UDC 681.305:629.5.072

MODELS OF DECISION MAKING BY A NAVIGATOR UNDER IMPLICIT AGREEMENTS WITH COLREG RULES

Nosov P. S., *Ph.D., Associate Professor of Navigation and Electronic Navigation Systems Department, Kherson State Maritime Academy, e-mail: pason@ukr.net, ORCID:0000-0002-5067-9766;*
Zinchenko S. M., *Ph.D., Senior Lecturer of Ship Management Department, Head of Laboratory navigation simulator, Kherson State Maritime Academy, e-mail: srz56@ukr.net, ORCID: 0000-0001-5012-5029;*
Ben A. P., *Ph.D., Professor, Associate Professor, Deputy Rector for scientific and pedagogical work, Kherson State Maritime Academy, e-mail: a_ben@i.ua, ORCID: 0000-0002-9029-3489;*
Nahrybelnyi Ya. A., *Ph.D., Associate Professor, Dean of Navigation Department at the Kherson State Maritime Academy, e-mail: yar1507@ukr.net, ORCID: 0000-0003-3266-5798;*
Dudchenko O. M., *Ph.D., Associate Professor, Kherson branch of the National University of Shipbuilding adm. Makarova, Ukraine, e-mail: kbnuos@gmail.com, ORCID: 0000-0002-7724-089*

The purpose of the article is the model of perception of difficult situations by the navigator where the rules of COLREG are inconsistent. To build these models, a formal analysis of the situations was carried out, which allowed to design a decision-making support system to reduce risks and accidents related to sea transport. The article presents formal approaches that take into account the factors of vessel speed, qualification of a navigator, and the situations that influence the formation of maneuvering strategies. The illustrations show difficulties and ambiguous situations from the point of view of the rules. An important factor for decision-making is the ability of an adequate perception of the situation by a navigator, and the conditions in which this process is considerably difficult are given. The arguments are made in favor of the use of ECDIS and AIS navigation information systems, and the examples that indicate the difficulties of making decisions at the time of a large number of vessels are given. A relationship between the perception of service information by the navigator and the choice of maneuvering strategies is made. The recommendations on the development of a decision-making support system for navigators in difficult navigation situations are given. The approaches to apply a decision-making support system, as well as the formation of data about the navigator are proposed.

Keywords: *navigation information systems, maneuvering strategies, human factor, navigator.*

DOI: 10.33815/2313-4763.2019.1.20.031-039

Introduction. Navigator controls the vessel using international rules and conventions that ensure the safety of navigation [1]. Difficult locations require from the navigator more than knowledge of the basics of international rules [2]. Hydrographs and high traffic implies the emergence of abnormal situations. Such situations introduce risk and uncertainty for the navigator [3]. A large list of accidents related to sea transport indicates that the rules do not cover all situations [4–5]. Many naval officers cite cases from world practice confirming these statistics. For example, in the general concept of COLREG it is indicated that the differences of two vessels are considered. This feature is also described in the works of S. Zinchenko [6–7] (Fig. 1). Another factor contributing to an increase in a stressful situation is high level of responsibility [8–10].

Experiments that were conducted at the Kherson State Maritime Academy confirm that an increased stress threshold arises even in simulators [11]. This means that in real conditions, stress indicators will be higher. Practice shows that in case of immediate danger or interference deviations from the rules are possible. But only the navigator determines the level of «immediacy.» This suggests that at the time of decision-making there may be an inaccuracy in assessing the situation. The opinion of one navigator may differ from the assessment of the situation of another. A difficult situation arises when it is difficult to determine the behavior strategy of navigators of other vessels in case of divergence [12].

