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COLLISION AVOIDANCE ACTIONS PLANNING

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Abstract: Traditional planning of actions for preventing a close quarter situations with other vessels has the row of failings. Therefore we develop alternative approach to the decision of this task, based on the use of graphic elements (area marks) reflecting limitations of targets on motion and manoeuvres of own ship (OS). For assessment of situations danger the area marks at targets' closest points of approach (CPA) are offered. On the collision avoidance system (CAS) display these marks are shown in the field, which is safe for movement and manoeuvres. CPA area marks give the clear picture of dangerous regions distributed along OS way. These area marks are expedient to apply also for prognostication of situation after circulation, speed alteration and course change. One of widespread anti-collision actions is B-manoeuvre, which in a number of sources is called as Z-manoeuvre. The graphic elements - marks of predicted area of danger at B-manoeuvre (PAD_B), are effective at the choice of this action. PAD_B is the area, which reflects limitations of targets on B-manoeuvre of OS. If necessary, PAD_B marks can be applied for forecasting of other anti-collision actions. The offered method considerably simplifies planning of preventing collision strategies in the dialog mode with CAS. It can be used in marine CAS, ECDIS and modern radars.

KEY WORDS: collision avoidance, B-manoeuvre, Z-manoeuvre, predicted area of danger, manoeuvre selection.

1. INTRODUCTION

An encounter situation of ships should be shown in a kind that allows assessing this situation operatively and facilitates the choice of anti-collision action. The "operative" here designates possibility of rapid recognition of safe, limiting, potentially dangerous targets and OS duty to give road or to save former course and speed. Reflection of collision risk distributing along the OS path is important also. The last circumstance consists of selection of regions, where limiting and dangerous targets will appear close to the OS. The relative and true motion vectors and also predicted areas of danger (PAD_K), which reflect limitations of targets on course alteration of OS, is traditionally used for assessment of encounter situation and selection of anti-collision actions [1-4]. Such elements scarcely can be considered effective enough for making decisions on collisions prevention. Therefore the problem of development of an alternative method for selection of anti-collision actions was set. At consideration of this problem solving direction and length of vectors at the symbols of vessels position on figures below characterize these vessels course and speed over ground.

2. METHOD FOR PROBLEM DECISION

The area marks of targets closest points of approach (CPA) are offered for assessment of encounter situations danger [5]. On the CAS display these marks are shown in the safe for motion and manoeuvres region – MMR (fig. 1). On this figure OS has number 0, and targets - 1, 2, 3, 4. It is expedient to represent MMR by right and left bars, direction of which coincides with the line of OS way. The external scopes of these bars must cut off dangerous in the navigational respect water areas. A MMR is determined by width (ξ_S, ξ_P) of its bars and border angle (γ) of deviation.

Every target CPA area mark includes target number at CPA, dotted and continuous segments. CPA is initial point of both segments. The first segment is directed on the target and second - on the CPA of OS. Distance at closest points of approach (DCPA or $\overleftrightarrow{d}$) is the interval between the target CPA and CPA of OS.

