Evaluating of Marine Traffic Simulation System through Imazu Problem

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1. INTRODUCTION

Marine Traffic Simulation System (MTSS) is a powerful tool that can be applied for safety assessment of congested waterways. In the congested waterway like Singapore Strait and Shanghai area[11)], due to the high density of traffic flow, emergent encounter of multiple ships will occur frequently, which may result in near misses and even collisions[2)].

MTSS equipped with a collision avoidance subsystem based on Fuzzy control[1)] can instruct own ship to search for the most dangerous ship to take effective action against it while focusing on the other threat and take action again if necessary[3)].

Imazu problem[7)] is a series of ship encounter situations, which are considered very difficult for collision avoidance action. Therefore, it can be used for evaluating the collision avoidance ability of MTSS. In this paper, simulation of Imazu problem has been conducted.

2. Collision Avoidance and Imazu Problem

Nowadays, even though many advanced navigational aids and safety countermeasure are regulated by the IMO and we have international regulation of collision avoidance at sea (COLREG), it is still very difficult to avoid collision for multiple-ship encounter situations. In order to solve this problem, we have defined a general way for collision avoidance based on the two ship encounter situation, which can also be applied to multiple-ship encounter situation[3)].

The 22 cases of Imazu problem are shown in Figure 1. The circle shows the position of every ship while short bar gives the speed direction for easy looking. It covers both the two ships' encounter and multiple ship encounter situation and can be used for automatic system evaluation.

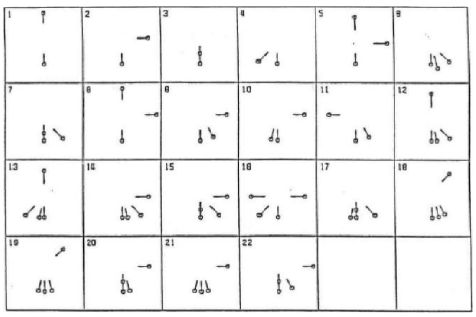

Fig. 1　Imazu problem

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All the 22 cases have been simulated by our system. Here we choose cases 17 and 19 for discussion.

Figure 2 shows the ship trajectory for case 19. In this figure, the triangles give the position of all the ships and the four lines show the trajectories in time series. The arrows reveal the direction of every ship. From this figure we can understand the every ship's route and collision avoidance action roughly. We can also know that no collision happens in this case.

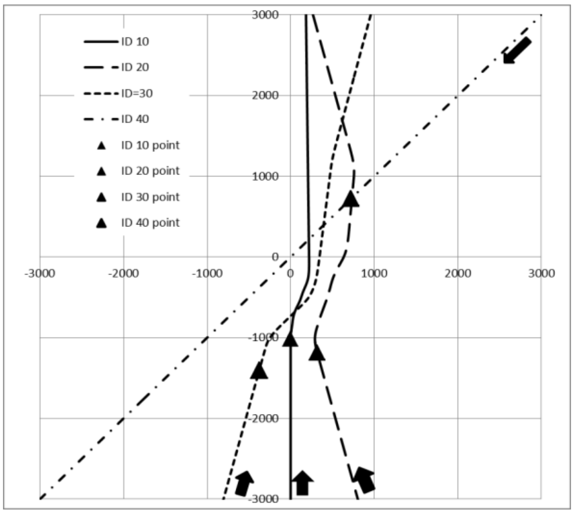

Fig. 2　Ship Trajectory for case 19

Figure 3 gives the time series of heading change, ship speed and collision risk (CR). A ship will take collision avoidance action by either turning right or reducing speed (only when it cannot turn right) as soon as CR exceeds 0.7 if the ship is not in the crossing hold-on condition. For the crossing hold-on ship, it will avoid collision when CR is over 0.9.

