Planned Route Based Negotiation for Collision Avoidance between Vessels

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ABSTRACT: Automatic vessel collision-avoidance systems have been studied in the fields of artificial intelligence and navigation for decades. And to facilitate automatic collision-avoidance decision-making in two-vessel-encounter situation, several expert and fuzzy expert systems have been developed. However, none of them can negotiate with each other as seafarers usually do when they intend to make a harmonious and more economic overall plan of collision avoidance in the COLREGS-COST-HIGH situations where collision avoidance following the International Regulations for Preventing Collisions at Sea(COLREGS) costs too much. A negotiation framework was put forward in our previous research to enable vessels to negotiate for optimizing collision avoidance in the COLREGS-COST-HIGH situations at open sea. In this paper, the negotiation framework is improved by considering the planned route of both vessels. The simulation results show that more economic overall plan of collision avoidance may be achieved by the improved framework when one or both parties deviate from their planed route or are approaching their next way points.

Key words: vessel collision avoidance, automatic negotiation, planned route.

1 GENERAL INTRODUCTION

Automatic vessel collision-avoidance systems have been studied in the fields of artificial intelligence and navigation for decades. And to facilitate automatic collision-avoidance decision-making in two-vessel-encounter situation, several expert and fuzzy expert systems (Chengneng, H. 2002, Coenen, F. et al. 1980, Hanjin, L. et al. 2001, 1993, Hasegawa, K. et al.1989, Iwasaki, H. et al. 1986, Koyama, T. et al. 1987, Saburo,T. et al. 1987) have been developed. However, none of them can negotiate with each other as seafarers usually do when they intend to make a harmonious and more economic overall plan of collision avoidance in the COLREGS-COST-HIGH situations where collision avoidance following the International Regulations for Preventing Collisions at Sea(COLREGS) (Leo, P. 1979) costs too much. A negotiation framework was put forward in our previous research (Qinyou, H. et al. 2006a, b) to enable vessels to negotiate for optimizing overall collision avoidance plan in the COLREGS-COST-HIGH situations at open sea. Planned routes of both vessels, however, were not considered in our previous work. As a result, better overall collision-avoidance might not be achieved when one or both vessels deviate from their planed route or are approaching their next way points.

In this paper, we have involved the planned route information in the negotiation framework. That is to say, when vessels are not proceeding on their planned route or are approaching the next way points, they would prefer to return to their planned route or to navigate on the new course line easily at the next way points when they take collision-avoidance action. Therefore, taking the vessel's planned route information into consideration when they are negotiating will enable them to achieve a better action plan to avoid collision.

This paper is organized as follows: Section 2 briefs our previous work, i.e. the CANFO negotiation framework for collision avoidance between vessels in the COLREGS-COST-HIGH situations. Section 3 improves our previous negotiation framework by considering the planned route information of the involved vessels. Section 4 illuminates the simulation results of this research. Finally, main conclusion and future researches are offered in section 5.

2 CANFO

The previous automatic Collision-Avoidance Negotiation FramewOrk (CANFO) can be defined by Equ. (1).

$$CANFO = < A, X, R, U, P, \Pi, \xi > \quad (1)$$

Where:

The Ag denotes the set of the participants involved in a negotiation, which is usually comprised of a give-way vessel and a stand-on vessel or two give-way vessels.

The X stands for the set of negotiation issues. The negotiation issues are the overall collision-avoidance plan that the vessels in Ag will negotiate on.

The R presents the reserved values of both parties. The reserved value of a stand-on vessel is the extent to which the stand-on vessel would like to compromise, while a give-way vessel's reserved value is the action plan generated by its expert system. To a give-way vessel, the negotiation result should be more economic than its reserved plan, while to a stand-on vessel, the negotiation result should not worse than its reserved value.

The U describes the utility model of each vessel in Ag .

