SOME RECENT RESEARCHES ON NEXT GENERATION MARINE TRAFFIC MODELS AND ITS APPLICATIONS

Kazuhiko HASEGAWA (Osaka University, Osaka 565-0871, Japan)

Abstract: Marine Traffic Simulation System is a tool to reproduce realistic marine traffic flow based on a certain OD table developed since 1987 in Osaka University. The main part of the system is automatic collision avoidance subsystem. It is based on the international regulation to prevent collisions (COLREG) and ship operators' experience using fuzzy reasoning. The system is already proposed to be widely used for various applications such as designing waterways and ports, safety assessment of waterways, intelligent simulator and testing automated system (Hasegawa, ISME, 1990). The system is mainly applied for the safety assessment of congested waterways such as Tokyo Bay, Osaka Bay, Ise (Nagoya) Bay in Japan, Malacca and Singapore Straits, and Shanghai area. It is also applied for inland waterways such as Albert Canal in Belgium and Huangpu River in Shanghai. Near-miss and critical collision risk are defined as safety indices as well as collisions. The close relation between these indices and the congestion of waterways is also found. The limitation of the congestion to be accepted from the view-point of safety will be discussed in this paper. In 2011, the system was implemented into a ship handling simulator for the first time in the world, where target ships are automatically change their course and/or speed each other or with corresponding to the own ship behaviour. This intelligent simulator was applied to analyse ship casualties. These results will be introduced including generation of OD table utilising AIS data and other AIS application for next generation marine traffic model.

Key words: marine traffic simulation; automatic collision avoidance; congested waterways; safety assessment; ship handling simulator

1. INTRODUCTION

In this paper, the author will summarize author's 25-year research activities [1-31] for the next generation marine traffic, and will give some new recent result as well.

Many advanced navigational aids and safety countermeasures are regulated by IMO to prevent ship casualties since Titanic incident happened 100 years ago. Even if new apparatuses and regulations are enforced, new disasters still occur. How to prevent them is quite hot issue.

One of the difficulties is the commitment of human beings. Human error is the major cause of ship casualties. We cannot neglect human element in the ship navigation. The skill, education and training of crew and bridge resource management (BRM) are another subjects of this paper, but they are also very important issue *e.g.* [32].

2. MARINE TRAFFIC SIMULATION SYSTEM

The system is already described in the references [1-31], but in this section, some extra explanation will be added.

2.1 History of Marine Traffic Simulation

The first marine traffic simulation system is just like a chess game. Each ship was moved stepwise by human based on its speed and direction. Then some conflicted situation or encounters are discussed quantitatively. Later the system is automated by a computer and is called macro simulation, but each ship is operated without taking account of any collision avoidance and even each ship's dynamics yet. Some system is modified with taking account of ship dynamics and is used to called micro simulation.

First trial to taking account of collision avoidance or other human factor into marine traffic simulation is done by Yamada and Tanaka [33]. Fig. 1 is the photo of this system [34]. Ships are generated by computer, but moved by human operators taking account of waterways and neighbour ships.

The first automatic collision avoidance function used for marine traffic simulation is, maybe, Nagasawa Model [35]. The model is a kind of micro simulation model, but taking account of collision avoiding actions. This model is used in Japan for several official safety assessment committees of JAMS (The Japan Association of Marine Safety), but detail is not well described in their reports *e.g.* [36].

