

Procedure for Marine Traffic Simulation with AIS Data

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ABSTRACT: It is essential to evaluate safety of marine traffic for the improvement of efficiency and safety of marine traffic. Spread of AIS makes observation of actual marine traffic more easily and faster than before. Besides, description of collision avoidance behaviours of ships are indispensable to simulate a realistic marine traffic. It is important to develop and implement an algorithm of collision avoidance corresponding to a target traffic or target area into the marine traffic simulation because actual actions for collision avoidance depend on circumstances where ships are sailing. The authors developed an automated marine traffic simulation system with AIS data. And in this paper, we proposed a series of systematic procedures for marine traffic simulation including analysing for collision avoidance behaviours using AIS data.

1 INTRODUCTION

The transportation amount at sea has been increasing all over the world and it is expected that ships' size become bigger and marine traffic increases. Therefore, it is essential to evaluate safety of marine traffic for the purpose of improvement of efficiency and safety of marine traffic. Traditionally, visual or radar observation has been conducted to investigate actual traffic flow of ships. Then the observed data is used as base data for the evaluation of the aforementioned marine traffic. On the other hand, it is becoming possible to observe the actual marine traffic more easily and faster than before, according to rapid spread of Automatic Identification System (AIS). Goerlandt et al. (Goerlandt 2011) presented a method for obtaining a realistic input data for the marine traffic simulation through analysis of AIS data.

Besides, description of collision avoidance behaviours of ships are indispensable to simulate a

realistic marine traffic. However, the actual actions for collision avoidance depend on circumstances where ships are sailing, i.e. ship domains which never let other ships enter are different between in harbours and in the coastal sea area (e.g. Inoue 1994, Miyake 2015). Therefore, it is important to develop and implement an algorithm of collision avoidance corresponding to a target traffic or target area into the marine traffic simulation.

The authors developed an automated marine traffic simulation system with AIS data. In this paper, we propose a series of systematic procedures for marine traffic simulation including analysing for collision avoidance behaviours using AIS data.

Firstly the procedure for marine traffic simulation with AIS data are introduced. And the procedure for analysing collision avoidance behaviours using AIS data is introduced. Specifically, we proposed a method for identifying a time when a give-way ship evade a stand-on ship. Finally, the examination of the method is shown.

2 MARINE TRAFFIC SIMULATION

2.1 General steps of marine traffic simulation and required data

General procedures of marine traffic simulation are composed of the following steps: (e.g. Nakamura 2011)

Step 1: observation of actual marine traffic;
 Step 2: description of the observed marine traffic;
 Step 3: simulation of the observed marine traffic; and
 Step 4: evaluation of the simulated marine traffic.

At the first step, data of actual marine traffic in a targeted area is acquired through an investigation based on visual or radar observation, or video recording (e.g. The Japan Association of Marine Safety 1991). At the second step, the acquired data is analysed to get attributes of ships and the traffic such as ship type and size. Then traffic volume or general traffic route including waypoints are obtained. At the third step, a series of traffic flow data, which represents traffic conditions of target area, is generated using these attributes. Then the target traffic is simulated based on the traffic flow data. In this step, it is possible to include the future prediction or new traffic systems such as traffic separation schemes according to the purpose of simulation. At the last step, the results of the simulation are evaluated with appropriate means corresponding to the purposes. For instance, frequency or position of one to one ship encounter situations is examined for the purpose of assessment of the effect of modification of a shape of channel.

2.2 Required data obtained from AIS

The authors have proposed modified procedures for marine traffic simulation using AIS data. We developed tools for obtaining some attributes from AIS data and an automated data generation systems for these attributes. Table 1 shows analysable attributes by traditional procedure with radar observation and by the proposed procedure with AIS data, which are the required data for the marine traffic simulation. The attributes denoted by "yes" and "no" are available and not available, respectively. The attributes denoted by "hard" have seldom been obtained from visual or radar observation because it requires unrealistic amount of work to analyse them by hand. For this reason, many researchers have focused on whole marine traffic rather than the movement of individual ships in their analyses.

