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THE CRITERION OF EFFECTIVENESS OF ANTI-COLLISION MANOEUVRES

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Abstract. Analysis of the history of navigation allows making the conclusion that the task of planning of anti-collision manoeuvres is a multi-purpose. In solving this task it is necessary to use several partial criteria of efficiency and then combining them to produce a generalized criterion for assessment of the efficiency of measures for the collisions prevention. Partial criteria should describe all important aspects of collision avoidance system (CAS) goal, but it is desirable to reduce amount of them to a minimum. In this paper the generalized criterion for assessment of efficiency of plans for collision avoidance with a few ships by successive changes of course is offered. It describes such important aspects of purpose of the collision avoidance system as safety, done early, substantiality and economy of recommended by this system actions. The offered criterion can be used in CAS and ECDIS for an assessment of anti-collision manoeuvres efficiency.

KEY WORDS: collision avoidance, manoeuvre of ship, criterion of efficiency.

1. INTRODUCTION

Questions of criteria selection for the assessment of efficiency of plans for the safe passing by other ships are examined in many literary sources, dedicated to the problems of navigation, for example, in books [1, 2]. Quantitative determination of the collision risk in the process of ships approach and assessment of efficiency of chosen anti-collision actions are discussed, in particular, in works [2, 3, 4]. Different methods are offered for the solution of such tasks. Usually these methods are based on using a single criterion of efficiency with application of probabilistic approach to the assessment of planned manoeuvres. The accounting of uncertainties, which can not be described in terms of probability and that are present in the problems of collision avoidance, are not fully worked out yet. Therefore, the task is to develop a generalized criterion of efficiency for the assessment of the effectiveness of anti-collision plans in conditions of uncertainty of fuzzy nature.

2. REQUIREMENTS TO THE PLAN OF ACTIONS FOR COLLISION AVOIDANCE

On the basis of the analysis of requirements and recommendations of COLREG and usual sea practice it is possible to define that when planning actions for elimination of collision threat such purposes are pursued:

- safety;
- done early;
- substantiality;
- sparing (collision avoidance should not be accompanied by the considerable increase Δ_S of the vessel path).

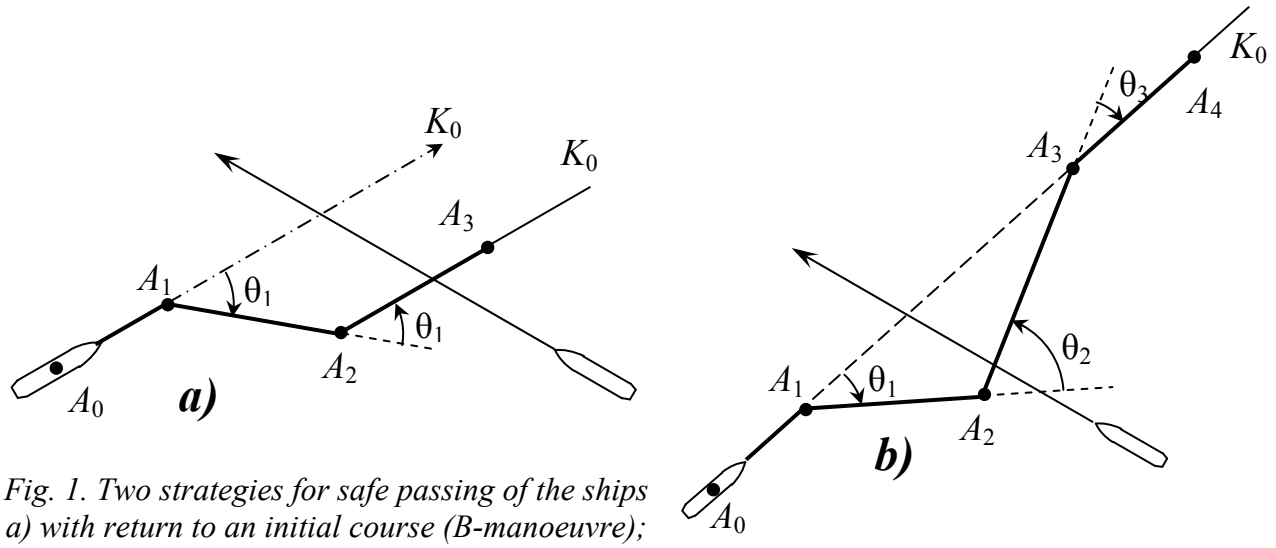


Fig. 1. Two strategies for safe passing of the ships a) with return to an initial course (B-manoeuvre); b) with return to the set line of the route.

