

**UDC 656.61.052**

**OPTIMIZATION OF ROUTE LAYING TAKING INTO ACCOUNT THE  
LEVEL OF RISK**

**Маменко Р. Р.**, deep sea captain., senior lecturer, **Зинченко С. М.**, Dr. Sci.,  
docent, **Кырыченко К. В.**, Ph.D., senior lecturer, **Матеичук В. М.**, senior lecturer  
Kherson State Maritime Academy

The movement of the ship from the port of departure to the port of destination can be carried out by various routes. The choice of a safe route is influenced by navigation restrictions, meteorological conditions, the presence of pirate zones, the presence of other ships, etc. But, even with such restrictions, there remains an infinite number of safe transition trajectories between the port of departure and the port of destination. Today, there are standard guidelines for manual routing, and many routes can be routed that meet these guidelines, but none of them will be optimal. To lay out the optimal route, optimization of the selected optimality criterion is required, which can be implemented only if numerical optimization methods are used in the on-board computer.

The paper considers the problem of automatic route smoothing in the on-board controller, for which integral risk is minimized [1-6]

$$\begin{cases} L^*(\mathbf{x}(t)) \rightarrow \min C, \\ C(\mathbf{x}) = \frac{C_m}{2\pi\sigma_x\sigma_y} \int_{L(t)} e^{-\frac{1}{2-2r_{xy}} \left[ \frac{(v_x t - x_0)^2}{\sigma_x^2} - \frac{r_{xy}(v_x t - x_0)(v_y t - y_0)}{\sigma_x^2 \sigma_y^2} + \frac{(v_y t - y_0)^2}{\sigma_y^2} \right]} dt \end{cases} \quad (1)$$

From the determined starting point of the route, a step is taken in the direction of the given course and the risk at the new point is assessed. If the risk value at the new point does not exceed the specified level, then we continue laying in the direction of the shoulder of the route. If the risk at the new point exceeds the specified one, the zero

gradient of the risk field at the current point is calculated and a step is taken in the direction of this gradient. This is repeated until the trajectory of bypassing the navigation hazard does not cross the shoulder of the route on which this navigation hazard is located, after which the algorithm takes steps in the direction of the given shoulder of the route. The gradient of the risk function is the most dangerous direction of increasing field risk. The presence of the most dangerous direction of increasing risk also means the presence of the safest direction in the opposite direction and directions with a zero value of the gradient, on which the specified collision risk is preserved [7-14]

$$\left\{ \begin{array}{l} \mathbf{x}(0) = \mathbf{x}_0 \in L^* \\ \mathbf{x}_0 \rightarrow \min |\mathbf{grad}C(\mathbf{x})| \\ C(\mathbf{x}) \leq C^* \\ \mathbf{x}_{j+1} = \mathbf{x}_j + \frac{v}{|\mathbf{grad}C(\mathbf{x})|} \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} \mathbf{grad}C(\mathbf{x}), j = 1..m \\ \mathbf{x}_m \in L^* \end{array} \right. \quad (2)$$

**Conclusions.** The method of automatic route laying using gradient procedures is considered, which allows to reduce the time of route laying and the total time of preparing the ship for the voyage. Algorithmic and software of the module of automatic routing of the route in the on-board controller has been developed. The workability and effectiveness of the method, algorithm and software are verified by mathematical modeling on a closed circuit simulation bench with mathematical models of the Navi Trainer 5000 simulator.

## REFERENCES

1. Lednev N. I., Maksimov V. A. Bezopasnost moreplavaniia, otsenka riskov i upravlenie riskami. Navigatsiia i gidrografiia, GNIGI №51. – 2019. - s. 7-15.
2. Nosov P., Zinchenko S., Ben A., Prokopchuk Yu., Mamenko P., Popovych I., Moiseienko V., Kruglyj D. Navigation safety control system development through

navigator action prediction by data mining means. Eastern-European Journal of Enterprise Technologies. Information and controlling system, vol. 2, 9 (110). - 2021. DOI: <https://doi.org/10.15587/1729-4061.2021.229237>

3. Nosov P., Zinchenko S., Popovych I., Safonov M., Palamarchuk I., Blah V. Decision support during the vessel control at the time of negative manifestation of human factor. CEUR Workshop Proceedings, vol. 2608. - 2020. - pp. 12-26. <http://ceur-ws.org/Vol-2608/paper2.pdf>