The P is the set of the preference model of each vessel in Ag . In a two vessel encounter situation, one vessel can be either a give-way vessel or a stand-on vessel. Different role means different preference model. The preference model of a give-way vessel includes four sub-models. 1) the negotiation intention model which describes the favor degree of negotiation when a give-way vessel encounters a collision risk; 2) the collision avoidance action preference model which describes the preference to different kinds of collision avoiding action, such as turnaround, shift or both; 3) the collision risk tolerance model which describes the adjacent degree of the target vessel in space and time that the give-way vessel can tolerate; and 4) the negotiation strategy model which describes the strategies the give-way vessel will adopt in a negotiation process. The preference model of a stand-on vessel also includes an action preference model and a collision risk tolerance model, describing the same things as is in the case of a give-way vessel. Besides that, a benevolence model, which describes the extent to which the stand-on vessel may compromise in a negotiation process, is also included.

The Π denotes the set of the reasoning model of each vessel in Ag . The reasoning model of a give-way vessel will determine whether it should start a negotiation process with another vessel or not based on its expert plan and its negotiation intention model. Whether the give-way vessel need the co-operate action of stand-on vessel or not is also determined by the reasoning model. After received the proposals from stand-on vessel, the give-way vessel's reasoning model shall calculate the utilities of each proposals and determine which proposal should be accepted. At the same time, the reasoning model should generate the counter offer. The reasoning model of stand-on vessel shall generate counter offer based on its preference model, and determine whether accept the proposals received from the give-way vessel or not.

The ξ defines the negotiation protocol, which controls the negotiation process.

For more information about the negotiation framework, please consults our previous work (Qinyou, H. et al. 2006a, b).

3 IMPROVING CANFO BY CONSIDERING VESSELS' PLANNED ROUTES

When vessels are not proceeding on their planned route or are approaching the next way points, they would prefer the collision action which can enable them to return to their planned route as soon as possible or to navigate on the new course line economically at the next way point while they take collision avoidance action. Therefore, in these situations, the preferred course and speed of the vessels are not their planned course and speed which are assumed to be the preferred course and speed of negotiation participants in our previous work.

For simplicity, in this paper, we assume that vessels only alter their courses when they avoid a collision. Therefore, the calculation of the preferred course (denoted by c^{pre}) of vessels which are deviating from the planned route or approaching the next way point is the base work to improve the CANFO framework (see section 3.1).

The new preferred course will influence the definitions of the negotiation intention space of give-way vessel, utility model of the negotiation participants and the reasoning model of a negotiation responder. The new definitions will be described in section 3.2, 3.3 and 3.4 respectively.

3.1 *Calculation of* c^{pre}

1) Vessel only deviating from its planned route

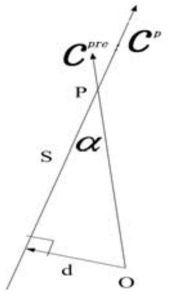

Fig. 1. Diagram for calculating the preferable course of a vessel when it deviates from their planned routes, where D is the distance that the vessel departs from its planned route; S is the distance from the vessel's present position O to its next waypoint or next planned position; c^p is the planned course.

Figure 1 shows a situation where a vessel deviates from its planned route. The c^{pre} of the vessel can be calculated by Equ. (2).

$$c^{pre} = c^{p} \pm \arcsin(\frac{D}{S}) \tag{2}$$

In (2), when the vessel is on the right side of its planned route, the operator shall be "+", otherwise it shall be "-".

2) Vessel approaching its next way point

Figure 2 illuminates the situation that a vessel is approaching a way point.

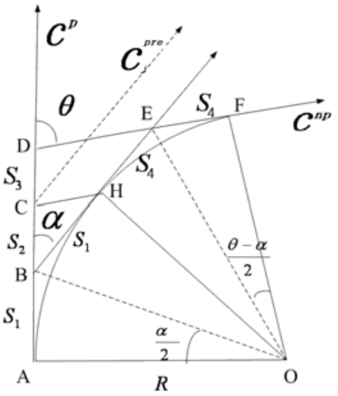

Fig. 2. Diagram for calculating the preferable course of a vessel when it deviates from their planned routes, where AD is the plan route; D is the waypoint; C is the vessel's present position

The c^{pre} in Figure 2 can be calculated by algorithm (1).