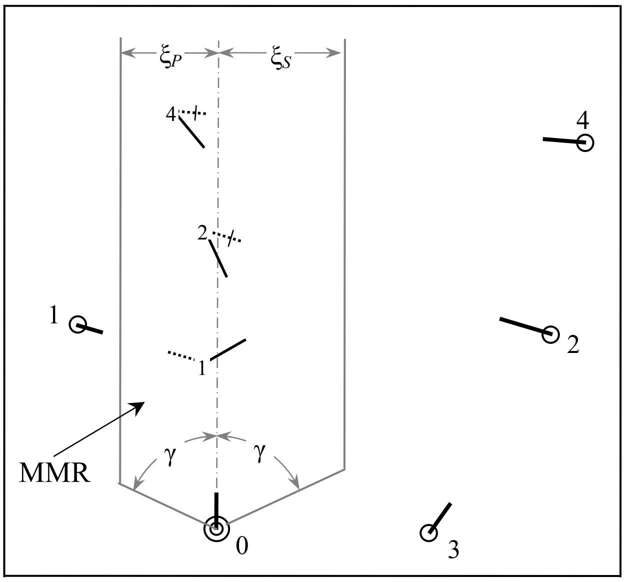


Fig. 1. Target CPA area marks for collisions threat assessment

Continuous segment length of target CPA area mark is equal to the set limit d^s of the safe DCPA values. If this segment crosses the OS future path, the target represents the threat. Among a few such targets the most dangerous of them has the nearest to OS area mark of CPA. There is the ship No.1 in the situation shown on the fig. 1. On the target CPA area mark it is easy to set, whether OS crosses target course ahead or astern. To allocate the targets, the course of which is crossed astern, the dotted segment of its CPA area marks may be intersected as shown on the fig. 1.

Anti-collision strategies may include course (K) or/and speed (V) alteration, circulation and shift to the parallel line of way (B-manoeuvre). It is offered for planning of these actions to use target CPA and PAD_B marks. The last elements reflect limitations of targets on B-manoeuvre of OS. In a number of sources the B-manoeuvre is called as Z-manoeuvre.

B- or Z-manoeuvre (fig. 2) is characterized by shifting distance ξ and the angle of deviation $и$ from an initial path [5]. The initial OS course we designate $K_{Ш}$, the course of deviation to the port - K_P, and to the starboard - K_S. The point F determines B-manoeuvre. The angle $и$ is selected in the range $10^0 \div 150^0$.

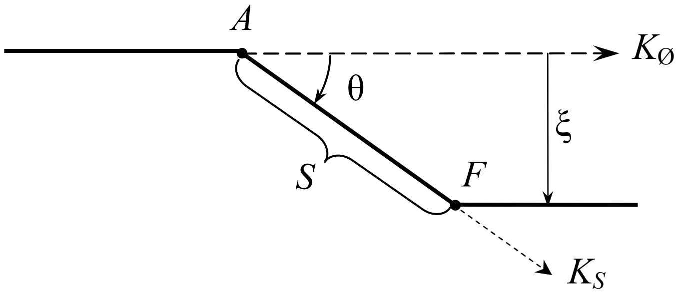


Fig. 2. Simplified B-manoeuvre presentation

For B-manoeuvres selection angle γ of MMR is adopted equal to angle $и$. On fig. 3,*a* PAD_B mark is shown in the right MMR bar. Offered PAD_B mark consists of the target number, dotted and continuous (*MZ*) segments. The first segment is directed on the target. Segment *MZ* is determined by coordinates A_M, A_Z, B_M, B_Z. First two coordinates show on OS path the points, in which course alteration on angle θ results in passing by the target at distance $d^{\underline{s}}$. The same DCPA will be, when OS returns to the former course at points B_M, B_Z. The algorithm of segment *MZ* coordinates calculation is submitted in work [6].

