия решений позволил усовершенствовать эргатические системы навигационной безопасности и заранее спрогнозировать вероятные риски морских аварий.

В статье рассматриваются подходы, позволяющие алгоритмизировать процессы восприятия навигационных ситуаций капитаном. При этом приводится формальное описание наиболее существенных элементов человеческого фактора капитана, вляющих на процессы планирования маршрутов. Также рассматриваются вопросы, связанные с восприятием сложных навигационных ситуаций капитаном, приводятся зависимости от объема и многопоточности входной информации.

С целью подтверждения фактического влияния элементов человеческого фактора капитана на процессы планирования безопасного маршрута был проведен ряд эспериментов с применением навигационного симулятора Navi Trainer 5000 и последующего моделирования средствами Data Mining. В результате моделирования были получены типовые конструкции планирования маршрутов водного транспорта. А также подтверждение адекватности построеных моделей на примере фактора Fs 3 – «погодные условия». Предложенные подходы позволят в дальнейшем расширить возможности прогностических моделей возможных аварий на водном транспорте по вине человеческого фактора.

Ключевые слова: *водный транспорт, человеческий фактор, планирование безопасного маршрута, эргатические системы.*

Носов П. С., Зінченко С. М., Прокопчук Ю. А., Попович І. С., Литовченко В. І. ВПЛИВ ЛЮДСЬКОГО ФАКТОРУ НА БЕЗПЕКУ ПЛАНУВАННЯ МАРШРУТУ ВОДНОГО ТРАНСПОРТУ

Метою статті є формальний аналіз алгоритмів планування капітаном безпечних маршрутів у складних навігаційних ситуаціях на водному транспорті. Формальний і алгоритмічний аналізи на основі дерев прийняття рішень дозволив удосконалити ергатичні системи навігаційної безпеки і заздалегідь спрогнозувати ймовірні ризики морських аварій.

У статті розглядаються підходи, що дозволяють алгоритмізувати процеси сприйняття навігаційних ситуацій капітаном. Водночас наводиться формальний опис найбільш істотних елементів людського фактору капітана, що вливають на процеси планування маршрутів. Також розглядаються питання, що пов'язані із сприйняттям складних навігаційних ситуацій капітаном, наводяться залежності від обсягу і багатопоточності вхідної інформації.

З метою підтвердження фактичного впливу елементів людського фактору капітана на процеси планування безпечного маршруту була проведена низка есперриментів із застосуванням навігаційного симулятора Navi Trainer 5000 і подальшого моделювання засобами Data Mining. В результаті моделювання були отримані типові конструкції планування маршрутів водного транспорту. А також підтверджено адекватність побудованих моделей на прикладі фактору Fs 3 – «погодні умови». Запропоновані підходи дозволять у подальшому розширити можливості прогностичних моделей можливих аварій на водному транспорті з вини людського фактору.

Ключові слова: *водний транспорт, людський фактор, планування безпечного маршруту, ергатичні системи.*

Статтю прийнято
до редакції 02.05.21