The procedure with AIS data makes analyses easier, faster and more accurate than the traditional procedure. This procedure also makes it possible to analyse the detail of the individual ship movement, in addition to the analyses of whole traffic flow. Here, it should be noted that AIS data does not include the information of small ships where AIS are not installed, such as domestic ships of less than 500 GT and international ships of less than 300 GT (IMO 2003).

Table 1. Comparison of analysable attributes which are the required data for the marine traffic simulation

Object	Required data	Availability	
		with Radar	with AIS
Individual ship movement	OD data (gate)	hard	yes
	OD data (port)	hard	no
	Ship's speed	hard	yes
	Way points	hard	no
	CA* behaviours	hard	yes
Distribution of traffic flow	Ship size and type	yes	yes
	Ship's speed	yes	yes
	Trajectories	yes	yes
	Traffic volume	yes	yes
	Traffic route	yes	yes
	OD table	yes	yes

* collision avoidance

3 MODIFIED PROCEDURE FOR MARINE TRAFFIC SIMULATION WITH AIS DATA

Figure 1 shows the proposed modified procedure of marine traffic simulation with AIS data. In this figure, rectangles with grey shading indicate the unique process by using AIS data. Rectangles without shading indicate the common process, which are also included in the traditional procedures with visual or radar observation. Rectangles drawn by heavy line indicate the automated processes.

Here, we briefly describe the outline of the procedure with AIS data for marine traffic simulation.

3.1 Step 1 - Gate setting for OD survey

Preparation of an origin and a destination survey (OD survey) in a targeted area is conducted at Process 1-1. Gates, which represent a starting point and an end point of traffic flow as well as an origin and a destination of a ship, should be set at appropriate places, considering the observed traffic flow of the targeted area in order to cover all arterial traffic routes.

3.2 Step 2 - OD survey and modelling

At the next step, OD survey and modelling for the traffic simulation are conducted. At Process 2-1, OD survey is conducted based on the set gates. At Process 2-2, each data of each ship which passed the gate based on the OD survey is extracted as a series of position data, i.e. trajectory. Then the trajectories, which enable to reproduce the target traffic for marine traffic simulation, are classified according to the routes defined by origin and destination gates. Irrelevant data for the purpose of analysis such as anchored ships is filtered out in this process.

