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THEORETICAL FUNDAMENTALS OF IMPROVING SAFETY NAVIGATION IN THE FIELD OF RISKS

P.P. Mamenko*, S. M. Zinchenko*, K.V. Kyrychenko*, V.M. Mateychuk*
Kherson State Maritime Academy (Ukraine)

Introduction. Analysis of the development of the world economy indicates that along with the growth of trade, the share of maritime traffic is growing. Maritime transport provides about 90% of world trade, which leads to a constant intensification of human activity at sea. The number of maritime accidents has decreased over the last decade. However, as ships involved in maritime accidents continue to grow in size and speed up, one incident, such as an oil spill from a "super" tanker or the blocking of the Suez Canal when a "mega" container ship ran aground, could have catastrophic and long-term consequences marine ecosystems, the environment and local and global economies. Maritime accidents are complex and are caused by a combination of events or processes that can ultimately lead to the death of people and marine habitats, as well as irreversible environmental and economic damage [1-3].

The increase in the number of vessels and the intensity of their movement leads to accidents resulting from errors in the control of the movement of the vessel. Studies of maritime accidents such as collisions, crashes, groundings indicate direct or indirect human error as the root cause of such accidents, which raises many unanswered questions about the best way to prevent catastrophic human errors that have led to accidents.

One of the most promising areas that can dramatically reduce the impact of the human factor on the management of ship traffic and reduce the number of accidents and catastrophes at sea is the development and implementation of automated control systems with automatic modules [1-5].

Figure 1 shows a diagram of the ratio of gross domestic product (GDP) in international maritime trade and the ratio of maritime trade to GDP in 2006-2021 (percentage annual change and ratio).

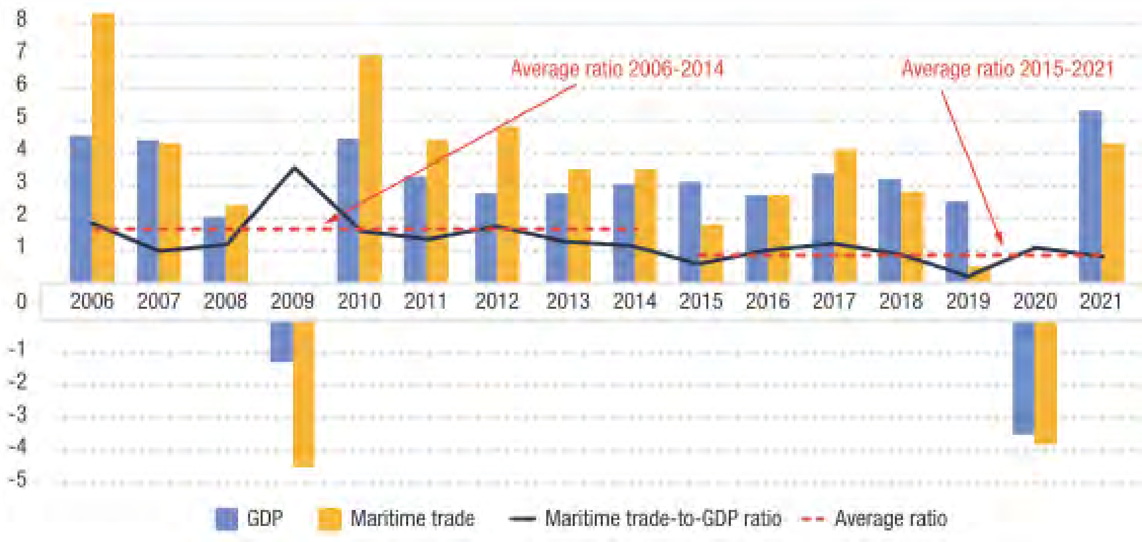


Figure 1 – GDP and Maritime Trade-to-GDP ratio 2006-2021

Relevance of research. Existing methods of optimal route planning and divergence are based on the hypothesis of absolute safety. However, ship collisions do occur and it becomes clear that the absolute safety hypothesis does not guarantee safe navigation. It is more rational to plan the route and divergence of vessels in the field of risk, which allows to take into account various uncertainties associated with errors in measuring parameters of own vessel and targets, proximity of mathematical models, errors of numerical integration, uncertainty of target behavior, etc. Therefore, the development of methods for optimal route planning and differences in the field of risks is an urgent scientific and technical task [6-26].