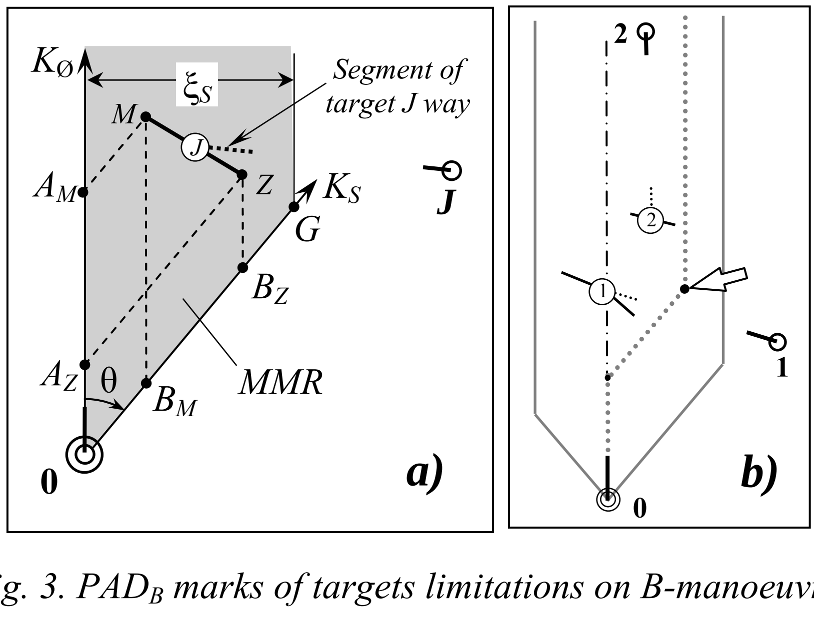


Fig. 3. PAD_B marks of targets limitations on B-manoeuvre

Target J is dangerous, when its PAD_B mark continuous segment crosses the OS path. The part of such mark for course alterations to the starboard does not appear in the left bar at display on the screen. Part of the dangerous target PAD_B mark for course alterations to the port is not shown in the right bar of MMR accordingly. In both MMR bars PAD_B mark of dangerous target contains the shown parts of continuous segment of marks for course alterations to the starboard and to the port. Such general mark is represented on the fig. 3,*b* for target No. 1. Principle of B-manoeuvre planning by the cursor is characterized on the fig. 3,*b*. The B-manoeuvre is safe, when the planned OS path does not cross the continuous segment of PAD_B marks.

Shown in the table 1 parameters are used for determination of OS trajectory at the manoeuvres. In this table MOE is mode of engine operations for reaching new speed. The parameters values in the table are taken as example. On ENC the trajectory of manoeuvring ship at circulation, course and speed alteration is shown by the points, calculated on the mathematical model of ship movement. These points, for example, are possible to select proper to every second of manoeuvring process.

Table 1. Data for manoeuvres prognosis

B-manoeuvre, *K* alteration		**Circulation**	***V* alteration**	
Alteration (θ^0)	Rudder (β^0)	Rudder (β^0)	ΔV, knt	MOE
40	15	15	-5,5	Slow astern

It is offered to select special strips on the CAS display (fig. 4) to plan the manoeuvres of different types by a cursor. Modes "K-old" and "K-new" are foreseen for B-manoeuvre or course alteration planning. B-manoeuvre (mode "K-old") is set by pointing its determining point F by a cursor (fig. 5,*a*) in the proper strip of MMR (see fig. 4). This action result is always assessed on PAD_B marks. On the fig. 5 the points A and C designate start and end of manoeuvre accordingly. In the mode "K-new" the segment of course alteration on the angle и is determined by the any of this segment point. At course change planning such point (P) is set by a cursor (see fig. 5,*d*). Mode "K-new" is intended mainly for situation prognosis on the moment of OS output on the new segment of the route.