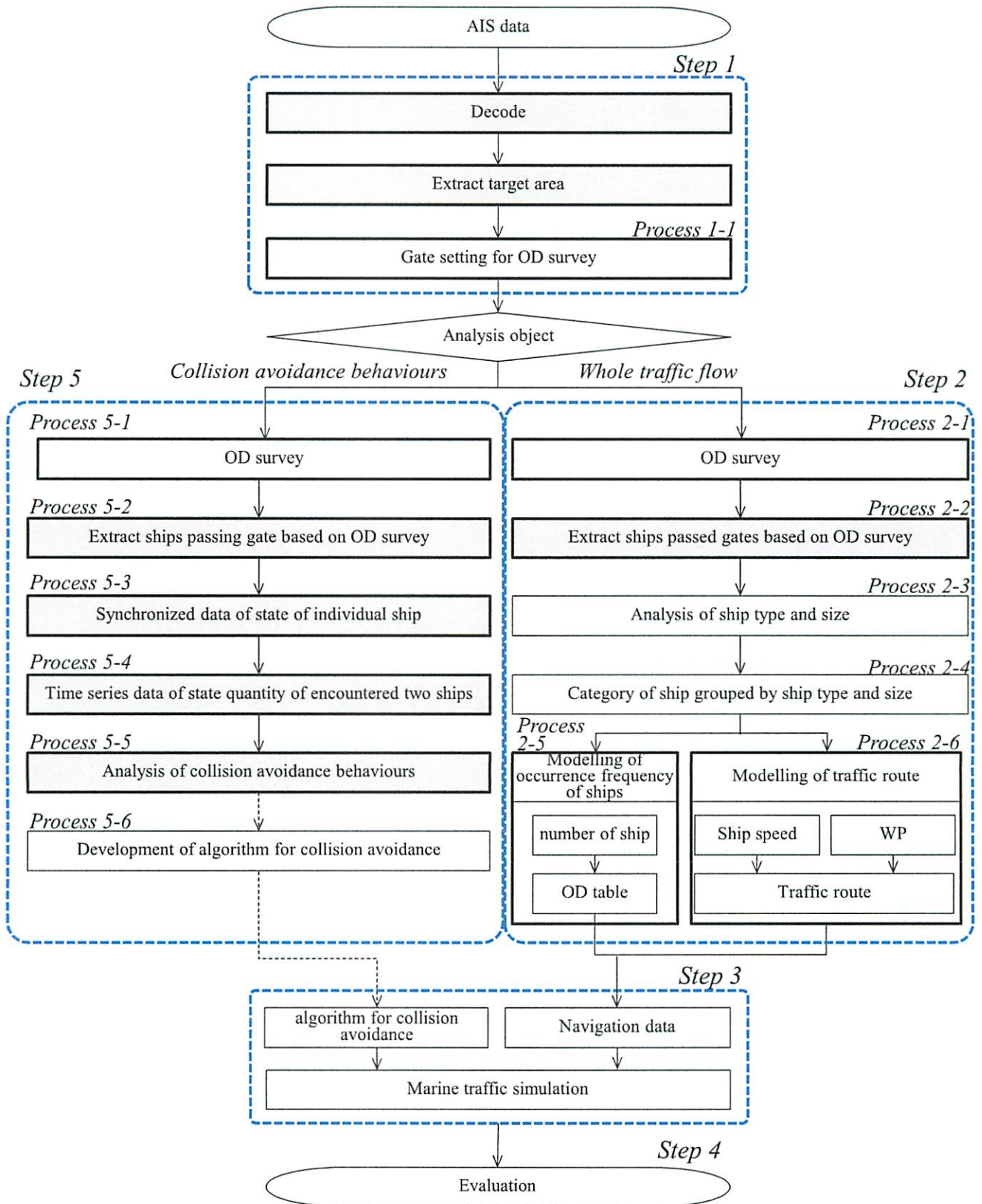


Figure 1. Modified procedure of marine traffic simulation with AIS data

Figure 2 shows the trajectories of all extracted ships that passed the origin gate and the destination gate. Based on attribute data of the extracted ships from AIS data, at Processes 2-3 and 2-4, ships are grouped according to ships' types and sizes. Then categories of ships are created for the model. They should be classified according to the appropriate ship size and type because the attributes of traffic route depend on ship size and type.

Through Processes 2-5 and 2-6, modelled data such as traffic routes and occurrence frequency of ships in the simulation is generated using the developed tools. Specifically, at Process 2-5, the numbers of ships in the respective categories are counted, and then OD table is generated. At Process 2-6, average speed of ships or waypoints of traffic flow are observed and then a traffic route model is generated for respective categories of ships' types and sizes.

3.3 Step 3 - Simulation and Step 4 - Evaluation

At the third step, based on the modelled data such as OD table and traffic routes, navigation data of ships for simulation is created. The navigation data describes simulation conditions of individual ship such as appearance time to the simulation, waypoints and speed and so on.

Using the navigation data, the marine traffic is simulated at Step 3 and the simulation results are evaluated according to the purpose of the study at Step 4.

3.4 Step 5 - Analysis for collision avoidance behaviours

Description of collision avoidance behaviours of ships is indispensable to simulate a realistic marine traffic. However, the actual actions for collision avoidance depend on circumstances where ships are sailing, for example, ships' domains where never let other ships enter are different between in harbours and in coastal sea areas (e.g. Inoue 1994, Miyake 2015). Therefore it is important to develop and implement an algorithm of collision avoidance corresponding to the target traffic or the target area into the marine traffic simulation.

At Step 5, collision avoidance behaviours of individual ship are analysed, in order to develop the algorithm. The detailed procedure of the analysis is described in Chapter 4. In our other paper (Miyake 2015), ships domains where never let other ships enter in a coastal sea area were modelled based on the procedure of analysis presented in this paper.