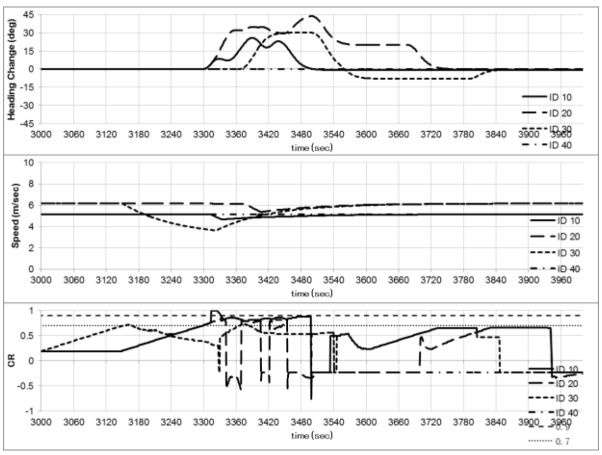

Fig. 3　Ship heading change, speed and CR for case 19

We can also check the avoiding action through the relative trajectories, which are shown in Figure 4. The arrows give the approaching direction of other ships to own ship, which is put at the origin of the coordinate. The lines show the relative trajectories. From this figure, we can understand that minimum distances between the ships have been kept in case an accident.

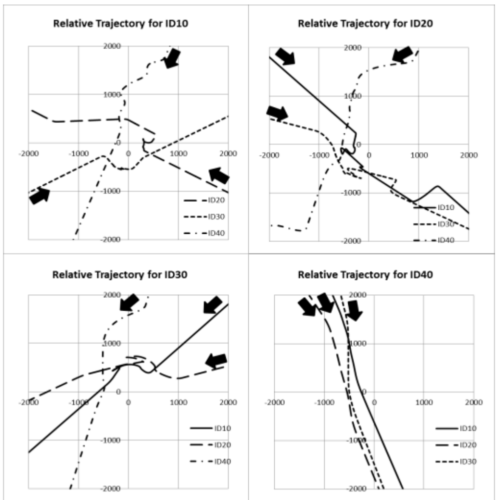

Fig. 4 Relative Trajectory for case 19

From the above example case, we can see that no collision happens in the simulation area. The two ships avoid each other when necessary and there is no strange behavior like fluctuation in ship heading change and speed either. Also, the avoiding actions follow the international regulation of collision avoidance at sea (COLREG). Therefore, we can conclude that the MTSS instruct four ships properly to avoid each other successfully in this case.

Similar conclusion can be made by analyzing the Figure 5-7 below for case 17. We can see that all the ships avoid collision successfully and go back to their original sailing route after that. However, it doesn't mean they avoid effectively enough. Because our system can only treat the most dangerous target ship at one time, the avoiding action may make even more dangerous encounter situation with other ships or make the own ship deviate too much from the original route.

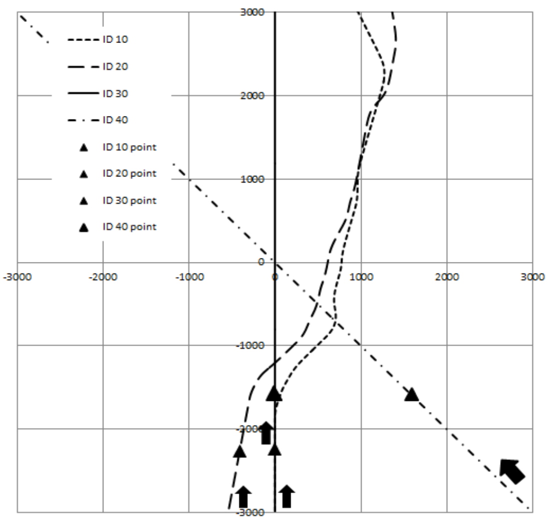

Fig. 5 Ship Trajectory

For this case, the avoiding action may be more effective if the ship ID 20 avoids ID 10 and ID 40 together when it tries to avoid ID 40 at the first beginning.

