SOLUTION OF THE PROBLEM OF OPTIMIZING ROUTE WITH USING THE RISK CRITERION

Mamenko P.P, Zinchenko S.M., Tovstokoryi O.M., Mateichuk V.M., Kyrychenko K.V., Moiseienko V.S.
Kherson State Maritime Academy
(Ukraine)

Introduction. Sea transportation provides about 90% of world trade, which leads to an increase in the number and tonnage of ships, as well as the intensification of human activity at sea. The issue of safety and trouble-free operation of shipping is still a key issue today, since the number of accidents at sea is practically not reduced, annually claiming human lives, causing significant damage to the global economy and harm to the environment. According to statistics, about 70% of the causes of accidents at sea is the "human factor". The influence of the human factor on the accident rate in maritime transport is investigated in the works of many authors.

Automatic control systems can radically reduce the influence of the human factor on the ship's control processes, since the operator decides only on the use of the automatic module, and further control of the ship is provided by an automatic control system, some of which are considered, for example, in [2-12].

Particularly important is the factor of the emergence of autonomous ships and systems, the actions of which have a clear algorithm and a specific goal. Thus, it becomes possible to reduce the uncertainty in the task of forecasting the actions of ships, which expands the possible range of actions of own ship. The simplest method of preventing collision of ships is maneuvering by changing the course or speed of own ship [1,8]. A more efficient method is to determine a safe trajectory of the vessel, taking into account the trajectories of all vessels involved in the operation. However, there is considerable uncertainty associated with the actions of the courts in the divergence process. Uncertainty reduction can be achieved if the actions of own ship are consistent with those of other ships. This task requires the use of optimal control methods.

Relevance of research. Recently, the intensity of shipping has increased significantly, autonomous ships and transport systems have appeared, the traffic control algorithms of which obviously require an optimal approach. The criterion of optimality is the minimization of risk along the entire route. In this regard, the problem of finding a control algorithm that delivers the best results for all participants in the operation is urgent. The ability to obtain a general solution to the problem of optimal ship control makes this study expedient.

Problem statement. The task of optimal plotting of a course first of all requires the determination of an optimality criterion or goal function. It becomes necessary to plot the trajectory of the vessel $S(x)$ in such a way as to avoid possible collisions, loss of cargo and other complications. This need is formulated as minimization of the risk C on the trajectory of the vessel. Obstacles to navigation are expressed by constraints such as the equalities $\varphi_i(x) = 0,$ $i = 1..m,$ and inequalitie, $\varphi_i(\mathbf{x}) < 0,\ i = m = 1,\ldots,n$, that is, we obtain the Lagrange problem.

$$\mathbf{x}^* \to \min C(S(\mathbf{x})),$$
$$\varphi_i(\mathbf{x}) = 0,\ i = \overline{1.m} \qquad (1)$$
$$\varphi_i(\mathbf{x}) < 0,\ i = \overline{m.n}$$

Research results. The well-known technique for solving this problem involves the formation of the Lagrange function $L(x, \lambda)$, the gradient of which on x^* vanishes:

$$\frac{\partial L}{dx} = 0 \quad ,$$

$$L(x,\lambda) = \lambda_0 S(x) - \lambda_1 \varphi_1(x) - \lambda_2 \varphi_2(x), \quad gradL = 0, \rightarrow \ \frac{\partial L}{\partial \lambda_1} = 0 \ , \qquad (2)$$

$$\lambda_2 \varphi_2(x) = 0$$

Condition (2), known as the Kuhnna-Tucker theorem, defines the optimum point as a point stationary in the coordinate when constraints such as equality are satisfied and the goal function is insensitive to constraints such as inequality. In this simple but important problem, let us trace the meaning of the Lagrange multipliers λ :

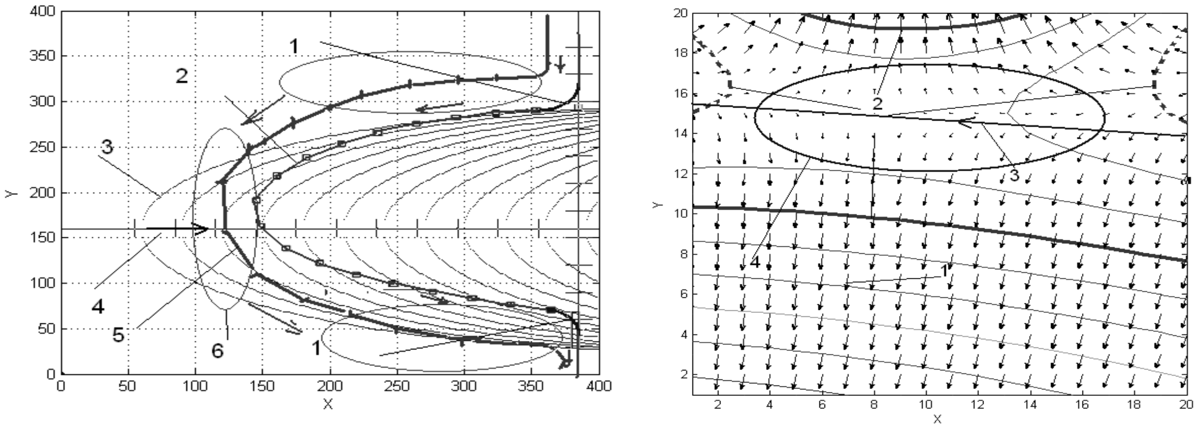
$$gradL(x, \boldsymbol{\lambda}) = 0 \rightarrow \frac{\partial S}{\partial x} = \lambda \frac{\partial \varphi}{\partial x} \quad \rightarrow \quad \lambda = \frac{\partial S}{\partial \varphi}. \qquad (3)$$

Taking into account the meaning of Lagrange multipliers (3), we can write down the optimality condition in problem (4):

$$\frac{\partial S_i}{\partial S_j} = 0; \quad i = \overline{1,n}; \quad j = \overline{1,n}; \quad i \neq j;$$
$$i \neq j \rightarrow \frac{\partial S_i}{\partial S_i} = 1. \qquad (4)$$

From condition (9) it follows that the optimal solution should not worsen any of the solutions, that is, the components of the goal vector are independent and their states do not affect each other. This result is known as the Pareto criterion or the Jeffrion effective solution].

In fig. 1 shows the results of mathematical modeling of the processes of divergence of ships. In fig. 5a shows a divergence trajectory 5 with one vessel, built for the case of no intersection of the zones of a given risk 3, 6. In this case, the sliding trajectory 2 is repeated with an offset to the minor axis of the self-risk ellipse.



a) b)

Figure 1 – Results of mathematical modeling of ship divergence processes

In fig. 5b shows the results of mathematical modeling of divergence processes with several vessels. In this situation, the intersection of the lines of the given risks 2 and 4. To ensure the optimal divergence, in this case, the movement is organized along the minimum of the gradient.

Conclusions:

– for the first time, the problem of optimal control of a system of dynamic objects with a vector – a functional goal was posed and solved;

– optimality of control is achieved due to optimization of the vector – functional on the entire trajectory of motion;

– the problem of optimal control with a vector – the goal functional, when fulfilling the hypothesis of the convexity of the integrands of the components of the vector – goal functional, is solved using the methods of the calculus of variations;

– as a result of solving the optimal control problem, a simple algorithm for constructing the optimal trajectories of the ship's movement during the divergence maneuver was obtained;

– an algorithm for constructing the optimal trajectory of the vessel's movement using risk fields has been obtained;

– mathematical modeling of divergence processes with one or more vessels was carried out using the risk criterion.

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