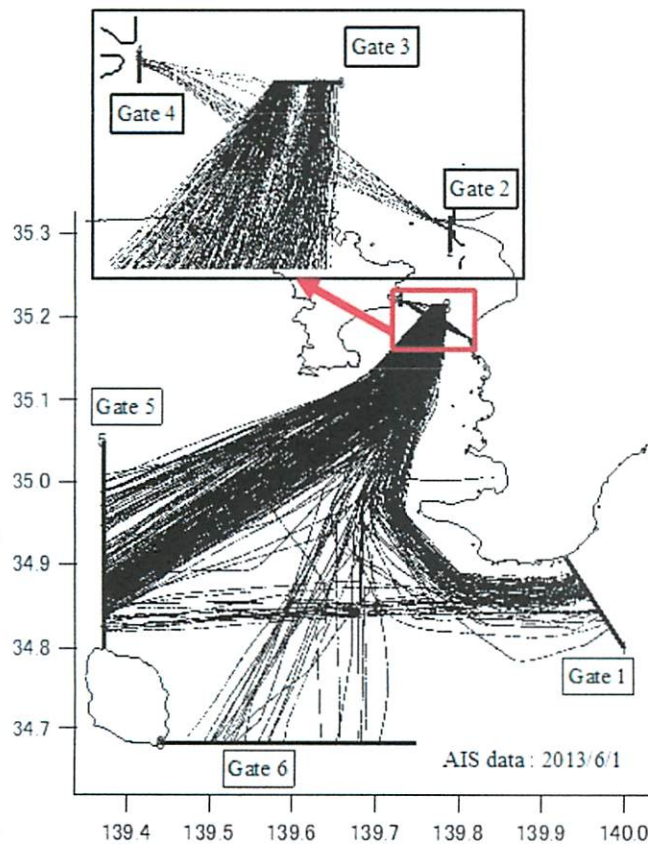


Figure 2. Trajectories of extracted ship passed the gate based on the OD survey

4 PROCEDURE OF ANALYSIS FOR COLLISION AVOIDANCE BEHAVIOURS

4.1 OD survey

An origin and destination survey (OD survey) in a targeted area is also conducted firstly.

The easiest means to analyse the collision avoidance behaviours is to focus on one-to-one encounter situation between two ships. Therefore, at Process 1-1, gates are set in order to extract ship data passing intersected two routes.

Specifically, in the case mentioned in Figure 2, four gates, i.e. Gates 1, 3, 5 and 6 as illustrated in the figure, were set at Process 1-1, in order to analyse the collision avoidance behaviours in crossing situation. At Process 5-1, OD survey is conducted based on the set gates. Then, data of ships passing the two intersected routes are extracted from whole AIS data at Process 5-2, e.g. in Figure 2, one route is Gates 1 and 5, and the other is Gates 3 and 6.

4.2 Calculation of synchronized state data of ships

Before analysis for collision avoidance behaviours on one-to-one encounter situation at Process 5-5, state of ships is calculated at every synchronized 10 seconds at Process 5-3, because it is essential to compare respective state quantities of ships at the same time for analysis of collision avoidance behaviours. The states of ships are position, heading and speed and so on.

The synchronized interval should be set according to the purpose of study. In this study, the interval was set at 10 second, for the reason that ships' data at this interval was deemed to include an appropriate amount of information about variations of rate of turn or acceleration by altering course or reducing speed for the purpose of the analysis of collision avoidance behaviours.

4.3 Calculation of state quantities and analysis of collision avoidance behaviours

From the synchronized state data of individual ship, time series data of state quantities of encountered two ships, such as DCPA, TCPA and distance of them, are calculated at Process 5-4. In the example, the time series data was calculated in the situations satisfying all the following conditions: (1) distance between give-way and stand-on ships was within 18520 m (10 nautical miles); (2) TCPA was within 30 minutes; and (3) DCPA was within 3704 m (2 nautical miles).

And then, at Process 5-5, collision avoidance behaviour of individual ship is analysed based on the time series data. The detailed procedure of the analysis is described in Chapter 5.