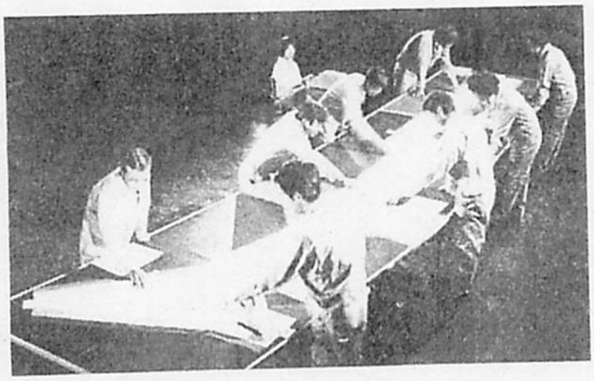


Fig.1 Marine Traffic Simulator with Human Operators [33, 34]

Nowadays marine traffic simulation is widely done in such committees, but there are still discussions whether collision avoidance function is necessary or not. The negative opinion is, of course, due to its complicated algorithm, which is not yet exactly representing human's behaviours nor widely recognized, computation time, and there is an opinion that no significant difference can be seen on the evaluation safety indices, assuming collision avoidance manoeuvres are successfully done, when the dangerous situation happens.

2.2 Influence of Automatic Collision Avoidance Function in Marine Traffic Simulation

In [25], we have conducted the simulations for the same area without (NN mode) and with (CA mode) automatic collision avoidance function. The simulated area is southward off Tokyo Bay where, especially near the entrance to Tokyo Bay ship collision frequently occur and Fig. 2 shows the ship trajectories recorded by AIS on May 10, 2010. Results of marine traffic simulation for NN and CA have no significant difference in terms of trajectory as shown in Fig. 3. However, if we consider certain safety indices such as the counts of near-miss and emergent encounter which we define by collision risk (CR >0.9) (for more detail of their definition, please refer to [31]), there is significant difference on their distribution and count as shown in Figs. 4 and 5.

It is not simple to conclude only by this result, but it is true there are cases to be considered the collision avoidance function.

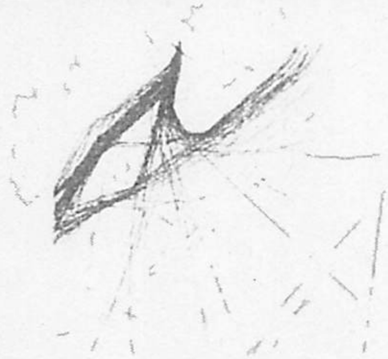


Fig.2 Ship trajectories measured by AIS on May 10, 2010 at Southward off Tokyo Bay [25]

NN mode CA mode

Fig.3 Results of marine traffic simulation without (right) and with (left) collision avoidance function [25]

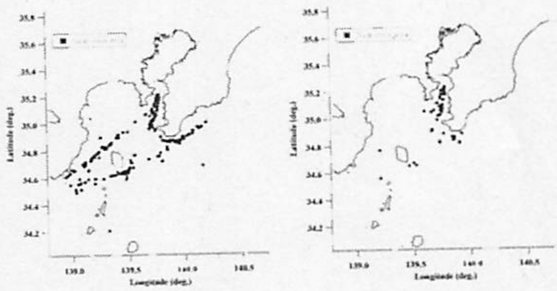


Fig.4 Comparison of the result of near-miss distributions in case of without (NN mode) and with (CA mode) collision avoidance function [25]

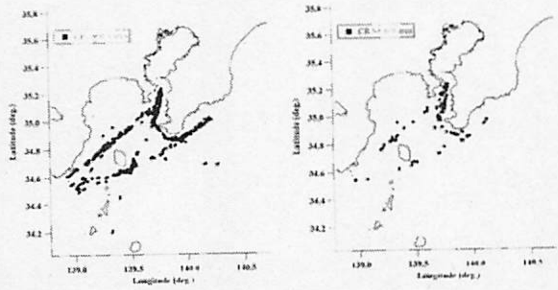


Fig.5 Comparison of the dangerous encounter distribution in case of without (NN mode) and with (CA mode) collision avoidance function [25]

2.3 Risk of Collision

Because fear of collision is quite cognitive, it is not yet uniquely defined. Ship domain is one of the oldest concepts for this recognition [37, 38]. It is originally continuous field concept like potential function, but it is normally used for the on-off bumper model of certain area around a ship. So one of the problem is the recognition is done suddenly, when the neighbour ship touches the domain. Another problem is that if we use the fixed domain, there is certain limitation of traffic density. Exceeding certain density, no more active traffic may occur, a kind of dead evacuation flow at the exit of a theatre etc. in emergency case. We normally change our domain area according to the traffic density.

