Navigator's Decision-making and Action Model - Synthetically subjective risk of collision -

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***Abstract-* The aim of this study is to generate a standard ship's navigator's decision-making and action model that might become one index for safety navigation and navigational education area. It is important for a navigator to avoid targets and secure a navigation space for the prevention of collision. In this study, a navigator' decision-making and action for avoidance is focused and navigator's decision-making and action model is illustrated. And synthetically subjective risk of collision which is possible to be a new index of evaluation for avoidance is proposed and the example of application is shown.**

I. INTRODUCTION

It is important for a navigator to avoid targets and secure a navigation space for the prevention of collision. Especially it is more difficult to do them near a coastal area and narrow sea area where is congested with traffic of ship. The traffic of ship is increasing rapidly in Japanese narrow sea area. Because many industrial zones are located at the area densely, additionally pleasure boats and fishing boats are increasing in late years. And it needs a practiced skill for the navigator to avoid targets at such a narrow sea area, but it does not generate an index and system to educate how he avoids at the area yet. Therefore it makes a strong effort to take measures for avoiding targets and securing a navigation space in Japan.

In this study, focused on the prevention of collision, a navigator's decision-making and action when he avoids a target is described. The action to avoid a collision goes through the following process in Fig. 1.

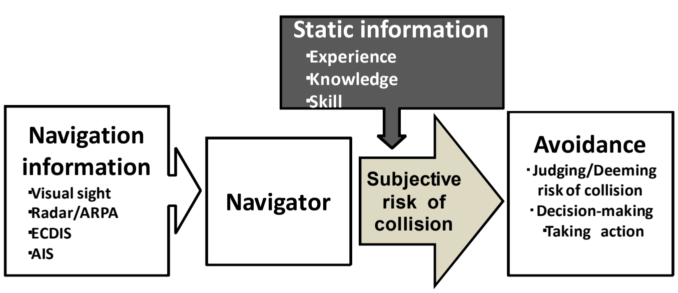

Figure 1 Navigation Information and Navigator's process

In Figure 1, A navigator always should obtain navigation information for a target during navigation by means of his visual sight and other modern navigational aids, especially Radar, Automatic Radar Plotting Aids (ARPA), Electric chart display and information system (ECDIS) and Automatic Identification System (AIS). If he judges there might be a potential risk of collision for the target, he continues an observation of the target. And he deems risk of collision for target. After he deems, he applies to navigation rules for the target. Finally he makes a decision to change course and he takes action to avoid a collision.

However his decision-making and action to avoid a collision are carried out by his subjective risk of collision that is different by each navigator. As a judgmental index of the risk of collision is underspecified, each student who does not have much experience of navigation, judges the risk of collision discretely and the student would not understand whether he was able to avoid a collision appropriately or not. Additionally, if it becomes a serious accident when a navigator misunderstands and mistakes the decision-making and action, it is difficult to assess his decision-making and action, and figure out the factor of accident because there is not the judgmental standard index as comparable. Therefore it is necessary to investigate how a professional navigator makes a decision and takes an action subjectively and to generate an index about the subjective risk of collision.

In this paper, firstly Navigator's decision-making and action model and navigation information about previous study is illustrated. Secondly SROC1 (Subjective Risk Of Collision) is expressed as a function of target's TCPA (Time to the Closest Point of Approach of target). And SROC2 is expressed as a function of target's DCPA (Distance at the Closest Point of Approach of target) is proposed by the index from result of experiment using navigation simulator. And SYSROC (SYnthetically Subjective Risk Of Collision) is consequently synthesized from the SROC1 and the SROC2, which is able to measure navigator's subjective risk to avoid a collision. Thirdly one collision case scenario is selected to assess the SYSROC, and the time change of SYSROC is expressed. Next the SYSROC is calculated and some action space to avoid a collision is expressed by maximum SYROC value at each situation when a navigator would like to change her course and speed. Finally some predicted change of SYSROC value for near future is expressed under the some courses and speeds of own ship and all targets to make possible a navigator's decision-making and action easy.

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II. NAVIGATOR'S MODEL

It is appropriate for expression of navigator's decision-making and action to use a modeling. Because a modeling is expressed a cognitive process, an activity (control and management of an artificial system etc.) and a human's characteristic for a specific purpose in the field of a cognitive science. So a navigator's model by the modeling is proposed to understand his decision-making and action process.