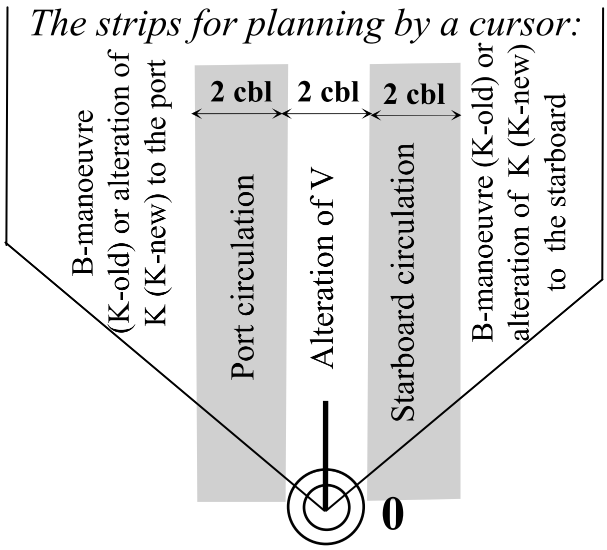


Fig. 4. Strips for manoeuvres setting by a cursor

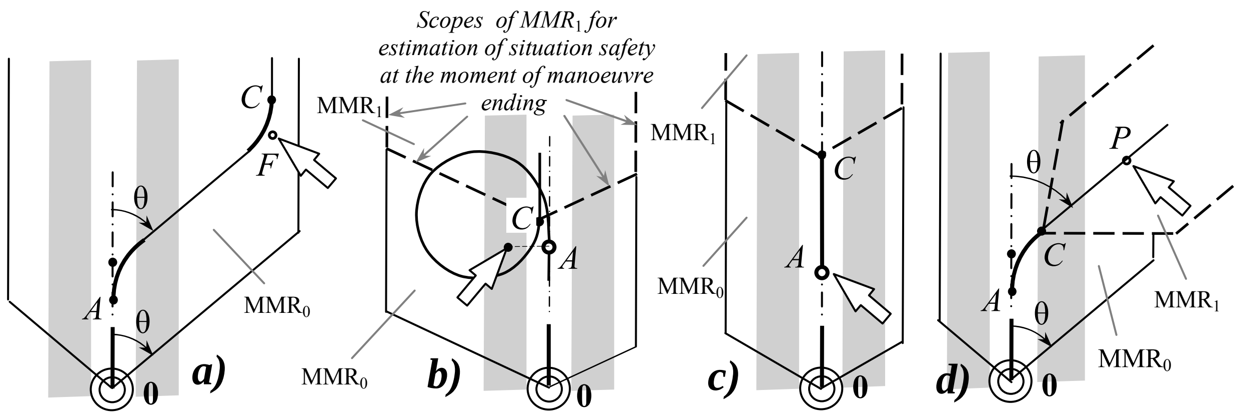


Fig. 5. Principle of manoeuvres planning by a cursor

For circulation and speed alteration the cursor specifies the position A of these manoeuvres started in proper strip of MMR (see fig. 5,*b,c*).

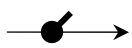
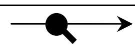
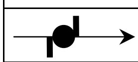
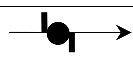
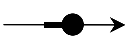
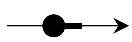
Accuracy of manoeuvre forecast gets worse with growth of time to manoeuvre start. Therefore setting more than two, maximum three successive anti-collision actions are inadvisable. In addition, existent probability of targets actions and new objects appearance require providing possibility to adjust or to replace the selected anti-collision strategy in real time.

At planning of manoeuvres it is expedient to determine:

- limiting point of safe manoeuvre beginning;
- risk of collision after manoeuvre;
- probability of close quarter situations with targets in the process of OS manoeuvring.

The limiting point of safe manoeuvres start on the future OS way allows simplifying the choice of these actions. This point may be marked as shown in table 2.

Table 2. Conditional denotations of limiting point of manoeuvre start

Denotation	Manoeuvre	Denotation	Manoeuvre
 $K_Ø$	B-manoeuvre or course alteration to the port	 $K_Ø$	B-manoeuvre or course alteration to the starboard
 $K_Ø$	Circulation to the port	 $K_Ø$	Circulation to the starboard
 $K_Ø$	Decrease of V	 $K_Ø$	Increase of V

Safety of situation after planned anti-collision actions can be assessed upon the target CPA or PAD_B marks in MMR_1 , formed for the forecast moments of these actions end (see fig. 5,*b,c,d*). It is preferable to apply the first marks, because they have less dimentions, than the second marks.

At description of prognostication of collision risk for the processes of the selected manoeuvres implementation we will note the following. Course alteration is transient. Probability of considerable change of distance to the targets in the process of this manoeuvre fulfillment is small. Therefore for the safe manoeuvre by the course the danger of collision appearance in the process of course alteration is improbable. At B-manoeuvre planning PAD_B marks allow to make sure in absence of the threat of excessive approach to targets in the process of OS manoeuvring. For circulation and manoeuvre of speed it is necessary to define the procedure for such danger assessment. Principle of this task solving is explained by the example of circulation.