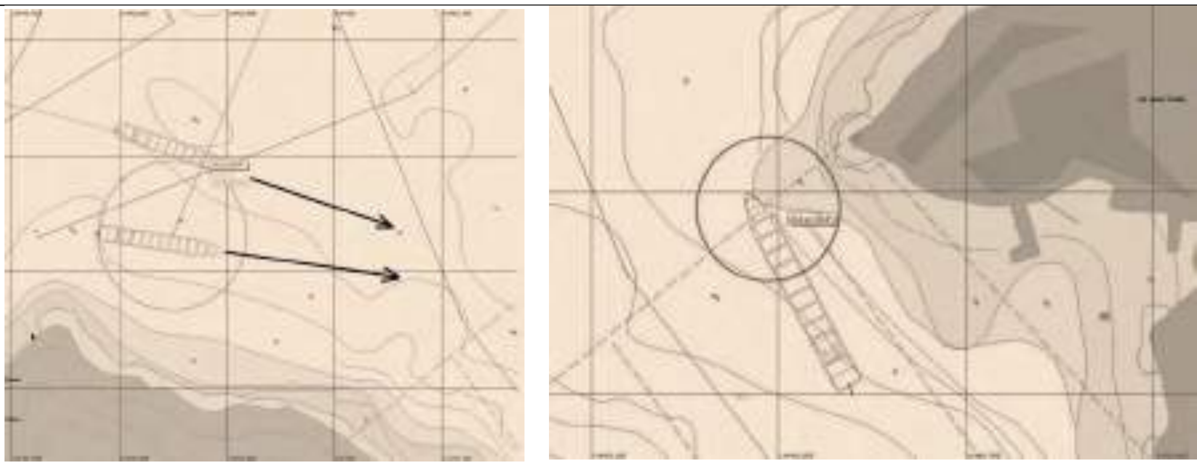

Figure 1 – Interaction of two vessels / vessel and obstacles

The organization of the watch on the captain’s bridge is very important. Errors in making decisions are increased if on the captain’s bridge there is a substitution of roles in the team.

In the conditions of watch keeping, especially when practicing maneuvers in relation to locations, the decision to manage the ship is influenced by several members of the watch keeping duty. In some cases, when it’s required by the changes in the situation, the captain gives the command to immediately strengthen the watch on the bridge. Typically, this decision is affected by: visibility, weather and sea conditions, the intensity of navigation and other features of the navigation situation. At the same time, the number of members of the watch keeping duty is increasing, which also contributes a factor capable of adversely affecting the decision of the navigator. To construct a formal model, consider the following scheme for the interaction of watch members. During the maneuvers, the naval officer requests the watch personnel to specify the indications of navigational instruments and other parameters necessary for steering the vessel.

In this case, local interactions occur short-term in time between the members of the watch and the deck officer (captain).

We will assume that two subjects are involved in the interaction: D is a deck officer or a captain and F is a member of the personnel on duty. In this example, the captain instructs before the start of the passage of the location, and immediately at the time the first mate takes command. Thus, the participant at number 1 (the captain) does not participate in team interaction, but can prompt the first mate. Each watch interaction solves the micro-task of steering the vessel at the current moment.

During the transition, the command performs a different kinds of tasks n consisting of a finite sequence of operations depending on the complexity $h_i, i = 1,...,n$. Members of the watch keeping duty D and F are divided into interacting groups $D_1,...,D_{\bar{J}}$ and $F_1,...,F_{\bar{S}}$ depending on the level of qualification and experience. This leads to the formation of groups D_L, F_S for completing the tasks n and accomplishing the result K_i^L, $\overline{K}_i^S$.

But the transition from dynamic positioning to manual vessel control may cause inadequate response of specialists if the team is not ready. Testing of such events were conducted on the navigation simulator NTPRO 5000 and confirmed our fears. The experiment has shown that the actions of navigators with the loss of control over the vessel cause spontaneous movements on the bridge.

At a certain point in time, the watch keeping begins to independently make decisions from the whole team, this can be seen in the chronology of events (Fig. 2):

Figure 2 – Interference with the navigation watch

A study of the trajectory of the control vessel confirmed the fact of loss of control. A computer program was developed to analyze the vessel's control path. The graph shows that loss of control occurs soon after turning off the dynamic positioning due to the human factor (Fig. 3).

There is a direct relationship between the spontaneous behavior of the watch crew and the loss of control over the vessel. Therefore, it is important to track the movements of the watch crew on the bridge using software tools. These software tools are important to add to the overall complex of the decision support system of the navigator.

The navigator needs to know the characteristics of maneuvering other vessels in such situations [13]. Maneuvering situations often lead to a vessel drift. For example, the navigator is forced to increase the speed of the vessel in order to have time to make a U-turn near Ma Van in Hong Kong (Fig. 4) [14].

This situation forces you to make a difficult decision, the risk of a vessel being stranded or avoiding collision with a counter vessel. The cases that were considered in the introduction a lot and it speaks of the problem of perception of the navigator.

The purpose of the article is to simulate the perception of difficult situations by the navigator where the rules are rejected. Formal analysis will allow to design a decision support system for the navigator. The system will significantly reduce the risks and accidents on maritime transport in situations that are considered.