A. Navigator's model

First, it aims to understand a navigator's process on usual navigation and the navigator's model's is proposed referring to OFM (Operator Function Model). The OFM is clearly expressed the process and the transition on navigation [1]. In the previous study, navigator model in ferryboat have already proposed by the OFM [2]. Figure 2 shows a navigator's decision-making and action model.

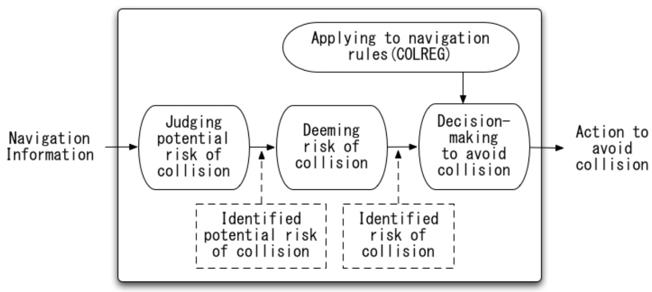


Figure 2 Navigator's decision-making and action model

In Figure 2, on the usual navigation, a navigator always collects navigation information. In case that he judges there might be a potential risk of collision for a target, he continues an observation of the target. And he deems risk of collision for the target. After he deems, he applies to navigation rules for the target. Finally he makes a decision to change course and he takes action to avoid a collision. Heretofore it was clear that navigator's decision-making and action come under the influence of the quantity of navigation information by navigational modes: his visual sight and ARPA [3].

A. Navigation information

Secondly, navigation information as the part of input in the model is described. A navigator must have a complicated skill and it is difficult process to obtain navigation information at a time in the past. For example, he must find a long-distance target by binocular glasses or his visual sight and observe it continuously, in order to understand how it closes or has risk of collision. However the computer equipment was developed for about ten years, many new navigational equipments based on computers were invented, such as ARPA which is possible to calculate target's closest point of approach (DCPA) and time to CPA (TCPA) and let him know to prevent collision automatically, and AIS which is possible to know more detailed data: target's name, destination and so on. And then he could obtain the information without the skill easily and his work changed monitoring the equipments. Although a lot of information is filled by new equipments, he should select and judge a lot of information properly. Furthermore, he cannot have much time to learn those new equipments. If he misunderstand the information, cannot make a decision and take an action smoothly or it might cause a serious accident. To understand the relation the information and navigator's decision-making and action, the navigation information flow visual sight and ARPA was proposed [4]. Figure 3 shows the most simple information flow.

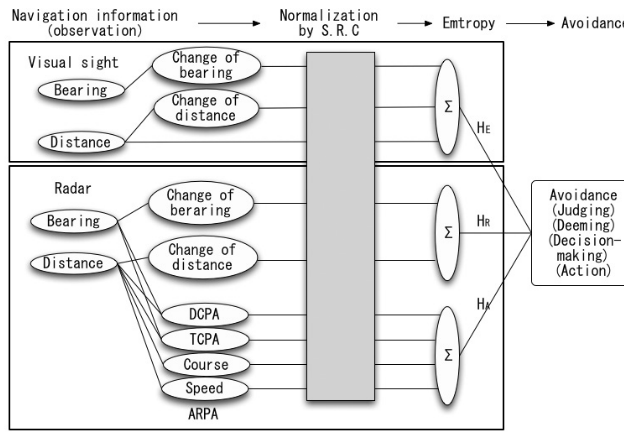


Figure 3 Navigation information flow

In Figure 3, the quantity of information by each mode is pretty different. the navigation information is related with judging risk of collision for a target directly are distance, bearing, change of distance and change of Bearing by Visual sight and ARPA included Radar, DCPA and TCPA, course and speed by ARPA. The information is normalized by a navigator's subjective risk of collision and exercises an influence on the decision-making and action.

III. EXPERIMENT

It was necessary for an analysis of the navigator's decision-making and action by each navigation mode to observe how some navigator makes a decision and take an action actually on the same circumstance. Therefore some experiments were carried out to figure out the navigator's decision-making and action process to avoid a collision. 42 professional navigators joined as experimental subjects.

A. Navigational Simulator

Our navigational simulator was set up for a purpose of wide range of maritime education and training, a research on a navigator's visual cognition and an assessment for safety navigation. Figure 4 shows a layout and a picture of the navigation simulator.