The circulation we will represent in the coordinate system *A*ож, in which A is the point of manoeuvre start (fig 6,*a*). The axis $A\zeta$ of this system is directed along the initial course $K_{\text{Ш}}$. Axis $A\xi$ is perpendicular to $A\zeta$. From circulation data received on the mathematical model in the coordinate system *A*ож the period τ_M of that manoeuvre fulfillment is selected. This time is divided by n_τ intervals $\Delta_\tau = \tau_M / n_\tau$. On fig. 6,*a* n_τ value is twelve. Then values ξ_i, ζ_i are selected proper to $\tau_i = i \cdot \Delta_\tau$ of calculated coordinates of circulation points, where $i = 0, 1, 2, \dots, n_\tau$.

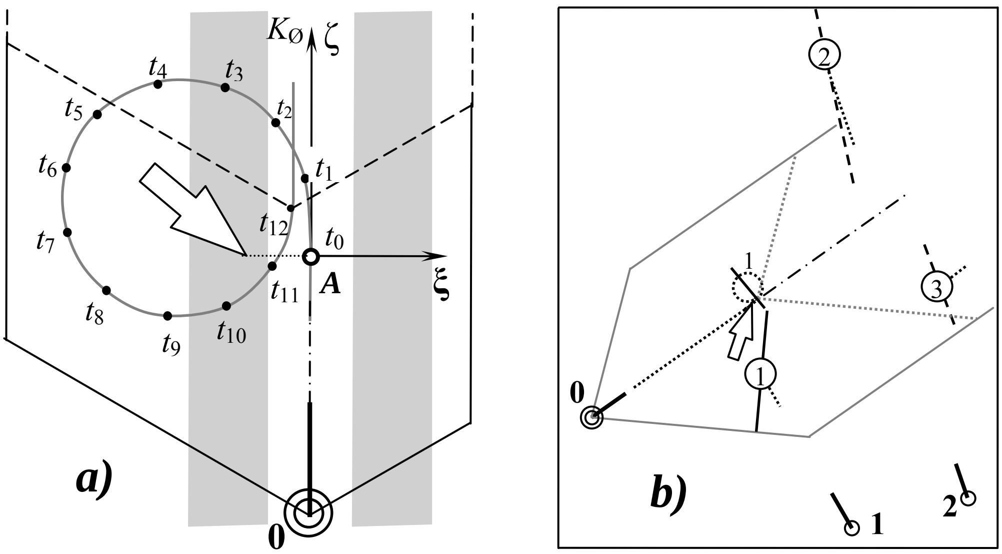


Fig. 6. For assessment of collision danger in the process of circulation

At the change of cursor position in the strip for circulations prognosis such values are determined (see fig. 6,*a*):

- the point A of manoeuvre start and moment t_0 of OS arrival to A;
- the moments $t_i = t_0 + \tau_i$ of OS arrival to the selected points;
- proper to t_i coordinates of OS, of targets and distances D_{iJ} from OS to every target, where $J = 1, 2, \dots, n$ (n - amount of targets).

The threat of collision will be in the process of circulation, if some distance D_{iJ} will appear less than $d^{\underline{s}}$. Crossing of manoeuvre trajectory by a segment (see fig. 6,*b*) or another method can be used for warning about this threat.

3. SELECTION OF APPROACH STAGES

We will designate time to closest point of approach as TCPA or $\vec{t}$ **,** and limit of TCPA safe values - as t^{s}. Three stages [6] are selected in the interval $0 < \vec{t} < t^{s}$ of two ships dangerous approach:

- timely measures done ($t^{t} < \vec{t} \le t^{s}$), where $t^{t} \approx t^{s}/2$;
- belated actions of "give-way" ship ($t^{u} < \vec{t} \le t^{t}$) , where t^{u} - border, after which both ships must adopt anti-collision actions;
- urgent measures ($0 < \vec{t} \le t^{u}$).