The solution of the problem. The considered task is defined by various vessels and trajectories of movement. An example of such a task can be considered in the location of New York. The figure shows a large accumulation of vessels - targets on the radar (Fig. 5).

This task consists in finding patterns of navigator behavior in situations that are not provided for by the COLREG rules. Models of navigator behavior must pass the stage of formalization and further algorithm.

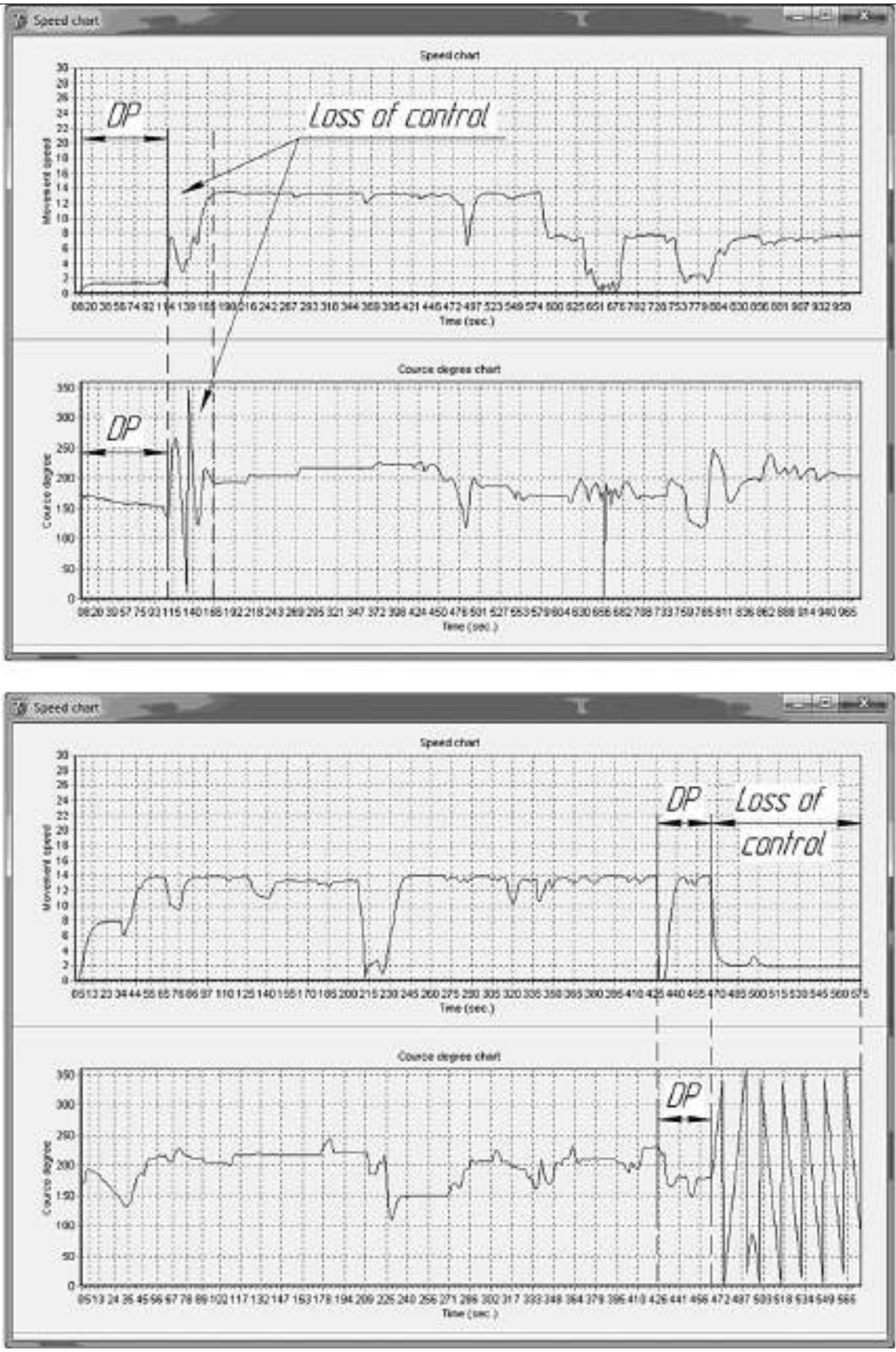

Figure 3 – Periods of loss of control due to the fault of the human factor

Figure 4 – Satellite image of difficult location and navigation map

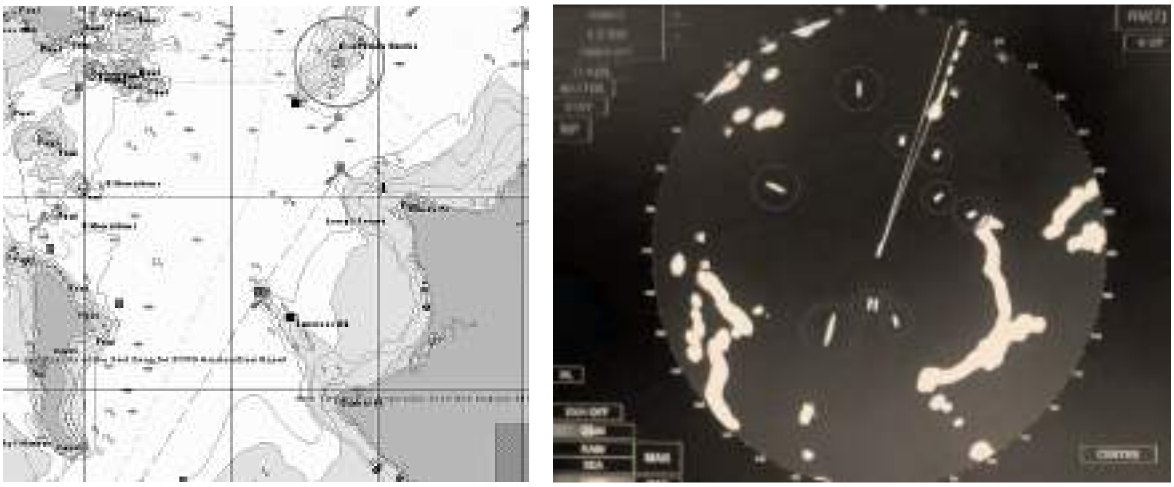

Figure 5 – Fragment of the navigation map and the image of the radar

The set of vessels will be represented as $Q=\{1,2,\ldots,q\}$. Factor deviations from the rules will be $\gamma \in \Delta$. This factor will be taken into account by all location navigators. Each navigator determines the strategy of behavior I_i, including maneuvers γ_i. Each navigator assumes the strategy of the behavior of another navigator, especially a vessel with a heading $\gamma_{ij} \in \Omega,\ j \in Q$. The strategy of the third vessel is considered first as $\gamma_{ijk} \in \Delta,\ j,k \in Q$. The number increases depending on the number of participants $\gamma_{ij_1 \ldots j_l} \in \Delta,\ j_1,\ldots,j_l \in Q$.

Situations can be described formally as follows $S_{t_1}=\{Q',(P_i)_{i\in Q},f_i(\cdot)_{i\in Q},I\}$:

where, Q' – a set of navigators, P_i – a set of actions navigators.