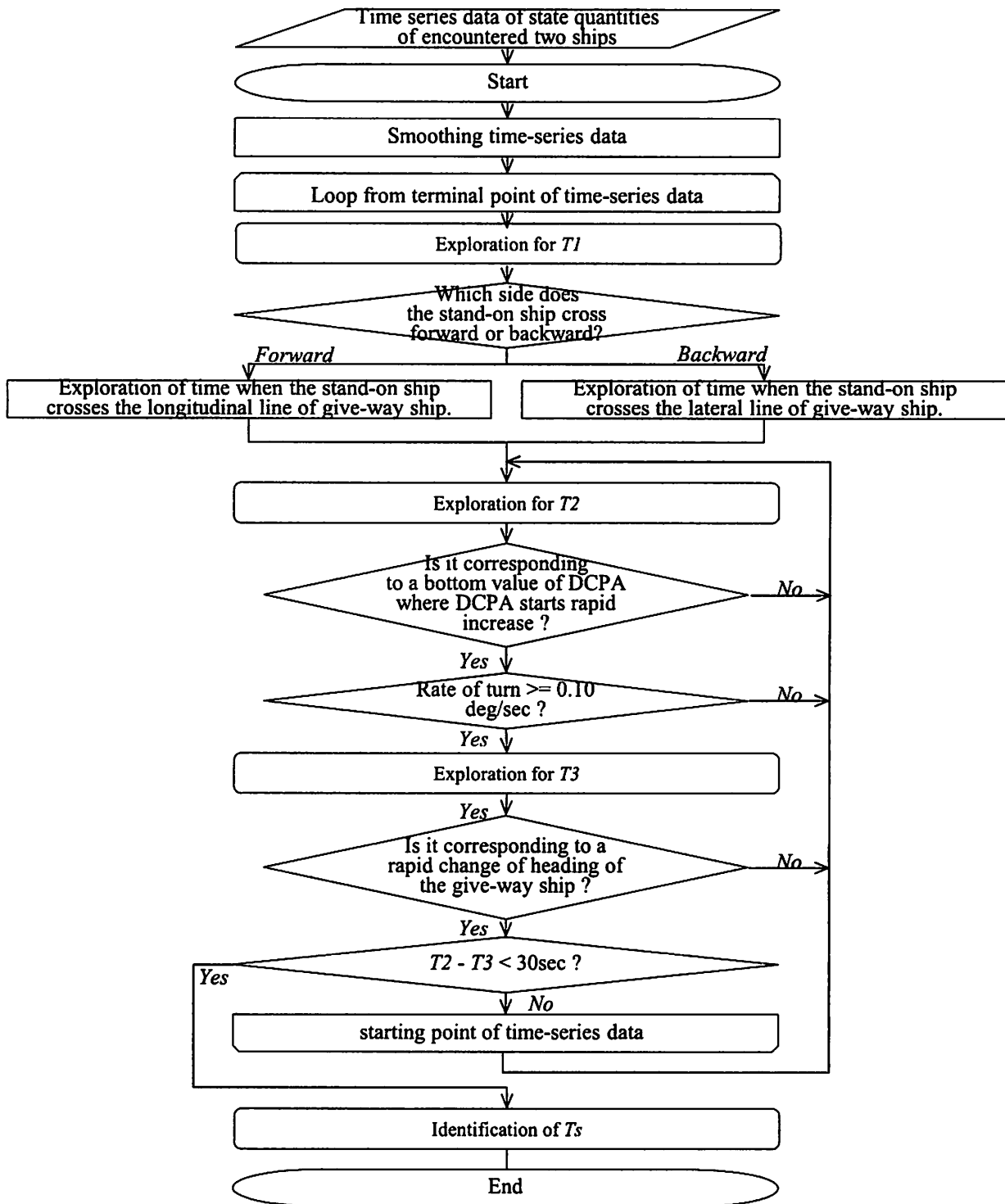


Figure 3. Method for identification of a time when give-way ship starts to evade its target ship

4.4 Development of algorithm for collision avoidance

As a step after Process 5-5, an algorithm of collision avoidance is developed based on the analysis, and be implemented to the traffic simulator.