The first stage segment may be allocated on the displayed line of OS path (fig. 7) to facilitate the selection of anti-collision manoeuvre.

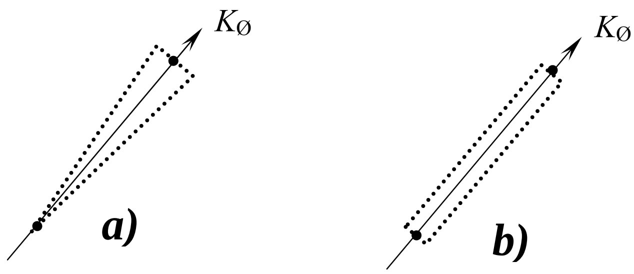


Fig. 7. Possible allocation of segment of the timely measures done on the displayed OS path
a) OS is "give-way" ship; b) OS is "stand-on" ship.

Belonging of own ship to the first ("give-way") or to the second ("stand-on") type is determined on the basis of CORLEG formalization.

When "give-way" OS plans the B-manoeuvre, the set angle θ must be substantial and not result in the superfluous loss of voyage time. Beginning of course alteration must be on the segment of the timely measures done (fig. 8,*a*).

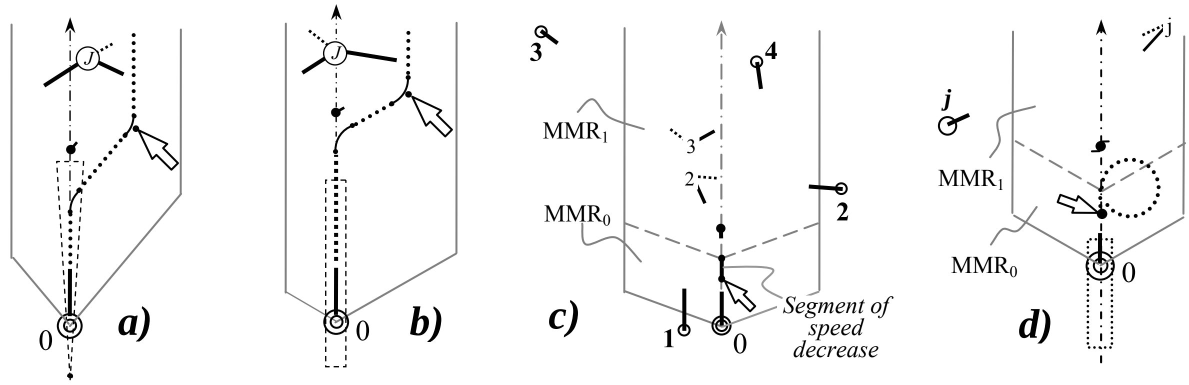


Fig. 8. Examples of manoeuvre selection

In case of non-acceptance of anti-collision action by "give-way" target, "stand-on" OS plans B-manoeuvre beginning in the area after the timely measures done segment (fig. 8,*b*). "Stand-on" OS can only undertake independent actions in those obvious cases, when the target do not act or its manoeuvre is not effective enough. Before that OS must inform "give-way" target by accessible methods that the encounter situation is dangerous.

The examples of speed decrease and circulation selection for the removal of collision threat are submitted on fig. 8,*c,d*.

4. SIMULATION REZULTS

The offered method of actions planning is characterized in the fig. 9 situation shown. PAD_B marks are used for this method explanation. On a fig. 9 they correspond to two parameters selected values: и and $d^{\underline{s}}$. The target No.3 is dangerous in the represented encounter situation, because its PAD_B mark is on the own ship way.

It admits, the circulation to the starboard with the rudder angle 15^0 is selected for preventing collision. At the end of this manoeuvre PAD_B marks are shown in the MMR_1 (fig. 10). Such circulation must be initiated after crossing the ship No.2 course on the bow. Otherwise this target will become dangerous.