This model is represented by the target function: $f_i(\cdot):\Delta \times P_1 \times \ldots \times P_n \to \Re^{t_1}$.

The perception of each navigator determines the mechanism for triggering a maneuvering strategy. Observation of the area allows the navigator to determine its position in the interaction of several participants in the event. Event participants can be divided into two conditional groups. The first group is active, which affects the strategy of other navigators on the map B. The second group is passive, which is in standby mode and adapts to the actions of the first G. A maneuver is considered effective if the risk is reduced when moving to a new state in a given area *w*

1. The divergence of the two vessels to minimize risks:

$$G(w)+B \xrightarrow{\xi_{t,r}} G(w)_1+G(w)_2 \qquad (1)$$

2. The status of the navigator becomes active, a maneuver is performed:

$$G(w) \xrightarrow{\xi_{t,r}} B \tag{2}$$

3. Navigator decides to give the other vessel:

$$B \xrightarrow{\xi_{t,r}} G(w) \tag{3}$$

4. Navigator changes the area for better maneuvering:

$$G(w)_1 + G(w^*)_2 \xrightarrow{\xi_{t,w^*} > \xi_{t,w}} G(w)_1 + G(w)_2 \tag{4}$$

where, $\xi_{t,w}, \xi_{t,w^*}$ – probabilities of transition states.

The main criterion of effectiveness is the value of the probability of the chosen strategy. Communication with the nearest vessels increases the likelihood of a result, but vessels of the second radius do not participate in the interaction. Navigator has the opportunity to observe the developments of the nearest vessels. His experience may allow to expand the number of vessels surveyed, but even an experienced captain cannot predict all events (Fig. 6).