Problem statement. It is necessary to develop a method, algorithmic and software for optimal route planning and differences in the field of risk for use in the onboard computer of the automated traffic control system.

Results of the research. The field of risks is a set of total risks from navigation hazards $C_н(\mathbf{x})$, own risk $C_o(\mathbf{x})$, risks of other vessels - target $C_i(\mathbf{x})$ participating in the operation.

$$C(\mathbf{x}) = C_o(\mathbf{x}) + C_н(\mathbf{x}) + \sum_{i=1}^{n} C_i(\mathbf{x})$$

The summary risks depend on the uncertainty of the characteristics of the vessel and its objectives, the presence of instrumental errors in measuring the parameters of the mutual movement of the vessel and targets, the uncertainty of the behavior of targets, the cost of the vessel and cargo. The total risk has a normal loss distribution probability law and can be represented as

$$C_i(\mathbf{x}) = \frac{C_m}{2\pi\sigma_x\sigma_y} e^{-\frac{1}{2-2r_{xy}}\left[\frac{(x-x_0)^2}{\sigma_x^2} - \frac{r_{xy}(x-x_0)(y-y_0)}{\sigma_x^2\sigma_y^2} + \frac{(y-y_0)^2}{\sigma_y^2}\right]}, i = 0..n, \qquad (1)$$

The summary standard errors of uncorrelated uncertainties are found by formulas

$$\begin{cases} \sigma_x = \sqrt{\sigma_{x1}^2 + \sigma_{x2}^2 + \ldots + \sigma_{xn}^2} \\ \sigma_y = \sqrt{\sigma_{y1}^2 + \sigma_{y2}^2 + \ldots + \sigma_{yn}^2} \end{cases},$$

The summary root mean square errors of the correlated uncertainties are found by the formulas

$$\begin{cases} \sigma_x = \sigma_{x1} + \sigma_{x2} + \ldots + \sigma_{xn} \\ \sigma_y = \sigma_{y1} + \sigma_{y2} + \ldots + \sigma_{yn} \end{cases}$$

For a given risk C^*, we obtain from expression (1)

$$\frac{2\pi\sigma_x\sigma_y C^*}{C_m} = e^{-\frac{1}{2-2r_{xy}}\left[\frac{(x-x_0)^2}{\sigma_x^2} - \frac{r_{xy}(x-x_0)(y-y_0)}{\sigma^2 x\sigma^2 y} + \frac{(y-y_0)^2}{\sigma_y^2}\right]} \qquad (2)$$

After logarithmization, expression (2) will take the form

$$-\frac{1}{2-2r_{xy}}\left[\frac{(x-x_0)^2}{\sigma_x^2} - \frac{r_{xy}(x-x_0)(y-y_0)}{\sigma^2 x\sigma^2 y} + \frac{(y-y_0)^2}{\sigma_y^2}\right] = \frac{2\pi\sigma_x\sigma_y C^*}{C_m},$$

or

$$\frac{(x-x_0)^2}{\sigma_x{}^2} - \frac{r_{xy}(x-x_0)(y-y_0)}{\sigma^2 x \sigma^2 y} + \frac{(y-y_0)^2}{\sigma_y{}^2} = \frac{-4(1-r_{xy})\pi\sigma_x\sigma_y C^*}{C_m},$$

$$\begin{cases} \dfrac{(x-x_0)^2}{(\sigma_x R)^2} - \dfrac{r_{xy}(x-x_0)(y-y_0)}{(\sigma_x\sigma_y R)^2} + \dfrac{(y-y_0)^2}{(\sigma_y R)^2} = 1 \\ R^2 = \dfrac{-4(1-r_{xy})\pi\sigma_x\sigma_y C^*}{C_m} \end{cases} \tag{3}$$

The first equation of the system (3) is an ellipse shifted relative to the beginning of the basic (geographical) coordinate system by the value of x_0, y_0 and rotated by some angle (Fig. 2). The angle of rotation of the ellipse is related to the correlation coefficient r_{xy}. The total root mean square errors σ_x, σ_y and the reduced radius R, which is proportional to the given risk C^*, determine the half-axis of the ellipse. Thus, it can be seen from the system (3) that the greater the given risk C^*, the smaller the half-axes of the ellipse. In fig. 2 shows ellipses of equal risks around your own ship and targets.