4. Nosov P. S., Popovych I. S., Cherniavskiy V. V., Zinchenko S. M., Prokopchuk Y. A., Makarchuk D. V. Automated identification of an operator anticipation on marine transport. Radio Electronics, Computer Science, Control, vol. 3. - 2020. - pp. 158–172. <https://doi.org/10.15588/1607-3274-2020-3-15>

5. Engau A., Sigler D. Pareto solutions in multicriteria optimization under uncertainty. European Journal of Operational. - 2020. [doi.org/10.1016/j.ejor.2019.08.040](https://doi.org/10.1016/j.ejor.2019.08.040).

6. Zhukovskiy V., Salukvadze M. Chapter 4 Geoffrion Optimality. Mathematics in Science and Engineering, Vol. 193. - 1994. - pp. 131-167. [doi.org/10.1016/S0076-5392\(08\)61972-4](https://doi.org/10.1016/S0076-5392(08)61972-4)

7. Abdelaal M., Franzle M., Hahn A. Nonlinear Model Predictive Control for trajectory tracking and collision avoidance of underactuated vessels with disturbances, Ocean Engineering, vol. 160. - 2018. - pp. 168–180. DOI: [10.1016/j.oceaneng.2018.04.026](https://doi.org/10.1016/j.oceaneng.2018.04.026)

8. Mamenko P., Zinchenko S., Kobets V., Nosov P., Popovych I. Solution of the Problem of Optimizing Route with Using the Risk Criterion. In: Babichev, S., Lytvynenko, V. (eds) Lecture Notes in Computational Intelligence and Decision Making. ISDMCI 2021. Lecture Notes on Data Engineering and Communications Technologies, vol. 77. - 2021. - pp. 252-265, Springer, Cham. [https://doi.org/10.1007/978-3-030-82014-5\\_17](https://doi.org/10.1007/978-3-030-82014-5_17)

9. Zinchenko S., Tovstokoryi O., Ben A., Nosov P., Popovych I., Nahrybelnyi Ya. Automatic optimal control of a vessel with redundant structure of executive

devices. In: Babichev, S., Lytvynenko, V. (eds) *Lecture Notes in Computational Intelligence and Decision Making. ISDMCI 2021. Lecture Notes on Data Engineering and Communications Technologies*, vol 77. - 2021. - pp. 266-281, Springer, Cham. [https://link.springer.com/chapter/10.1007/978-3-030-82014-5\\_18](https://link.springer.com/chapter/10.1007/978-3-030-82014-5_18)

10. Johansen T. A., Cristoforo A., Perez T. Ship Collision Avoidance Using Scenario-Based Model Predictive Control. IFAC. - 2016. <https://pdfs.semanticscholar.org/34a3/c1a0b699774fadab417ca2f5ef422edb1f0b.pdf>

11. Lisowski J. Simulation models of the safe ship's steering process in collision situations. *Risk Analysis II*, Wit Press, Computational Mechanics Publications: Southampton and Boston. - 2000. – pp. 13-22.

12. Zinchenko S. M., Mateichuk V. M., Nosov P. S., Popovych I. S., Solovey O. S., Mamenko P. P., Grosheva O. O. Use of Simulator Equipment for the Development and Testing of Vessel Control Systems. *Electrical, Control and Communication Engineering*. Vol. 16, Issue 2. - 2020. – pp .58-64. DOI: 10.2478/ecce-2020-0009.

13. Zinchenko S. M., Ben A. P., Nosov P. S., Popovych I. S., Mamenko P. P., Mateichuk V. M. Improving the accuracy and reliability of automatic vessel motion control system. *Radio Electronics, Computer Science, Control*, vol. 2. - 2020. – pp. 183–195. <https://doi.org/10.15588/1607-3274-2020-2-19>

14. Zinchenko S., Nosov P., Mateichuk V., Mamenko P., Popovych I., Grosheva O. Automatic collision avoidance system with many targets, including maneuvering ones. *Bulletin of University of Karaganda. Technical Physics*, vol. 4(96). - 2019. - pp. 69-79. DOI: 10.31489/2019Ph4/69-79