Navigation equipment ECDIS, AIS signals about intersecting courses and dangerous proximity with other vessels, but does not provide information about the strategies chosen by navigators.

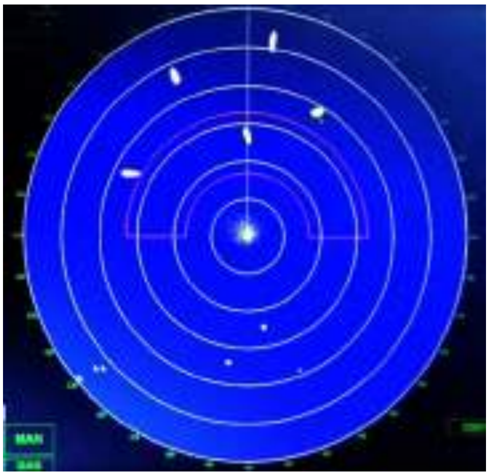

Figure 6 – Multiple strategies

The strategy is effective when the safety of further navigation at a high level. The linguistic safety scale has several levels: “catastrophe”, “dangerous”, “increased attention”, “usual situation”, “time to make decisions”. A completed maneuver results in one of the listed conditions. ξ_{P_i} .

Each navigator is in one of three states: 1 – the vessel follows to the waypoint without visible obstacles; 2 – the vessel is in the zone of increased attention and the navigator determines the strategy for maneuvering; 3 – the navigator performs a divergence maneuver.

This classification identifies three main criteria for assessing each state: 1 – navigator fatigue a; 2 – security level W; 3 – time spent on maneuver τ. The fatigue of the navigator increases depending on the sequence and complexity of the maneuvers performed during the passage of the location:

$$a_s = a_{s,t}^0 + a_{s,t+1}^1, \ldots, a_{s,t+q}^k \tag{5}$$

The fatigue of the navigator directly depends on the intensity of the occurrence of difficult situations when maneuvering a vessel. The intensity index also depends on the congestion zones of the sea transport [16]. The higher the accuracy of maritime transport, the higher the likelihood of fatigue in the navigator. The difficulty lies in the fact that the navigator initially chooses the basic average speed when planning the transition route (Fig. 7). This fact complicates the situation, because for emergency braking it takes a lot of time.

Figure 7 – Calculation of the average speed in ECDIS

To ensure sufficient security, it is necessary not to exceed the maximum speed $y^{\max,i}$. In this case, the navigator will have time to prevent a collision with the help of divergence maneuvers. The selected safe speed of the vessel $\dot{v}$ will be (6):

$$\dot{y} = \begin{cases} \dot{y}^i, \; if \;\; y < y^{\max,i}, \; t \in \left[t_b^i; \, t_b^i + T_b^i\right], \, w \in S^i \;\; \forall \tau \\ 0, \; elce \end{cases} \tag{6}$$

where t_b^i – the beginning of entry into the zone of increased attention; T_b^i – the duration of the maneuver on the discrepancy; S^i – territory, which is characterized by the presence of a difficult situation; $\dot{y}^i$ – permissible speed of sea transport.

Conclusion. The higher the experience and qualifications of the navigator, the more accurately the vessel's speed and types of maneuvering are chosen. We denote the integral indicator of experience-qualification as *Z*. The final group of navigators define the set $Z = \{Z_{t_1},...,Z_{t_k}\}$. Each navigator chooses an action with respect to the adopted strategy $\{p_{t_1},...,p_{t_k}\}, \; p_{t_1} \in P_{\varsigma(t_k)}, \; k \in \{1,...,y\}$, where ς determines its belonging to the COLREG rule.

In this case, the objective function will be: $f_t = (\gamma_{t_1}, \, p_{t_1},...,p_{t_k})$. Then, when designing algorithms, lowering the risk level is possible by identifying the complexity of the situation. However, at the moment there are no systems allowing to classify the situation with a high degree of accuracy. Visual observation does not give complete information about what is happening. Many vessels with different strategies make significant adjustments, complicating the process. Further research will be focused on the development of automated tools for identifying navigator strategies.

REFERENCES

1. Zobair Ibn, Awal & Hasegawa, K. (2017) A Study on Accident Theories and Application to Maritime Accidents. *Procedia Engineering*, *Vol. 194,* 298–306. DOI: 10.1016/j.proeng.2017.08.149.