Furthermore, it is essential to complement data of small ships with visual or radar observation, because AIS data hardly includes the data of domestic ships of less than 500 GT and international ships of less than 300 GT, as mentioned in Section 2.2.

5 ANALYSIS FOR COLLISION AVOIDANCE

5.1 Summary of method for analysis of collision avoidance behaviours

In this chapter, we describe the detailed procedure for analysing collision avoidance behaviours in Process 5-5. Specifically, the purpose, here, is to identify a time when give-way ship starts to evade its target ship because determining a moment of initiating collision avoidance action is critical in order to establish a collision avoidance algorithm. Figure 3 shows the method for identification of a time when give-way ship starts to evade its target ship.

As described in the previous chapter, the time series data of state quantities of encountered two ships is used for the analysis. It is also possible to distinguish an encounter situation whether a give-way ship takes a collision avoidance action or not. If the give-way ship evades its target ship, the time when the give-way ship starts to evade the other is identified.

Collision avoidance behaviours are, generally, understood as actions for increasing DCPA or TCPA of encountered two ships. Namely, they are changing the course or speed of ship resulting in increasing DCPA or TCPA. Therefore, in this method, collision avoidance behaviours are identified by analysing DCPA and TCPA.

To be precise, in this method, collision avoidance behaviours are limited to those meeting the following conditions: (1) one-to-one encounter situation between a give-way ship and a stand-on ship; (2) action which a give-way ship changed its course to increase DCPA; and (3) a stand-on ship is located on the starboard bow of the give-way ship at the time when both ships encountered under the conditions specified in Section 4.3.

In this method, three times are explored, i.e. $T1$, $T2$ and $T3$, as explained in Sections 5.2 to 5.4, in order to identify the time, T_s , which is defined as the time when a give-way ship starts to evade the other.

Here, an example of crossing situation is illustrated in Figures 4 and 5. Figure 4 shows a relative trajectory of a stand-on ship to a give-way ship. The relative trajectory is plotted on a body-fixed coordinate system, and the origin of coordinates is the centre of the give-way ship. Figure 5 shows a time series of status data of the give-way ship in the situation specified in Figure 4.