Then *TCPA* (Time to the Closest Point of Approach) and *DCPA* (Distance to the Closest Point of Approach) are used to define this fear. In our simulation system, *CR* (Collision Risk) defined using *TCPA* and *DCPA* is used and details are described in [1-2, 7-9, 31]. Timing of taking action, angle of avoidance and returning to the original path is all defined using *CR*.

2.4 Algorithm of Collision Avoidance

Collision avoidance action is much cognitive than that of collision risk. Even if we have regulation of collision avoidance at sea (COLREG), it will not solve multiple-ship encounter situation. We need experts' experience. However, the problem is the fact that they cannot express or describe their knowledge will. It means there are is no clearly describable rules. From our long-term researches and its simulation, we come up to define in a way, although it is not perfect ever.

The algorithm is described in [1-5, 7-9, 31] including some modifications and expansions, but the latest one [31] covers most for single encounter situation.

There are another rules for multiple-encounter situation. It is described in [4-5]. Main principle is always search for the most high *CR* target and take action against it, even if the own ship is taking action for another ship. Sometimes, there may be some problem like swinging between two target ships, if we follow this simple rule. Or if successive crossing ships appear, the own ship continues to avoid right-hand side and not returning to the original path. Some incorporative (which means that even though they are give-way situation, they don't avoid properly) target ships appear, the situation becomes quite hard to solve only by this rule. However, at this moment, this is the only way to cope with any arbitrary situation, and as far as all ship in the simulation area follow our algorithm, very few problems may occur. Some minor rules related the deviation from the original path etc. may improve the behaviour naturally.

The rules not yet described are a kind of know-how or programme-level matter, so here they are again omitted.

For checking the algorithm of collision avoidance, Imazu Problems [39] is quite useful. They are a kind of hard drills for collision avoidance problem. Twenty-two cases are shown in Fig. 6. Our system conducts collision avoidance successfully for all cases. Some snap shots of case No.13 is shown in Fig. 7.

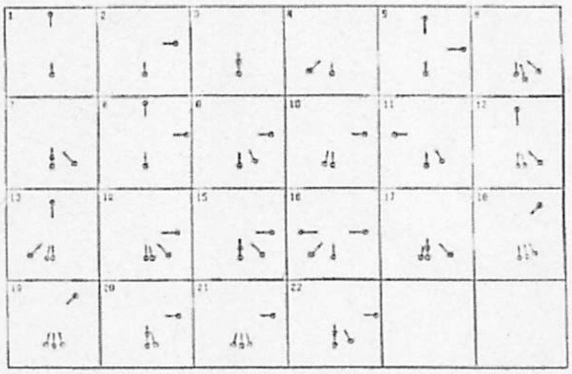


Fig.6 Imazu problems [37]

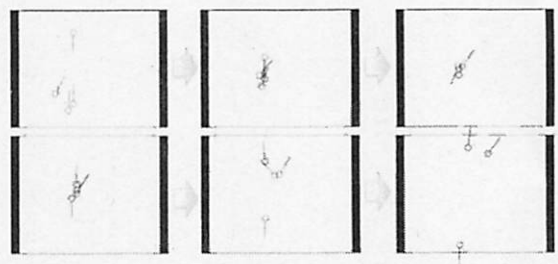


Fig.7 Result of the system for Imazu problem No. 13 [31]

2.5 Traffic Flow Generation Subsystem

This subsystem is explained in [6]. OD table is very important which provides all ship generation information including ship arriving time, type, length, speed, waypoints and indices of ship manoeuvring and speed response from given gates statistically based on the assumed distribution. Once a ship generated at a certain gate, the actual starting point is fixed by normal distribution from the centre line of the gate. All information except ship type and waypoints are also fixed by normal distribution individually. Thus no same ship appears, even these information are chosen from a limited number of database.