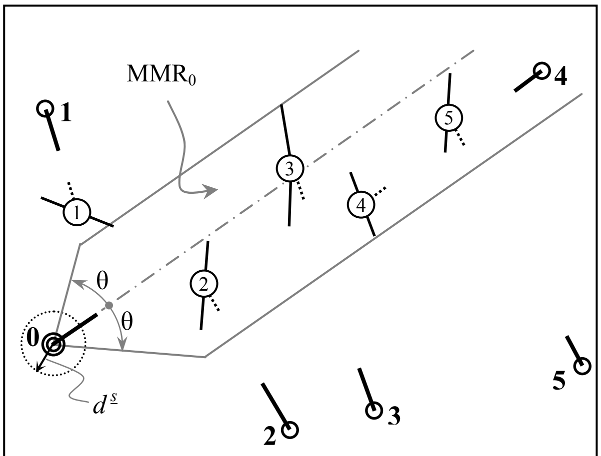


Fig. 9. Encounter situation

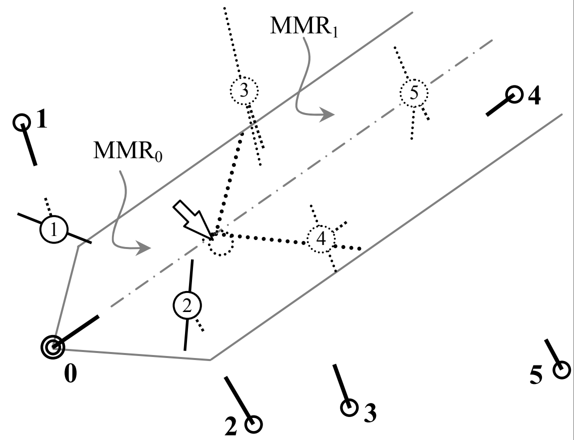


Fig. 10. Selection of the first manoeuvre

It is determined on PAD_B marks in a MMR_1 that after circulation the ship No.3 no longer represents the threat, because its PAD_B mark is not on OS path. However the target No.5 becomes dangerous. On fig. 10 butt end scopes of MMR_1 and PAD_B marks in it are dash segments. There is enough time after circulation to the moment of excessive approach to target No.5. Therefore this circulation is brought into the anti-collision plan.

Then B-manoeuvre with $и = 40^0$ is planned (fig. 11) for safe passing by the ship No.5. After determination of suitable variant of such manoeuvre it is added to the anti-collision plan. At the point of that variant action end (fig. 12) MMR_2 is formed. In this area B-manoeuvre with the angle $и = 20^0$ is planned for returning to the initial way.