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Algorithm (1)
suppose  $s = AD, l = CD$
let  $h = tg\frac{\theta}{2}, k = \frac{l}{s}$
then  $c^{pre} = c^p \pm 2arctg\frac{h(1-\sqrt{h^2k + k - h^2k^2})}{1-h^2k}$
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3) Vessel not only deviate from its planned route but also is approaching its next way point.

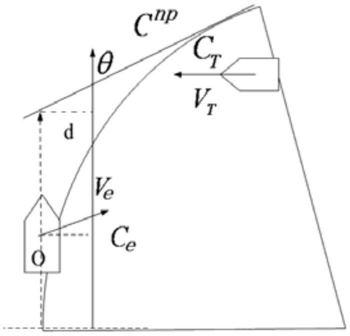


Fig. 3. Diagram for calculating the preferable course of a vessel when it deviates from their planned routes and is approaching the next way point, where d is the shortest distance from the vessel's present position to it's planned route

Figure 3 shows a situation that a vessel not only deviates from its planned route but also is approaching the next way point. While in such situations, then c^{pre} of the vessel can also be calculated by algorithm (1) with two small modifications shown in Equ. (3) and Equ. (4).

$$s = s + dctg\theta \tag{3}$$

$$l = l + dctg\theta \quad . \tag{4}$$

3.2 *Modifying the negotiation intention space of a give-way vessel*

Two negotiation intention spaces are defined in a negotiation–intention model of a give-way vessel *b*, namely *B* and *M*. $B = < \Delta_c^-, \Delta_c^+, \Delta_v^- >$ and $M = < \Theta_c^+, \Theta_c^-, \Theta_v^+, \Theta_v^- >$. If the action plan generated by the collision-avoidance expert system of *b* alone, denoted by I_b^*, does not belong to the space *B* defined (denoted by Ω_{bB}), The *b* will intend to make a negotiation with its opponent; Furthermore, If I_b^* does not belong to the space *M* defined (denoted by Ω_{bM}), The *b* will try to persuade the stand-on vessel to take a collaboration action. And if I_b^* belongs to Ω_{bM} while not belongs to Ω_{bB}, The *b* will try to persuade the stand-on vessel to permit *b* to break the COLREGS.

Given φ_b (Qinyou, H. et al. 2006a, b), the gross tonnages of *b* and a stand-on vessel *p*, denoted by g_b and g_p respectively, in the improved *CANFO* framework, *B* describes a new negotiation intention space:

$$\Omega_{bB} = < (c_b^{pre}, v_b^c), (c_b^{pre} \oplus \Delta_c^+ (\frac{g_p}{g_b})^{\varphi_b}, v_b^c + \Delta_v^- (\frac{g_p}{g_b})^{\varphi_b}) >$$

And its cost equivalent:

$$\bar{\Omega}_{bB} = < (c_b^{pre}, v_b^c), (c_b^{pre} \oplus \Delta_c^+ (\frac{g_p}{g_b})^{\varphi_b}, v_b^c + \Delta_v^- (\frac{g_p}{g_b})^{\varphi_b}) >$$

Where c_b^c and v_b^c are the current course and velocity of *b* respectively, and $\oplus$ is a course plus operator (Qinyou, H. et al. 2006a). *M* also describes a new negotiation intention space:

$$\Omega_{bM} < (c_b^{pre} \oplus \Theta_c^- (\frac{g_p}{g_b})^{\varphi_b}, v_b^c + \Theta_v^+ (\frac{g_p}{g_b})^{\varphi_b}), (c_b^{pre} \oplus \Theta_c^+ (\frac{g_p}{g_b})^{\varphi_b}, v_b^c + \Theta_v^- (\frac{g_p}{g_b})^{\varphi_b}) >$$