2.6 OD Table Generation

Normally, the table is created from statistics. In case of Osaka Bay [12] and Tokyo Bay [14], there are very detail OD tables already given by direct observation for big waterfront projects such as Kansai International Airport Construction Project and Haneda (Domestic) Airport Runway Expansion Project [16]. For Ise Bay (Nagoya area) [14], we made it artificially for the first time. In this case rough ship volume are estimated from the harbour statistics. Ship type and others are estimated based on this statistics and industries around the area. Fishing boat information is quite important for the total ship traffic in Japan.

Similar trial was done for Malacca and Singapore Straits [23]. This is the first case where statistical data including harbour report and VTS report are totally considered including unknown gates data not caught by statistics. Similar trial is also done for Shanghai area and Huangpu River area in Shanghai, too [24].

Now we are interested in automatic OD table generation based on AIS data. Tracing one ship data in time-series ships files, one ship path data is given. Doing for all ships in the files, all ship path can be obtained as shown in Fig. 1. However, we need to clarify waypoints from these ship paths. This method was first applied in [30]. At this moment we determine waypoints manually. For other information are again guess-base. Another trial is done for estimating K and T ship manoeuvring indices from AIS data [40]. Many things should be done for completing this subsystem to be applied any place in the world, but anyway AIS is a very strong tool for it.

2.7 Ship Dynamics Subsystem

For marine traffic simulation, so-called Nomoto's first-order equation composed of K and T is enough and for ship speed we use also first order equation.

$$T\dot{r} + r = K\dot{\delta} \tag{1}$$

$$T_U\dot{U} + U = K_n n \tag{2}$$

where

T, T_U: time constant for ship turning and advanced speed respectively (sec)

K, Kn: turning and thrust gain for rudder angle (δ (deg or radian)) and propeller revolution (n *(rps)*) (1/sec)

r: rate of turn (deg or radian)

U: ship advanced speed (m/sec)

If the ship is directionally unstable, we need modify eq. (1) taking account of nonlinear term or/and second order terms. If unstable ships are many in the area, it will be very hard to model the traffic well using these dynamics.

2.8 Autopilot and Track-keeping subsystem

For course-keeping PD control is enough. Autopilot parameters are pre-determined for each mother ship, and are not modified, even each ship's K and T are normally deviated. Parameter choosing is done suitable for course changing, and they are not always good for course-keeping, too. However, if we don't consider disturbances of wave, wind and/or current, the course-keeping is not important task.

In original papers [1-2], fuzzy autopilot is proposed. It is very smoothly changing parameters from course-keeping situation to course-changing situation, just leant from human being's strategy. It still works.

Another important task is track-keeping. It is really heuristic problem. There is no well-described method to automate it. In the original papers [1-2], fuzzy track-keeping model is also proposed. It changes order of course continuously from the angle to the next waypoint and that to the two-ahead waypoint depending on the nearness to these two waypoints. The nearness is reasoned by inverse concept of fear of collision, assuming the waypoint as stopped ship. Using this rule, we need not worry about the point to take course changing action for the angle to the two-ahead waypoint, if we consider the ship will pass somewhat deviated from the original waypoint due to certain reasons such as collision avoidance manoeuvres.

This is also very unique algorithm following human's behaviour, but if the deviation from the waypoint should be limited to certain amount such as certain percentage of the distance between these two waypoints. If it exceeds the limitation, the own ship should direct to the angle to two-ahead waypoint.

Another discussion is the point that if waypoints exist around there, it means there is no room for the ship to deviate much. Therefor we had better apply the modified algorithm suitable for narrow waterway to be explained next.