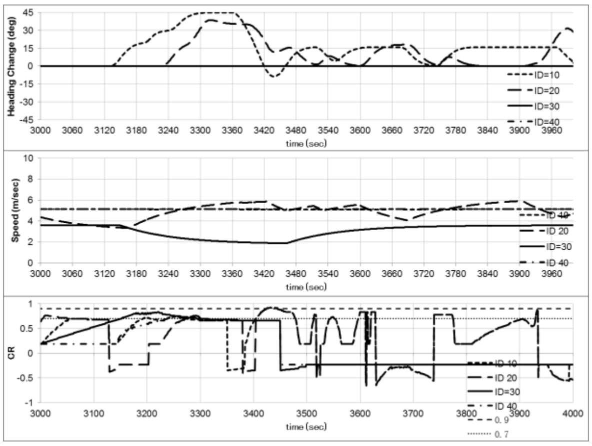

Fig. 6 Ship speed and heading change for case 17

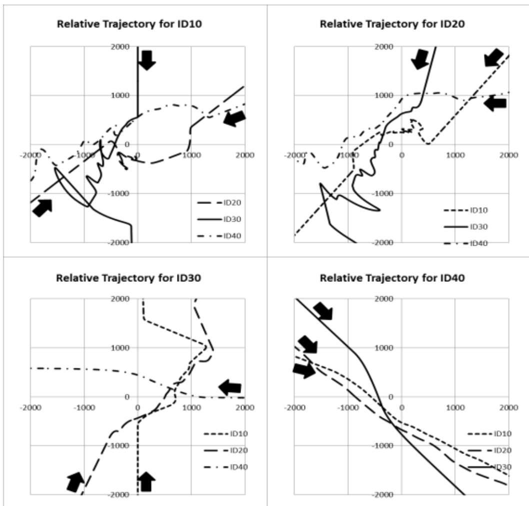

Fig. 7 Relative Trajectory for case 14

For the other 20 cases, our system also works properly and relative effectively to prevent collision to happen. Therefore we can conclude here that our system has a certain ability to instruct ships to avoid collision in multiple-ship encounters.

3. Collision Avoidance for Special Cases

Until now, all the simulations have been conducted by using the same ships equipped with our automatic collision avoidance system and their actions obey the COLREG. However, in the real situation, on one hand, not all the ships can be equipped by our automatic system. On the other hand, even for the equipped ships, sometimes they may fail to avoid collision properly or their actions don't follow the COLREG due to the breaking down of the system.

Compare to the situation discussed in chapter 2, the real situation can be more complicated and dangerous. It needs higher ability and intelligence of the collision avoidance system. In order to checking our system's avoiding ability towards this more severe situation, simulation has been carried out. For every case, one ship is chosen arbitrarily to be set to not take any collision avoidance action while other ships still maintain the collision avoidance function. Here, we may call it as special cases of Imazu problem. As the same with chapter 2, we also choose 2 cases (case 19 and 21) for discussion.

The following Figure 8-10 shows the sailing condition and the avoiding procedure of every ship in case 19.