Generally strategy of course changes for avoidance of close quarter situations with other vessels includes some turns and consists of straight line segments, i.e. is piece-continuous. Turn angles from one segment to another should not be small. From the beginning to the end of the fulfillment of anti-collision plan own ship (OS) in relation to all targets is «give-way» vessel. For an example two simple strategies for safe passing by the targets are given in fig. 1. The first $A_0A_1A_2A_3$ of them includes three, and the second $A_0A_1A_2A_3A_4$ - four pieces. On this picture K_0 is the initial course, and θ_i - angle of turn.

In any of segments of route for collision avoidance there must not be excessive approach of OS and targets. Besides, when the OS will approach the route turn points the targets should not be necessarily of the adoption of manoeuvre to evade the OS. It is especially unfavorably, when in this case the target becomes "give-way" vessel and with a high probability may accept the action interfering implementation of the OS plan. Therefore the first requirement to strategy for close quarter situations avoidance is necessary to divide into two parts:

- absence of excessive approach OS and targets at OS motion on the planned route;

– absence of need of targets manoeuvres for collision avoidance with OS in the process of fulfilling plan by OS.

Formalization of these purposes isn't very difficult, but at the further consideration the second of them is ignored for simplicity.

3. METHOD OF ANTI-COLLISION ACTION ASSESSMENT

The criterion of effectiveness of anti-collision plans must quantitatively reflect degree of these plans compliance to the set purposes. The task of an assessment of efficiency of multi-purpose system is difficult. Therefore, the numbers of the purposes are to be reduce to one, using additional restrictions on selected decisions or other methods. If such reduction affects the correctness of the obtained results, the methods of assessing the efficiency of multi-purpose systems are used. The selection of the suitable criterion, allowing to judge about efficiency of multi-purpose system, depends on that, how deeply this system is studied by the persons defining criterion. The prepared recommendations do not exist on the selection of efficiency criterion for control system of all kinds. Now there are many procedures for the solution of multi-purpose tasks [5]: method of main component; method of concessions, method of complex criterion, Germeyer's method, method of a fair compromise, method of the conditional centre of masses, method on the basis of Harrington's function, a method of an ideal point, Pareto's method, a graphic-analytical method, LPt – search, etc.

For an assessment of efficiency of ship anti-collision strategy we chose the method in something similar to the method of an ideal point. Setting the limits $D^{\underline{S}}$, $T^{\underline{S}}$ of safe values of CPA (D) and TCPA (T), taking into account the preferable angle $\theta^{\underline{P}}$ of deviation (θ) from the course and necessity to avoid the substantial increase Δ_S of the path, a navigator, essentially, determines the desired (ideal) parameters D_R, T_R, θ_R, Δ_{SR} to solve the task. Usually values $D^{\underline{S}}$, $T^{\underline{S}}$, $\theta^{\underline{P}}$ correspond to manoeuvres, which are recommended by COLREG. Taking into account, that these manoeuvres are not recommended, the allowed by COLREG actions, and forced measures, caused by non-fulfillment by another vessel the duties to remove the threat of collision. Manoeuvres with crossing of target course on a bow and turns in not recommendable side are the examples of the first actions. For not recommended and forced actions desirable values D_R, T_R, θ_R should be greater than $D^{\underline{S}}$, $T^{\underline{S}}$, $\theta^{\underline{P}}$. In these cases not less than 1.0 coefficients k_D, k_T, k_θ are applied to obtain D_R, T_R, θ_R on values $D^{\underline{S}}$, $T^{\underline{S}}$, $\theta^{\underline{P}}$. These coefficients depend on nature of not recommended and forced actions. Commonly desirable values of parameters D_R, T_R, θ_R, Δ_{SR} can be written down in a look

$$D_R = k_D \cdot D^{\underline{S}}, \quad T_R = k_T \cdot T^{\underline{S}}, \quad \theta_R = k_\theta \cdot \theta^{\underline{P}}, \quad \Delta_{SR} \to 0; \qquad (1)$$

where for recommended by COLREG action k_D, k_T, k_θ are equal to 1.0.