And its cost equivalent:

$$\bar{\Omega}_{bM} < (c_b^{pre} \oplus \Theta_c^- (\frac{g_p}{g_b})^{\varphi_b}, v_b^c + \Theta_v^+ (\frac{g_p}{g_b})^{\varphi_b}), (c_b^{pre} \oplus \Theta_c^+ (\frac{g_p}{g_b})^{\varphi_b}, v_b^c + \Theta_v^- (\frac{g_p}{g_b})^{\varphi_b}) >.$$

3.3 *Reforming the utility model*

In our previous work, we suppose that the utility of a plan is determined by its safety utility and economic utility, and the economic utility is determined by the cost of the plan. Given the plan's cost space $\bar{\Omega}_s$, its collision avoidance plan $I_s = < (c_s^c, v_s^c), (c_s^o, v_s^o), d_s >$, in the improved CANFO framework, the cost of I_s should be calculated by Equ. (5).

$$D_{I_s}(\bar{\Omega}_s) = D_{I_n}^V(\bar{\Omega}_s) + D_{I_n}^C(\bar{\Omega}_s) \tag{5}$$

Where, $I_n = < (c_s^{pre}, v_s^{pc}), (c_s^o, v_s^o), d_s >$, The v_s^{pc}, c_s^o and v_s^o are the current speed, the objective course and the objective speed of the vessel *s* respectively, $D_{I_n}^V(\overline{\Omega_s})$ return the cost of shift while $D_{I_n}^C(\overline{\Omega_s})$ return the cost of turnaround.

3.4 *Improving the reasoning model of a responder*

Given the current course of stand-on vessel c_p^c, current speed v_p^c, preference course c_p^{pre}, planned speed v_p^p, gross tonnage g_p, the course collaboration coefficient to a give-way vessel λ_c, the speed collaboration coefficient to give-way vessel λ_v and the benevolence control coefficient φ_p, for each request from give-way vessel, namely $<<(c_b^c, v_b^c),(c_b^o, v_b^o), d_b>, ?>$, the proposal space of the stand-on vessel *p*, namely $\bar{\Omega}_p$, can be calculated by Equ. (6).

$$\bar{\Omega} = <(c_p^c \oplus (-\lambda_c (\frac{g_b}{g_p})^{\varphi^p} (c_b^{o'} \oplus (-c_b^c))), v_p^p - \lambda_v (\frac{g_b}{g_p})^{\varphi_p} (v_b^{o'} - v_b^c)),$$
$$(c_p^{pre} \oplus (-\lambda_c (\frac{g_b}{g_p})^{\varphi^p} (c_b^{o'} \oplus (-c_b^c))), v_p^p - \lambda_v (\frac{g_b}{g_p})^{\varphi_p} (v_b^{o'} - v_b^c)) > \quad (6)$$

Where $c_b^{o'} \oplus (-c_b^c)$ denotes the variation of the give-way vessel's course while $(v_b^{o'} - v_b^c)$ stands for the variation of its speed.

4 COMPUTER SIMULATION

Suppose the negotiation rate between the give-way vessel *b* and the stand-on vessel *p* is 10 rounds/min. let *b*'s gross tonnage (g_b) be 15,000T, and its preference model be $P^b < P_I^b, P_S^b, P_A^b, P_R^b >$, where $P_S^b =< 0.3,1,1 >$, $P_R^b =< 2,10 >$ and $P_A^b =< 1,1,< 1,1,1,1,1,1,1,1 >, < 1/90,1/110,1/130,1/150,1/180,1/180,1/180,1/180 >>$, Let *p*'s gross tonnage (g_p) be 10,000T, and its preference model be $P^p < P_B^p, P_A^p, P_R^p >$, where $P_A^p =< 1,1,\phi, < 1/90,1/110,1/130, 1/150,1/180,1/180,1/180, 1/180 >>$ and $P_R^p =< 2,8 >$.

In crossing and overtaking situations, let $P_I^b =<< 30,30,0>,<60,60,2,2>,1,2 >$, and $P_B^p = <0.5,2,<10,0>,<0.5,0>,0.5,1>$. In head-on situations, let $P_I^b =<< 0,10,0>,<30,30,2,0>,1,2>$ and $P_B^p = <0.5,2,<0,0>,<1,1>,0.5,1>$.