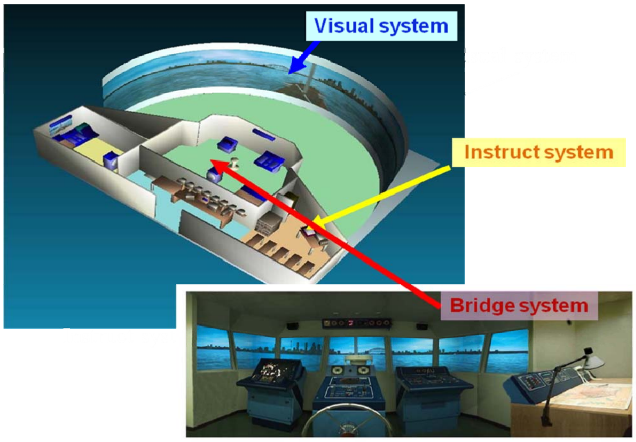


Figure 4 Navigation simulator

The experiment by means of a navigation simulator was carried out repeatedly, for the investigation of a navigator's decision-making and action. The navigator who had much experience of navigation was participated as the experimental subject, on the experiment, his subjective risk of collision for a target that was closing and time length for his decision-making and action by means of his visual sight and ARPA, were measured. And the navigator's process for decision-making and action to avoid a collision by means of the modes were compared and considered and quantified the model. And some index including the navigator's subjective risk of collision was become evident in the result.

B. Navigation Rule

A navigator must hold by navigation rule and take an action according to navigation rule. As it is explained, when a navigator makes a decision and takes an action to avoid a target, he respects the International Regulation for Preventing Collision at Sea, 1972 (CORLEG). Figure 5 illustrates an instruction of the rule.

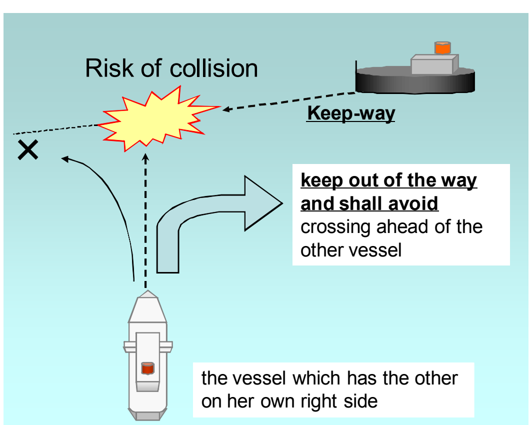


Figure 5 Navigation rule

According to the rule, in the crossing situation, the ship which has the other on her own right side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel. Consequently the crossing situation was selected in this experiment. An experimental subject maneuvers on the give way vessel as a navigator, and can take a large variety of action to avoid a collision.

C. Experimental scenario and data

(1) Scenario

The experimental scenario No. 5 is that the target crossing from right side and the target bearing is 45 degrees. DCPA is set-up 0 mile and TCPA is set-up 21 minutes in scenarios. Therefore the subjects should avoid the target under the navigation rule. In this experiment, a particular target was used to deny the experimental subjects the information except for minimum information to avoid a collision. Figure 6 shows the outline of the scenario.

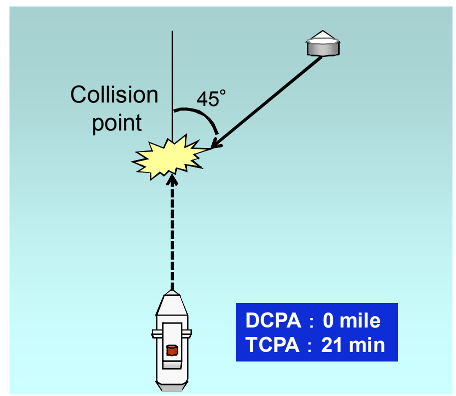


Figure 6 Experimental scenario

(2) Experimental data

During the experiment, the subjects answer a subjective risk of collision, SROC, every 1 minute. SROC was used to make a quantitative assessment of the risk of collision at 5 levels [5]. Level 1 is the first level which a navigator never feels an existence of the risk of collision. From level 2 to 5 are respectively to feel rarely, usually, strongly and extremely. Figure 7 shows SROC scales.