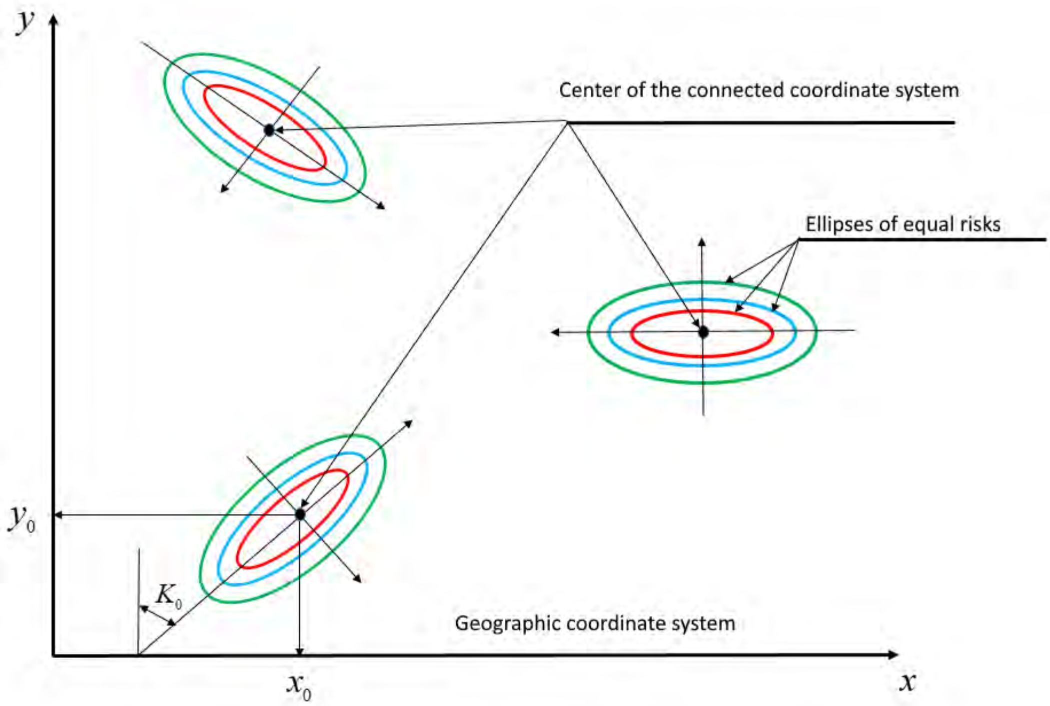


Figure 2 - Ellipses of equal risks of your own ship and targets

In fig. 3 shows the function of instantaneous risk and level line. The smoothness of this function allows the use of gradient procedures in the construction of controls.