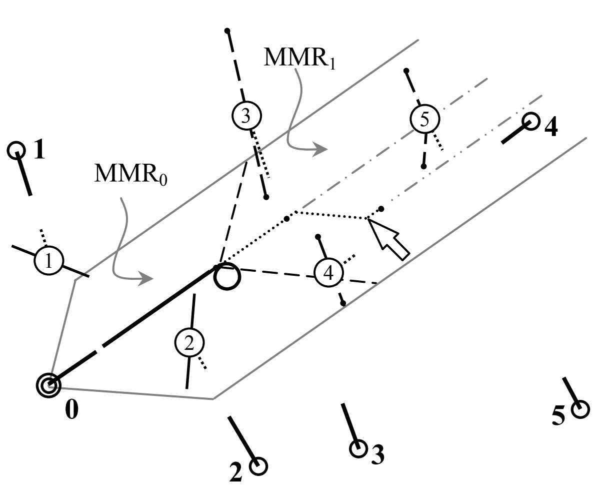


Fig. 11. Planning of the second manoeuvre

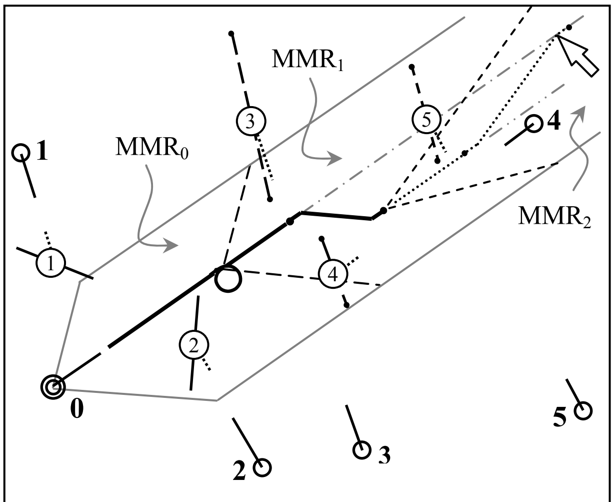


Fig. 12. Choice of returning to the initial way

The OS trajectory proper to drawn up plan is shown on the fig. 13. This plan may be fulfilled by watch officer or track control system under watch officer supervision.

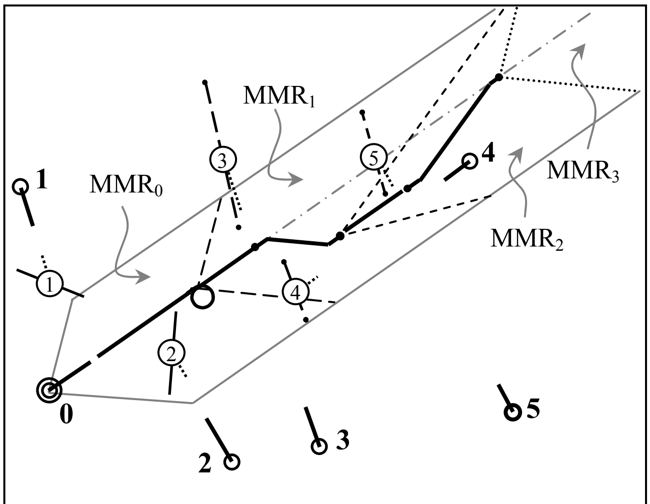


Fig. 13. Reflection of three manoeuvres strategy

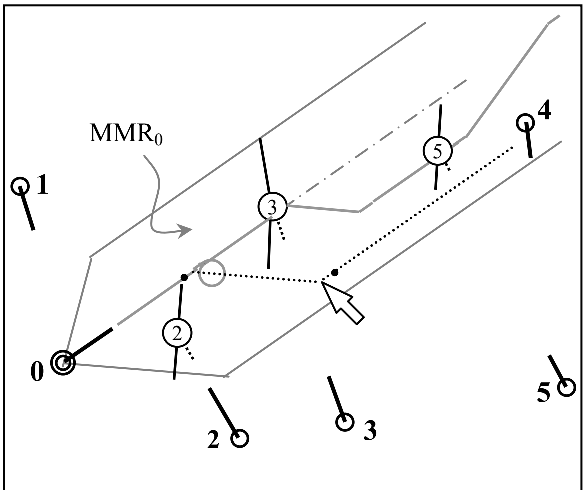


Fig. 14. Correction of anti-collision strategy

For the plan correction or replacement in real time possibility of transition to any of formed MMR may be used. If MMR_j is selected, then regions after it are not represented. In MMR_j new manoeuvre is planed. For example, when the target No.4 altered course and not limited actions of OS (fig. 14), one B-manoeuvre is planned in MMR_0 for safe passing by targets No.3 and No.5.

5. SUMMARY

The offered method simplifies planning of anti-collision strategies in the dialog with CAS.

The targets CPA area marks give the clear picture of dangerous regions distributing along OS way. These marks allow determining DCPA, TCPA and on a bow or on a stern the course of targets will be crossed. Also targets CPA area marks are expedient to use for forecasting situation after planed manoeuvres of different types.

PAD_B marks are effective at B-manoeuvre selection. If necessary, these marks may be applied for prediction results of other anti-collision actions.

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