2. Havold, J. I. (2010). Safety culture and safety management aboard tankers. *Reliability Engineering & System Safety*, *Vol. 95, Issue 5,* 511-519. DOI: 10.1016/j.ress.2010.01.002.

3. Rolf, J. Bye & Asbjørn L. Aalberg (2018) Maritime navigation accidents and risk indicators: An exploratory statistical analysis using AIS data and accident reports. *Reliability Engineering & System Safety*, *Vol. 176,* 174–186. DOI: 10.1016/j.ress.2018.03.033.

4. Ming-Cheng, Tsou. (2016). Multi-target collision avoidance route planning under an ECDIS framework. *Ocean Engineering*, *Vol. 121,* 268–278. DOI: 10.1016/j.oceaneng.2016.05.040.

5. Puisa, R., Lin, L., Bolbot, V. & Vassalos, D. (2018). Unravelling causal factors of maritime incidents and accidents. *Safety Science, 110(A),* 124–141. DOI: 10.1016/j.ssci.2018.08.001.

6. Zinchenko, S., Nosov, P., Mateichuk, V., Mamenko, P. &Grosheva, O. (2019). Automatic collision avoidance with many targets, including maneuvering ones. *MNPK pamiati profesoriv Fomina Yu. Ya. i Semenova V. S. (FS-2019), 24 – 28 kvitnia 2019, Odesa – Stambul – Odesa,*343–349.

7. Zinchenko S., Nosov P., Mateichuk V., Mamenko P. & Grosheva O. (2019). Use of navigation simulator for development and testing ship control systems. *MNPK pamiati profesoriv Fomina Yu. Ya. i Semenova V. S. (FS-2019), 24 – 28 kvitnia 2019, Odesa – Stambul – Odesa,* 350–355.

8. Özkan, Uğurlu, Serdar, Yıldız, Sean, Loughney & Jin, Wang (2018). Modified human factor analysis and classification system for passenger vessel accidents (HFACS-PV). *Ocean Engineering*, *Vol. 161,* 47–61. DOI:10.1016/j.oceaneng.2018.04.086.

9. Emre, Akyuz. (2016). Quantitative human error assessment during abandon ship procedures in maritime transportation. *Ocean Engineering*, *Vol. 120,* 21–29. DOI: 10.1016/j.oceaneng.2016.05.017.

10. Xi Y. T., Yang Z. L., Fang Q. G., Chen W. J., &Wang J. (2017). A new hybrid approach to human error probability quantification–applications in maritime operations. *Ocean Engineering*, *Vol. 138,* 45-54. DOI: 10.1016/j.oceaneng.2017.04.018.

11. Nosov P. S., Ben A. P., Matejchuk V. N., Safonov M. S. (2018) Identification of "Human error" negative manifestation in maritime transport. *Radio Electronics, Computer Science, Control. Zaporizhzhia National Technical University*, *№ 4 (47),* 204–213. DOI: 10.15588/1607-3274-2018-4-20.

12. Tor A., Johansen, Andrea, Cristoforo & Tristan Perez. (2016). Ship Collision Avoidance Using Scenario-Based. *Model Predictive Control*. IFAC.

13. Ventikos N. P., Papanikolaou A. D., Louzis K. & Koimtzoglou A. (2018). Statistical analysis and critical review of navigational accidents in adverse weather conditions. *Ocean Engineering*, *Vol. 163,* 502–517. DOI: 10.1016/j.oceaneng.2018.06.001.

14. Yuanzhi, Zhang, Erjia, Ge. (2013). Temporal scaling behavior of sea-level change in Hong Kong – Multifractal temporally weighted detrended fluctuation analysis. *Global and Planetary Change, Vol. 100,* 362–370. DOI: 10.1016/j.gloplacha.2012.11.012.

15. Seabrooke, W., Hui, E. C. M, Lam, W. H. K. & Wong, G. K.C. (2003) Forecasting cargo growth and regional role of the port of Hong Kong. *Cities*, *20(1),* 51–64. DOI: 10.1016/S0264-2751(02)00097-5.