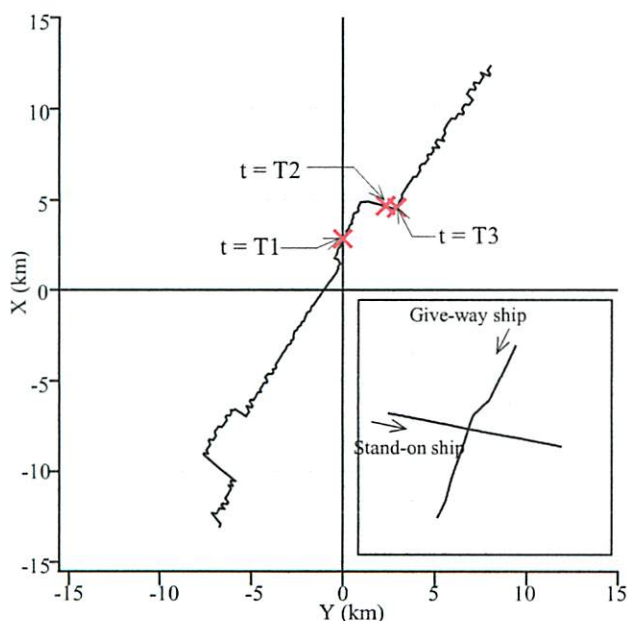


Figure 4. Relative trajectory of stand-on ship to give-way ship

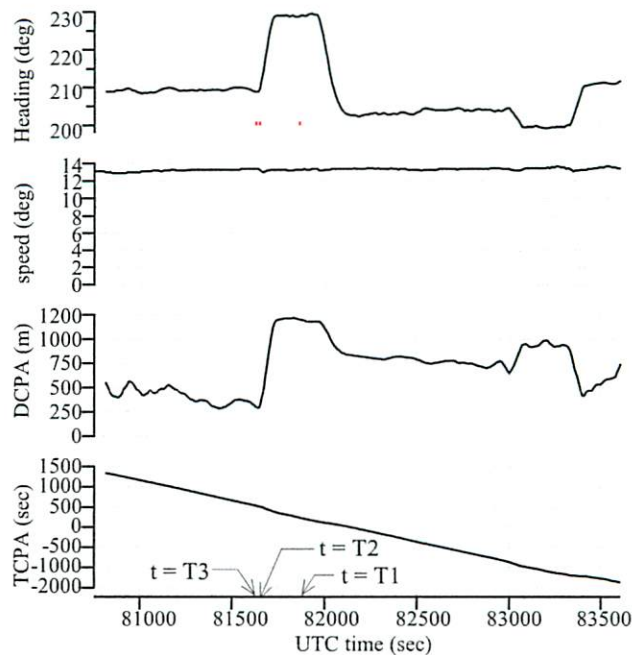


Figure 5. Time series data of give-way ship

Under the situation expressed in these figures, the stand-on ship was crossing from ahead of the give-way ship on the right and the give-way ship altered its course to the right. After the stand-on ship had crossed in front of the give-way ship, the give-way ship returned to its original course.

A time series data was firstly smoothed because it included a lot of insignificant small variations. The smoothing process is indispensable to explore, automatically, extreme values of each data such as heading and DCPA. We smoothed it based on the method of moving average of one-minute data. Through this process, small variations were eliminated. The graphs in Figure 5 are plotted based on the data after smoothing.

5.2 Exploration for $T1$ when stand-on ship crosses longitudinal or lateral line of give-way ship

The time $T1$ is when the stand-on ship crossed: the lateral line of the give-way ship from the starboard side of the give-way ship; or the longitudinal line of the give-way ship from the front of the give-way ship. Namely, in case where the stand-on ship passes ahead of the give-way ship, $T1$ is defined when the stand-on ship crosses the longitudinal line of the give-way ship. On the other hand, in case where the stand-on ship passes behind the give-way ship, $T1$ is defined when the stand-on ship crosses the lateral line of the give-way ship. In the case where the stand-on ship crosses the longitudinal line of the give-way ship plural times, $T1$ is defined as the time when the stand-on ship crosses the closest point on the longitudinal line of the give-way ship. Similarly, in the case where the stand-on ship crosses the lateral line of the give-way ship plural times, $T1$ is defined as the time when the stand-on ship crosses the closest point on the lateral line of give-way ship.

In encountered situation illustrated in Figure 4, $T1$ is the time corresponding to the crossing point of the relative trajectory and the ordinate.

5.3 Exploration for T2 when DCPA increased

The time T2 is corresponding to a bottom value of DCPA where DCPA starts rapid increase owing to the change of the heading of the give-way ship at the rate equal or greater than 0.10 deg/sec, as illustrated in Figure 5. The time T2 comes always earlier than T1, because T2 corresponds to the collision avoidance behaviours taken by the give-way ship against the stand-on ship sailing on the starboard bow of the give-way ship. Namely, T2 corresponds to the time before the stand-on ship crosses the longitudinal or lateral line of the give-way ship.

In Figure 4, cross mark corresponding to T2 denotes the relative position of the stand-on ship to the give-way ship at T2.

5.4 Exploration for T3 when heading of give-way ship changed

The time T3 is corresponding to a rapid change of heading of the give-way ship as illustrated in Figure 5.

In Figure 4, cross mark corresponding to T3 denotes the relative position of the stand-on ship to give-way ship at T3.

5.5 Identification of Ts when give-way ship started to evade the stand-on ship

Finally, the time Ts, i.e. the time when the give-way ship starts to evade the stand-on ship, is identified with T1, T2 and T3. The time Ts becomes T3 in the case where the following conditions are satisfied: (1) T1 is identified; (2) T3 is before or equal to T2; and (3) the difference between T2 and T3 is within 60 seconds. In the other cases, Ts cannot be identified. In other words, such cases are distinguished as that the give-way ship takes no collision avoidance behaviour to the stand-on ship.