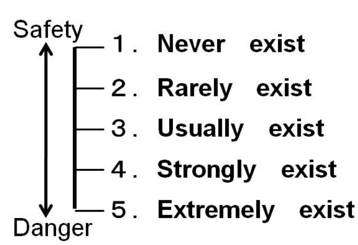


Figure 7 SROC scales

D. Analysis

From the result, some index of professional navigator's decision-making and action was measured, Navigator's subjective risk of collision (SROC) was measured in a minute by five scales evaluation for collision target, and approximated by sigmoid function [5]. In this study, the value aria of sigmoid function is normalized from 5 to 1 as following equation.

$$SROC_1(TCPA) = \frac{1.0}{1.0 + exp\{0.9(-10.5 + TCPA)\}} \quad (1)$$

In the equation, 0.9 and -10.5 are coefficients from the experiment by navigation simulator, the former means rate of increasing SROC and the latter means time delay of decision-making.

Next, subjective risk of collision for DCPA value in a nautical mile is measured from view of a target by the simulator, and approximated by exponential function as following equation [6].

$$SROC_2(DCPA) = exp\{-1.3 \times DCPA\} \quad (2)$$

E. Synthetically subjective risk of collision

From the analysis, equation (1) and (2) are assumed that they are independent subjective probability function mutually, synthesize for synthetically subjective risk of collision (SYSROC) which is simultaneous probability with TCPA and DCPA and multiplied as following equation.

$$SYSROC(TCPA, DCPA) = SROC_1(TCPA) \times SROC_2(DCPA) \quad (3)$$

In case that two or more targets exist, for expansion of SYSROC, SYSROC and each weighting factor λ ($\leqq 1$) are multiplied and these products are added as following equation.

$$SYSROC = \lambda_1\, SYSROC_1 + \lambda_2\, SYSROC_2 + \cdots \quad (4)$$

IV. EVALUATION

Next, it is calculated from concrete scenario which targets exist to evaluate how SYSROC is practical.

A. Evaluation scenario

The evaluation scenario is selected usual situation on actual navigation. Also it is difficult measurably for navigator to make a decision and take an action. Figure 8 shows the evaluation scenario. And Table 1 shows the details of setting situation of own ship and targets.

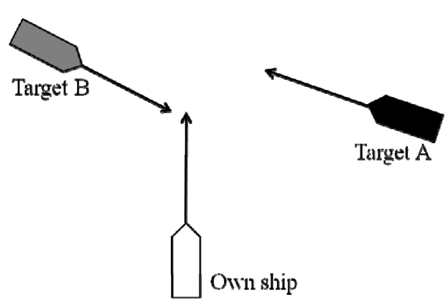


Figure 8 Outline of scenario

In Figure 8, these are own ship and two targets which are crossing from right and left side. Target A is crossing from right side and Target B is crossing from left side. Navigator should avoid the targets because they are closing and will close target B to 0.5 miles at 12minutes and collide with target A within 20 minutes. In this situation, our students who have no experience of navigation, often wonder how they do and it takes long times to avoid targets.

TABLE 1
Situation of own ship and two targets

	Own ship	Target A	Target B
Course	000	295	110
Speed (knots)	18.0	15.0	16.5
Distance (miles)	-	6.0	5.7
CPA (miles)	-	0.0	0.5
TCPA (min)	-	20.0	12.2

B. Time change of SYSROC

Time change of SYSROC in above scenario is calculated in case that own ship keep her course and speed. Figure 9 shows time change of the calculated SYSROC of each target and the sum of SYSROCs.

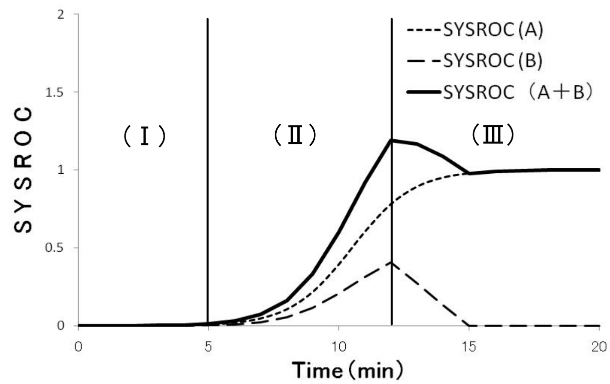


Figure 9 Time change of SYSROC

In Figure 9, Time change of SYSROC in this scenario could be divided into three time phases:

(I) From start to 5 minutes, SYSROC (A) and SYROC (B) is about zero because distances of both targets is far and navigator observes target's move. Also navigator can avoid widely less susceptible to navigation rule, it is sensible for navigator to avoid a collision during this period.