2.9 Algorithm for Narrow Waterways

In [4-5] some algorithm for narrow waterways are proposed.

The main point is regarding the navigational lane or limitation as virtual ships on the boundary crossing with the own ship's heading angle and on the line right-hand side vertical to the heading angle.

These virtual ships always follow the own ship ahead and aside in its right-hand side, if it approaches the boundary, the fear of collision may increase.

Some other parameters should be adjusted for the waterway, although the computation time is increasing around 10 times, if all ships are near the boundary. In [20, 24] simulation for confined waterways is done, but this algorithm is not applied, but limiting deviation from the scheduled waypoint-connected path is applied. Further consideration is expected.

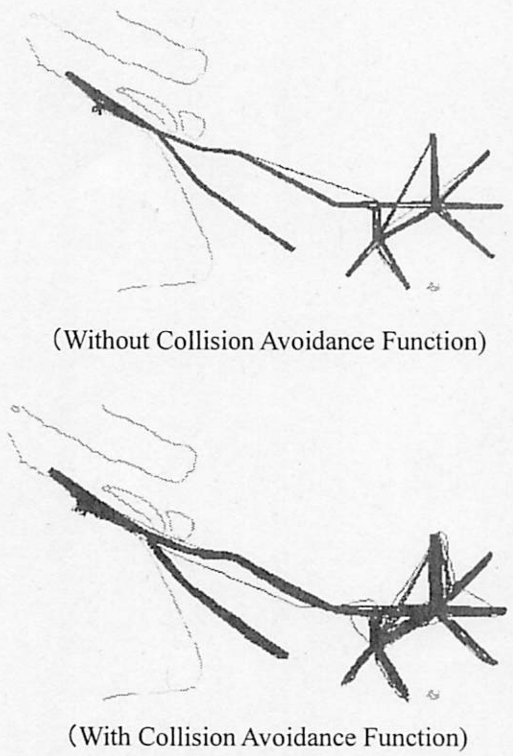
3. APPLICATIONS OF MARINE TRAFFIC SIMULAITON SYSTEM

In [6] several applications of marine traffic simulation system are proposed. Some of them will be briefly introduced.

3.1 Safety Assessment of Waterways

Many works are done for Miyanokubo Straits alternative waterway [4-6, 8], Bisan Straits cross traffic [4-7], Osaka Bay[14], Ise Bay [14], Tokyo Bay [14-18, 21], Malacca and Singapore Straits [23] etc.

Fig. 8 is a result for off Shanghai area.



(Without Collision Avoidance Function)

(With Collision Avoidance Function)

Fig.8 Influence of collision avoidance function in marine traffic simulation in case of off Shanghai waterways [41]

Similar application for narrow waterways are done for Albert Canal in Belgium [20] and Huangpu River in China [24].

3.2 Waterway Design

It is very useful tool for some alternative plan for safety measures. In [16] the influence of the extension of Haneda Airport is discussed and in [30] the influence of introducing separation lane scheme for entrance of Tokyo Bay is discussed.

3.3 Intelligent Ship Handling Simulator

In [25-28] the system is implemented into an existing ship handling simulator with automatic collision avoidance function, which we call intelligent ship handling simulator. This will be soon standard function of all ship handling simulators.

3.4 Evaluation of Automatic Navigation System

In [17-19,21] the system is used to assess AIS slot availability and Class B AIS applicability in Tokyo Bay. In [28] the system is utilised for evaluation the new navigation system, using intelligent ship handling simulator.

4. CONCLUSION

Marine traffic simulation system will be a key issue when we consider next generation marine traffic model. It will be a powerful tool to plan and evaluate the system.

Brief introduction of history, development and applications of marine traffic system is done mostly from the author's last 25-year research. As far as marine traffic is not deterministic but stochastic, we need the simulation system to assess it.

There are still many problems are remaining. To overcome these unsolved problems, we need users of the system. If you wish to improve it, join our users group and share our experience.

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