In encountered situation illustrated in Figures 4 and 5, Ts were T3.

6 EXAMINATION OF METHOD FOR ANALYSIS OF COLLISION AVOIDANCE BEHAVIOURS

6.1 Comparison of the times for starting collision avoidance behaviours

For examination of the method, we compared the identified times Ts through the analyses based on data obtained by both manual exploration and automatic exploration with the method. The both explorations have been conducted using the individual time series data of state quantities of encountered two ships in 59 encounter situations.

Among 59 encounter situations, no collision avoidance behaviours were distinguished in two situations. According to our detailed consideration, these situations were corresponding to where T2 were not identified. Specifically, in these encounter

situations, DCPA decreased after the give-way ship changed its heading.

Table 2 shows the difference between both manually and automatically identified times Ts in 57 situations. Out of 57 situations, only 7 situations were actual one-to-one encounter, and the others were situations where a give-way ship encountered plural ships and it took collision avoidance behaviours continuously.

Table 2. Difference between both manual and automatic identified starting time of collision avoidance

Difference	number of encounter situation	
	One-to-one*	non one-to-one**
10 sec	0	4
10 sec	1	10
20 sec	4	10
30 sec	1	7
30 sec < diff. < 60 sec	1	4
60 sec ≤ diff. < 90 sec	-	3
90 sec ≤ diff. < 120 sec	-	5
120 sec ≤ diff. < 150 sec	-	0
150 sec ≤ diff. < 180 sec	-	1
180 sec ≤ diff. < 210 sec	-	0
210 sec ≤ diff. < 240 sec	-	1
240 sec ≤ diff. < 270 sec	-	0
270 sec ≤ diff. < 300 sec	-	0
300 sec ≤ diff.	-	5
Total	7	50

* actual one-to-one encounter situation

** non one-to-one encounter situation

Here, we examine accuracy of automatic identification using 30 seconds as the threshold, taking into account the inaccuracy of state quantities of encountered two ships owing to the following reasons: (1) AIS data includes a lot of small variations originally; (2) AIS data might include some anomalous values; and (3) interpolation of AIS data was necessary to synchronize all time series data.

In 6 situations among 7 actual one-to-one encounter situations, the differences between the times Ts, which were manually and automatically identified, were within 30 seconds. In 31 situations among 50 non one-to-one encounter situations, the differences were also within 30 seconds.

For these reasons, it can be said that this method is valid for evaluating collision avoidance behaviours on the whole, though more accurate analysis may be necessary for evaluating encounter situations in detail.

6.2 Modification of method for accuracy improvement

To conduct more accurate analysis, identification of collision avoidance behaviours should be improved, especially with regard to the following points:

- treatment of decreasing DCPA after collision avoidance behaviours;
- simultaneous collision avoidance behaviours both by a stand-on ship and a give-way ship; and
- encountered situations with multiple ships and continuous collision avoidance behaviours.

The third bullet point is caused by the smoothing of the time-series data. Namely, many small extreme values of state quantities are eliminated through the smoothing process. Therefore, we need to consider a better way of smoothing in order to improve accuracy of the analyses.

7 CONCLUSIONS

The authors developed an automated marine traffic simulation system with AIS data. And we proposed a series of systematic procedures for marine traffic simulation including analysing for collision avoidance behaviours using AIS data.

We showed that some attributes, which are required data for the marine traffic simulation, are analysable with AIS data and that analyses become more easily and faster than based on visual or radar observation.

And then we briefly introduced the modified procedure for traffic simulation based on analysis with AIS data, in which we proposed five steps.

Besides, we described the detailed procedure for analysing collision avoidance behaviours with AIS data. Then we examined the method for analysis of

collision avoidance behaviours. Based on the results of examination of the method, it can be said that the method is valid for evaluating collision avoidance behaviours on the whole, though more accurate analysis may be necessary for evaluating encounter situations in detail.

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