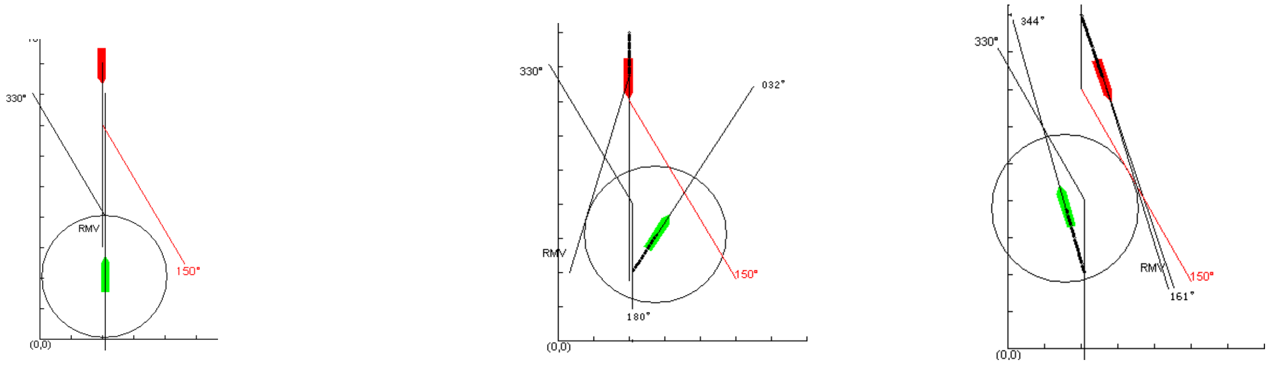
From Figure 4 to Figure 6 are the simulations of the collision avoidance negotiation in different COLREG-COST-HIGH encounter situations. In each figure, graph (a) shows the initial situation, graph (b) displays the negotiation results without considering the planned route information, and graph (c) demonstrates the negotiation results considering the planned route information.

The green vessel model represents a negotiation initiator vessel while red one represents a negotiation responder. Lines ending with number represent routes and the numbers are their courses. Lines ending with "*RMV*" represent relative motion vectors from the stand-on vessel *p* to the give-way vessel *b*.

The simulation results from these three typical situations and other more situations not presented in this paper proved the improved CANFO framework could enable the two vessels in an encounter situation to achieve a more economic overall collision-avoidance plan than our previous CANFO framework, if one or both of them deviates from their planned route or are approaching their next way point.

5 CONCLUSIONS AND FUTURE WORK

Negotiation is a very important method to optimize and coordinate the vessel collision avoidance actions taken to avoid collision. Enabling the vessel collision-avoidance (fuzzy) expert systems to negotiate with each other will greatly improve their usability. Based on our previous research, this paper took the vessel's planned route information into account and made out the influences it might bring to the negotiation framework for vessel collision avoidance. The results of the computer simulations proved that the improved CANFO framework could enable the two vessels in an encounter situation to achieve a more economic overall collision-avoidance plan than our previous CANFO framework, if one or both of them deviates from their planned route or are approaching the next way point.