(II) Target A and B are closer and closer, own ship should keep course against Target B, and then avoid Target A according to navigation rule. In the result, SYSROC (A) and SYROC (B) increase and also SYSROC (A+B) goes up gradually, shows a peak in the end of this phase. Unless navigator did not avoid in previous phase, he should avoid Target A to right side as soon as possible before the maximum of SYSROC.

(III) After Target B is passed the stern of own ship, SYSROC (B) decreases and becomes zero finally, only SYSROC (A) goes on increasing. And own ship and Target A collide after 20 minutes.

Thus, SYSROC changes under rate of closing Target by the minute and it is evaluated to be one time index of expressing synthetic and subjective risk of collision.

C. Action space by SYSROC

Next, in case of the evaluation scenario, Navigation space is considered, where navigator can make a decision and take an action to avoid collision easily. The maximum value of SYSROC which will be changed course and speed is expressed as the limit of action and shown more concrete use of SYSROC. Figure 10 shows Action space to avoid a collision by the maximum value of SYSROC.

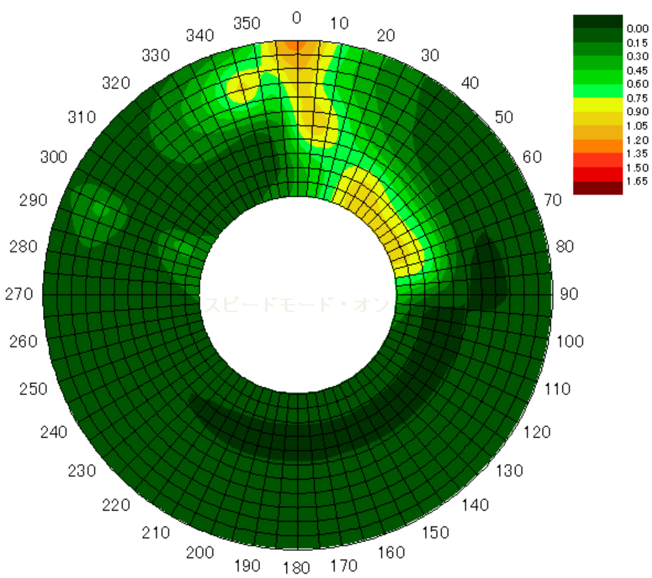


Figure 10 Action space to avoid a collision by maximum value of SYSROC

In Figure 10, Action space is shown the maximum value of SYSROC at each course and speed of change by contour line and the value of SYSROC classified by color, as SYSROC value becomes lower, Action space become green, and the part of darkest green is SYSROC becomes 0. The other way, as SYSROC value becomes higher, Action space become red. And each course is shown in a circle and speed in a radius, but from 7 knots as available. However, as you see, almost part of the Action space where is centering around <180> about 60 percents is low. Also navigator will not select these parts because of loss for navigation. So the important part where SYSROC is high and have relation with avoidance actually, is around own heading course <000>. And Action space where navigator has a high probability to select, from own course <000> to both 50 degrees: from <310> to <050> and own speed from 18 knots to 7 knots, is focused. Figure 11 shows action space limited from<310> to<050>. In Figure 11, if navigator will select the course and speed which are shown in green color, he makes the value of SYSROC lower easily.