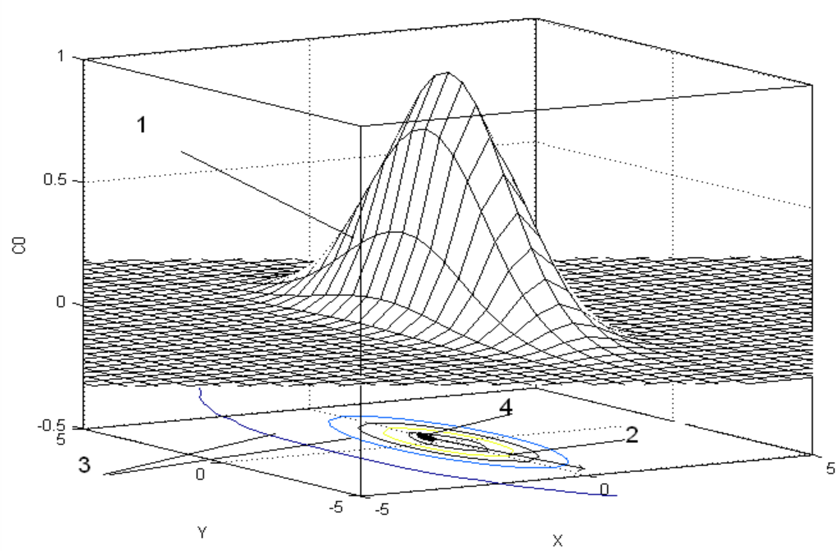
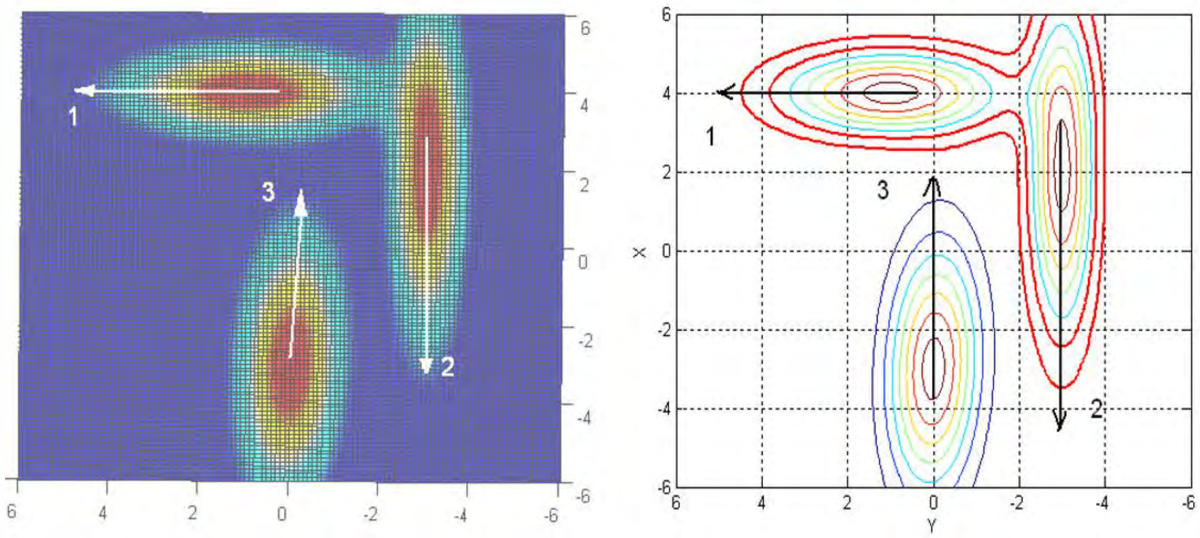


Figure 3 - Instantaneous risk function and level line

Figure 4 shows the field of risks of your own vessel and targets. Representing the scene as a field of risk allows you to create a user-friendly interface where the positions and trajectories of targets, as well as their size and the danger they pose, are easily perceived.



a) b)

Figure 4 - Risk field and level lines

Conclusion. The results of the study suggest that the method of solving the problem of ship divergence using the risk field provides:

• optimality of trajectories of movement at not exceeding the set risk and minimum of a way of maneuver;

• clarity of visualization of the navigation situation, simplicity of the calculation algorithm;

• a new principle of improving the safety of navigation was considered, which takes into account the interests of all participants in the operation at the stages of route planning, movement of the vessel along the route and during divergence, which reduces collision risks and increases safety;

• developed a method of constructing the risk field of own vessel and target vessels, which is to use as a ship's domain the total risk distribution around own vessel and target vessels, taking into account measurement, calculation errors and other uncertain factors to reduce collision risks and increase maritime safety;
• developed a method of constructing a total risk field, which consists in imposing risk fields of own vessel, target vessels, risk fields of other navigational hazards, which allows to obtain analytical expression of risk field, risk field level lines for visualization and further numerical processing in the onboard computer vessel traffic control.

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