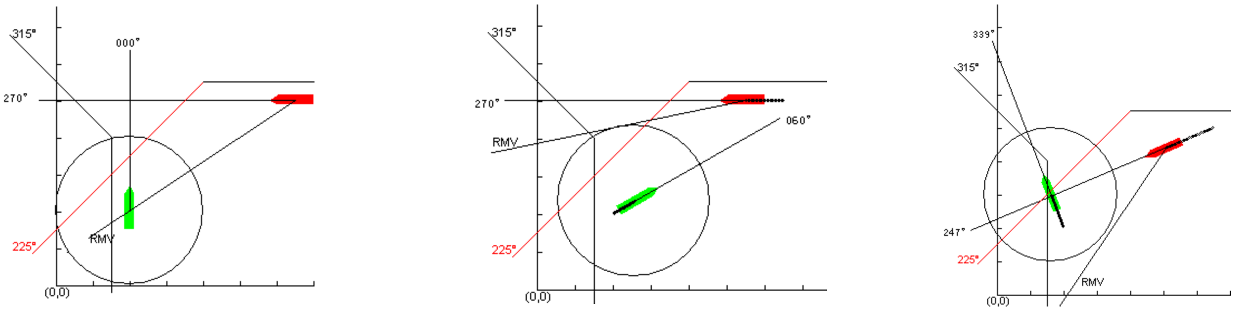


(a) Initial situation, where:
DCPA=0. 09 n miles
TCPA=11.11 minutes
Expert plan of *b*:<0°,032,starboard>

(b) Negotiation results
b:<0°,032°,starboard>
p:<180°,180°, null >
DCPA: 2.01 n miles

(c) Negotiation results
b:<0°,344°,port>
p:<180°,161°, port >
DCPA: 2.02 n miles

Fig. 4. A simulation of a head-on situation, where both vessels are approaching their next way points

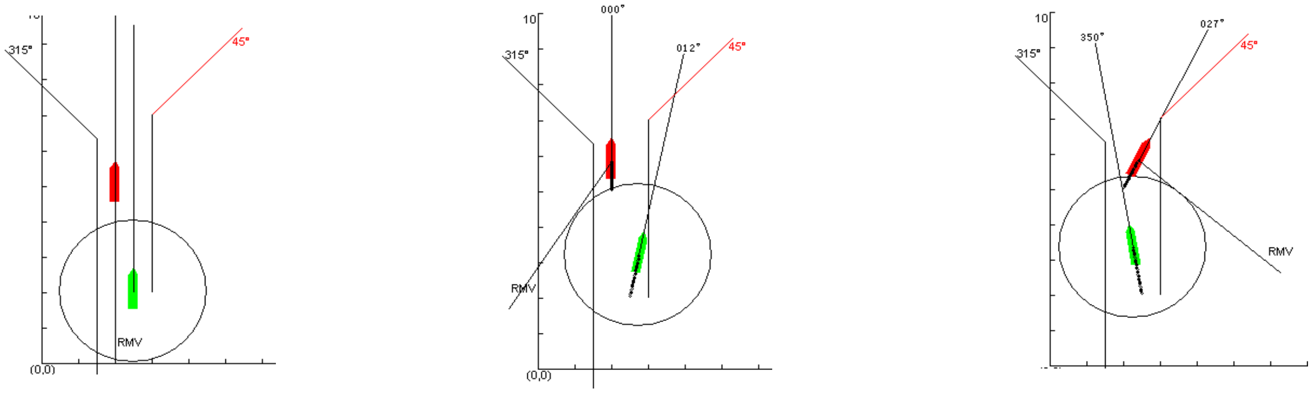


(a) Initial situation, where:
DCPA=0. 00 n miles
TCPA=18 minutes
Expert plan of *b*:<0°,060°,starboard>

(b) Negotiation result:
b:<0°,060°,starboard>
p:<270°,270°, null >
DCPA: 2.0 n miles

(c) Negotiation result:
b:<0°,339°,port>
p:<270°,247°, port >
DCPA: 2.05 n miles

Fig. 5. A simulation of a crossing situation, where both vessels deviate from their planned routes and are approaching their next way point



(a) Initial situation, where:
DCPA=0. 49 n miles
TCPA=36 minutes
Expert plan of *b*:<0°,012°,starboard>

(b) Negotiation results:
b:<000°,012°,starboard>
p:<000°,000°, null >
DCPA: 2.08 n miles

(c) Negotiation results:
b:<000°,350°,port>
p:<000°,027°, port >
*D*CPA: 2.00 n miles

Fig. 6. Simulation of an overtaking situation, where both vessels deviate from their planned routes and are approaching their next way point

The CANFO, however, is still on its starting stage. The preferred speed is also need to be considered in a negotiation when one or both vessels are not proceeding at their planned speed. And how to enable CANFO work in multi-vessel-encounter situations and in restricted waters also needs further research.

6 ACKNOWLEDGEMENTS

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