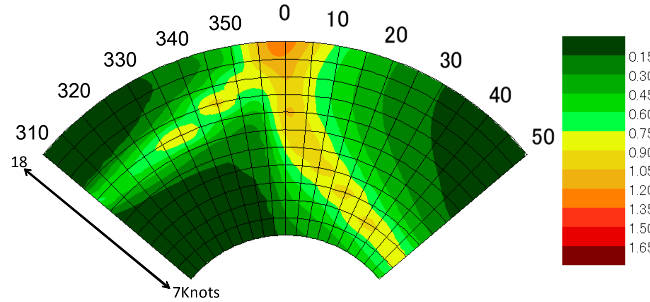


Figure 11 Action space to avoid collision from <310> to<050>

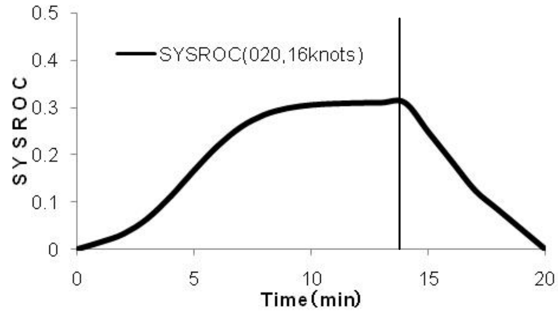


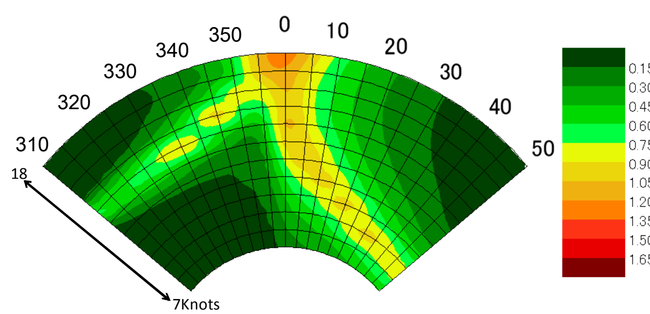
Fig.12 Time space of SYSROC

Furthermore, when navigator selects certain course and speed, it is shown how time space of SYSROC changes, in Figure 12. In Figure 12, it is shown time space of SYSROC on time axis when he changes a course from <000> to <020> and reduces a speed from 18 to 16 knots.

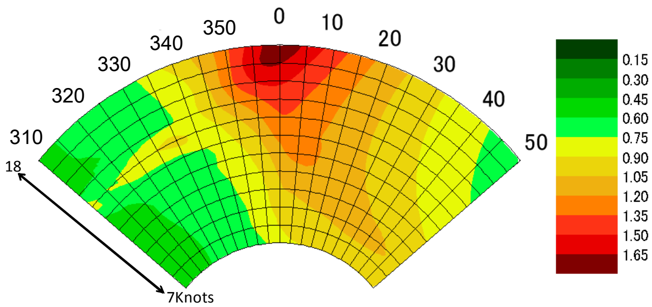
Thus, it is possible by combining the action and time space of SYSROC to be a significant index of decision-making and action at various environment of navigation.

D. Change of SYSROC

Next, In case that own ship and targets will not change the course and speed, action space by the maximum value of SYSROC is predicted and shown Fig.10 (a) and (b).



(a) Action space after 5 minutes



(b) Action space after 10 minutes

Figure 13 (a) Action space after 5 minutes,(b)Action space after 10 minutes

Fig.13 (a) shows action space after 5minutes and Fig.13 (b) shows after 10 minutes. When navigator will not change course and a speed, both action spaces become red than in Figure 12 and it is mean that he cannot secure action space to avoid safety, in case that decision-making and action are delayed. Thus, the action space is of assistance that a navigator sees the state himself is in dangerous condition at the moment.

E. Application of SYSROC

As mentioned above, although the example of SYSROC was proposed, the following application is considered;

(1) New index of Avoidance
SYSROC is compounded 2 original indexes, DCPA and TCPA which a navigator always uses for judgment of avoidance, expresses with 1 index value as subjective risk of collision. Therefore, SYSROC might be able to make judgment for avoidance easily, especially congested area.

(2) Investigation of collision factor
When collision of ships is occurred, if the environment is known where ships existed before the collision, SYSROC can be reproduced as the standard navigator's SYSROC. And navigator's decision-making and action can be compared with the standard SYSROC. Navigator's decision-making and action would be evaluated.

(3) Index of education
It is difficult for a student who have no experience of navigation to select proper action for avoidance and understand evaluation for own action. Then, the student can understand the proper action easily as compared with the standard SYSROC.

V. Conclusion

In this study, firstly Navigator's decision-making and action model and navigation information flow were illustrated. Next Navigator's subjective risk of collision was measured from the experiment by navigation simulator. Secondly SYSROC was proposed by the equations SROC1 is expressed as a function of target's TCPA. And SROC2 is expressed as a function of target's DCPA is proposed by the index from result of experiment using navigation simulator. And SYSROC is consequently synthesized from the SROC1 and the SROC2, which is able to measure navigator's subjective risk to avoid a collision. Secondly one collision case scenario is selected to assess the SYSROC, and the time change of SYSROC is expressed. Next the SYSROC is calculated and some action spaces to avoid a collision are expressed by maximum SYROC value at each situation when a navigator will change course and speed. Finally some predicted change of SYSROC value for near future is expressed under the some courses and speeds of own ship and all targets to make possible a navigator's decision-making and action easy. In the future, the assignment is to improve SYSROC including the use and display for practical application, and make a contribution to the education and navigation.

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