Носов П. С., Зинченко С. Н., Бень А. П., Нагрибельный Я. А., Дудченко О. Н. МОДЕЛИ ПРИНЯТИЯ РЕШЕНИЙ НАВИГАТОРОМ ПРИ НЕЯВНЫХ СОГЛАСОВАНИЯХ С ПРАВИЛАМИ МППСС

Целью статьи являются модели восприятия штурманом сложных ситуаций, в которых несогласованны правила МППСС. Для построения данных моделей проведен формальный анализ ситуаций, что позволило спроектировать систему поддержки принятия решений для уменьшения рисков и аварийности на морском транспорте. В статье приводятся формальные подходы учитывающие факторы скорости движения судна, квалификации штурмана и условий влияющих на формирование стратегий маневрирования. Приведены иллюстрации показывающие сложности и неоднозначные с точки зрения правил обстоятельства. Важным фактором для принятия решений остается способность адекватного восприятия ситуации штурманом, приведены условия, в которых данный процесс значительно затруднен. Приводится аргументация в пользу применения навигационных информационных систем ECDIS и AIS, *приведены примеры, указывающие на*

трудности принятия решений в момент скопления большого количества суден. Проводится зависимость между восприятием служебной информации штурманом и выборе стратегий маневрирования. Даны рекомендации по разработке системы поддержки принятия решений штурманом в сложных навигационных ситуациях. Предложены подходы применения системы поддержки принятия решений, а также формирования данных о штурмане.
Ключевые слова: *навигационные информационные системы, стратегии маневрирования, человеческий фактор, штурман.*

Носов П. С., Зінченко С. М., Бень А. П., Нагрибельний Я. А., Дудченко О. М. МОДЕЛІ ПРИЙНЯТТЯ РІШЕНЬ НАВІГАТОРОМ ПРИ НЕЯВНИХ УЗГОДЖЕННЯХ З ПРАВИЛАМИ МППСС

Метою статті є побудова моделі сприйняття штурманом складних ситуацій, де неузгоджені правила МППСС. У реальних умовах виникає протиріччя між вимогами міжнародних правил та високим трафіком морських перевезень. Особливі ускладнення у роботі судноводія виникають також під час виконання маневрів при розходженні суден з багатьма цілями, що також супроводжується факторами стресу та невизначеності. Такі обставини суттєво впливають на рівень безпеки під час переходу у проливах та небезпечних районах мореплавання.

З метою більш глибокого аналізу було проведено ряд експериментів засобами морських навігаційних стимуляторів у рамках проведення тренажерної підготовки з кадетами що підтверджують гіпотезу статті про виникнення ситуацій які змушують судноводія відхилятися від правил МППСС.

Враховуючи даний факт у статті було запропоновані моделі щодо визначення стратегії поведінки судноводіїв під час нестандартних ситуацій при розходженні з суднами у вузькостях.

Для побудови даних моделей проведено формальний аналіз ситуацій, що дозволяє спроектувати систему підтримки прийняття рішень для зменшення ризиків та аварійності на морському транспорті.

У статті визначено що під час виникнення помилок членами навігаційної вахти на капітанському містку при управлінні судном виникають несанкціоновані зміни ролей, коли член вахти тимчасово замінює іншого без дозволу капітана або старшого помічника. Таким чином формується стала реакція що змушує в окремих випадках спотворювати як спектр уваги кожного учасника ситуації так і сприяти розвитку практичних навичок щодо подолання складних ситуацій відповідно до кваліфікаційних вимог судноводія.

Враховуючи складність навігаційної ситуації, а також можливість прояву несприятливих погодних умов та інтенсивність морського трафіку за розпорядженням капітана вахта може бути підсилена що також впливає на модель поведінки кожного судноводія і формує його стратегію на майбутнє.

У статті наводяться формальні підходи що враховують фактори швидкості руху судна, кваліфікацію штурмана і ситуації, що впливають на формування стратегій маневрування. Наведені ілюстрації показують складності і неоднозначні з точки зору правил обставини. Важливим фактором для прийняття рішень залишається здатність адекватного сприйняття ситуації штурманом. Наводиться аргументація на користь застосування навігаційних інформаційних систем ECDIS і AIS, наведені приклади, що вказують на труднощі прийняття рішень в момент скупчення великої кількості суден.

Приводиться залежність між сприйняттям службової інформації штурманом і виборі стратегій маневрування. Дано рекомендації з розробки системи підтримки прийняття рішень штурманів в складних навігаційних умовах. Запропоновано підходи застосування системи підтримки прийняття рішень, а також формування даних про штурмана.
Ключові слова: *навігаційні інформаційні системи, стратегії маневрування, людський фактор, штурман.*

Статтю прийнято
до редакції 18.05.19