Determination of efficiency of multi-purpose systems, to which CAS belongs, includes finding of partial criteria and their association (convolution) in the generalized indicator of system effectiveness. In this work determination of partial criteria is based on application of fuzzy logic. Advantage of such approach consists in simplicity of quantitative assessment of efficiency of the systems with quality purposes.

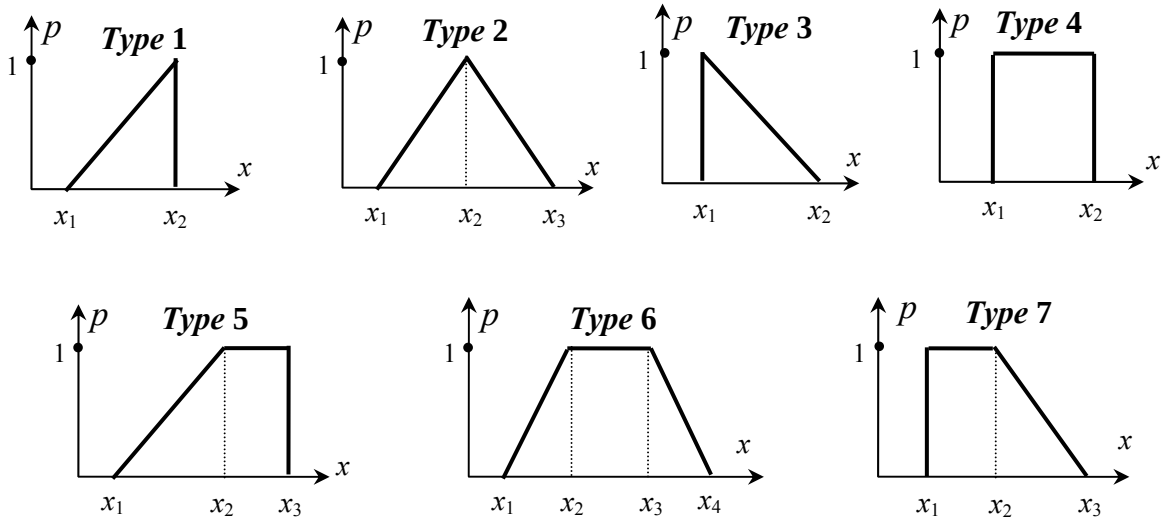


Fig. 2. Possible types of functions of desirability

Sometimes functions of desirability [5] are applied to the formalization of partial indicators of systems efficiency. Most widespread of these functions are submitted in fig. 2. The function of desirability varies from zero in the field of unacceptable values to one, when the value of the analyzed indicator of the efficiency is the best. As a result all quality and quantitative indicators are presented in a single dimensionless scale, that allows to produce comparison of this indicators and simplifies procedure of convolution of them in the generalized criterion.

Partial criteria for the assessment of anti-collision plan efficiency are accepted to the degrees p_D, p_θ, p_T, p_E of compliance of values D, T, θ, Δ_S, answering to this plan, to the levels: of safety (D_R), of substantiality (θ_R), of done early (T_R) and of sparing (Δ_{SR}). The following functions of desirability correspond to the chosen private criteria

$$p_D = F_D(D_M);\ \ p_T = F_T(T/T_R);\ \ p_\theta = F_\theta(\theta);\ \ p_E = F_E(\Delta_S). \qquad (2)$$

These functions are represented in fig. 3-6.

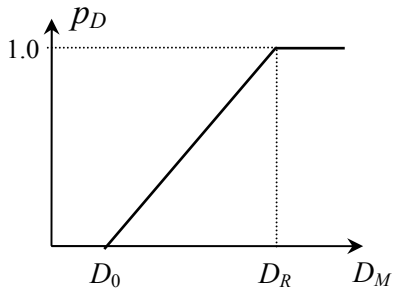


Fig. 3. Function $p_D=F_D(D_M)$

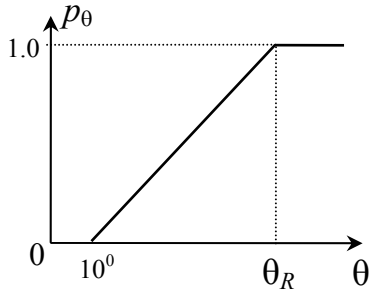
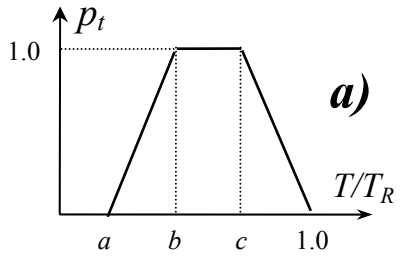


Fig. 4. Function $p_\theta=F_\theta(\theta)$



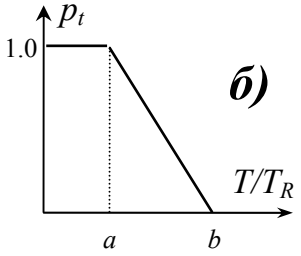


Fig. 5. Function $p_T=F_T(T/T_R)$
a) for "give-way" vessel; b) for "stand-on" ship.

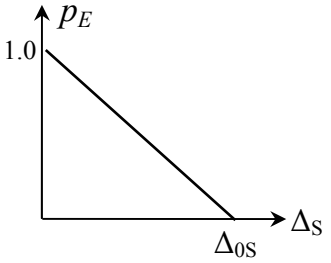


Fig. 6. Function $p_E=F_E(\Delta_S)$

The argument D_M of the first function is the minimum of distances from "give-way" vessel to other ships and to the border of safe in the navigation water area in the process of future implementation of anti-collision plan by "give-way" vessel. Parameters of the selected functions of desirability are defined by experts on the basis of experience of the solution of collisions avoidance tasks in various sailing conditions, on the analysis of requirements of normative documents and on the accounting of some other factors.

After the definition of partial criteria method of convolution of these criteria in the generalized criterion P_0 of the system efficiency is selected

$$P_0 = F_0(p_1, p_2, ..., p_n). \qquad (3)$$

where p_j - partial criteria of system efficiency.

The type of convolution function is defined on the basis of the careful analysis of the task being solved and the relationships of its purposes. On the example of system with two purposes the most widespread procedures of association of partial criteria are given below:

$$P_0 = (p_1 + p_2)/2;$$

$$P_0 = \frac{w_1 \cdot p_1 + w_2 \cdot p_2}{w_1 + w_2}, \text{ where } w_1, w_2 \text{ - weights of the purposes;}$$

$$P_0 = p_1 \cdot p_2;$$

$$P_0 = MIN(p_1, p_2).$$

For receiving the generalized criterion of anti-collision plan efficiency such convolution function is chosen

$$P_0 = \delta(\mathrm{x}) \cdot \frac{w_D \cdot p_D + w_\theta \cdot p_\theta + w_T \cdot p_T + w_E \cdot p_E}{w_D + w_\theta + w_T + w_E},$$

(4)

where w_D, w_θ, w_T, w_E - weights of p_D, p_θ, p_T, p_E;

$$x = p_D \cdot p_T \cdot p_\theta;$$

$$\delta(x) = \begin{cases} 0 \; at \; x \le 0 \\ 1 \; at \; x > 0 \end{cases}.$$

Analysis of the collision avoidance task shows that partial criteria have various importances in the solution of this task. Therefore, the values of partial criteria are taken with different weight at convolution. Experts appoint these weights, proceeding from idea of comparative importance of partial criteria.

Adequacy of the offered generalized efficiency criterion to the purposes of the task of the collisions prevention was checked by means of the created imitating model of processes of ships manoeuvring. The algorithm of search of the best variant of the safe passing by encountered ships is used in this model. The results of simulation showed suitability of the offered generalized criterion of efficiency for development of the recommendations to prevent collisions.

4. SUMMARY

The advantage of the offered generalized criterion of efficiency is the possibility of assessment of anti-collision plans taking into account the main requirements of COLREG.

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