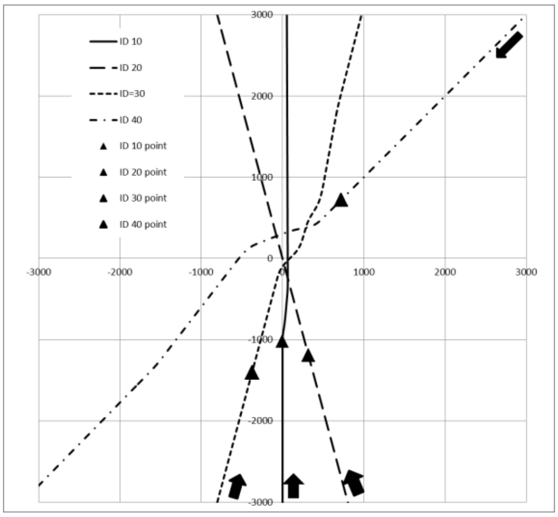

Fig. 8　Ship Trajectory for special case 19

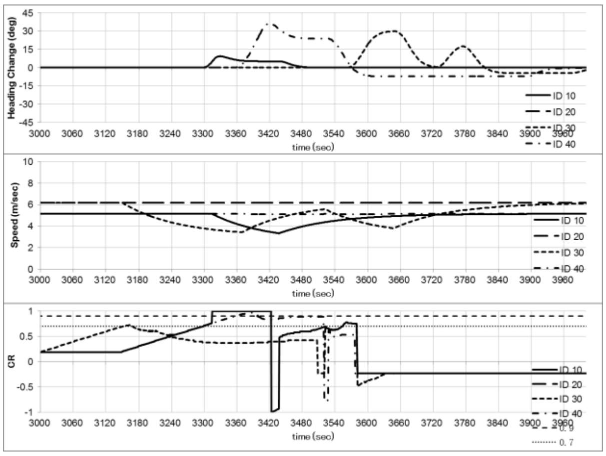

Fig. 9　Ship heading change, speed and CR for special case 19

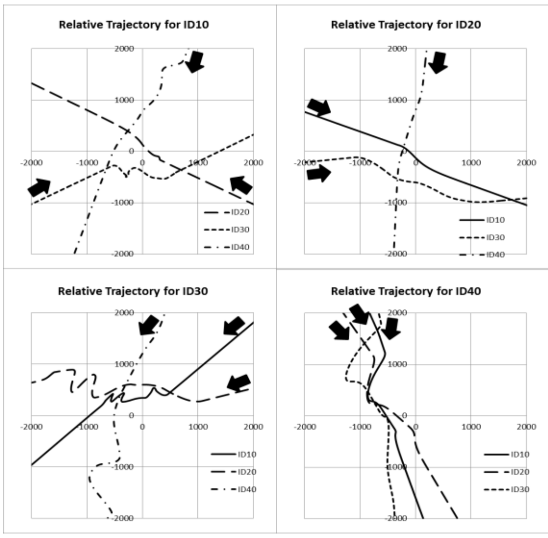

Fig. 10　Relative Trajectory for special case 19

Analyzing these three figures by the same way as chapter 2, we can understand that even though the ID 20 ship doesn't take any collision avoidance action, the other three ships still succeed to pass by each other safely without any strange behaviors like fluctuation in ship heading and speed.

However, for case 21, the collision happens due to the imperfection of our system's control rule. The following Figure 11-13 shows the simulation result of case 21.

As we can see in Figure 11, collision happens between ship ID 20 and ID 40. Also, there is an imperfection of avoiding action between Ship ID 10 and ID 30. It has resulted in the trajectory fluctuation of Ship ID 10 and speed fluctuation of ID 30.

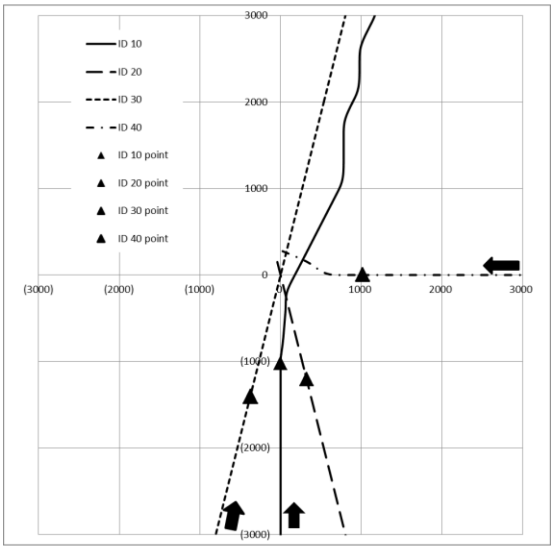

Fig. 11　Ship Trajectory for special case 21

From Figure 12, we can understand the whole procedure of avoiding action. When CR become over 0.9, the Ship ID 40 started to take avoiding actions by turning right because it is the Cross-hold on ship in the encounter situation. After some time, the turning action becomes more dangerous than reducing speed. So the ship's speed began to decrease. However, it has been too late to avoid collision.

The swinging of ship ID 10's trajectory also comes from the imperfection of our system. According to our rule, the ship ID 30 will reduce its speed while the ID 10 ship turns right to avoid it. After the avoiding actions, the ship ID 30 needs to speed up and ID 10 needs to return to the original route. These actions will make the situation dangerous again. Then the two ships have to take same avoiding action again. The repeating of this procedure results in the strange behavior of ship ID 10 and ID 30.

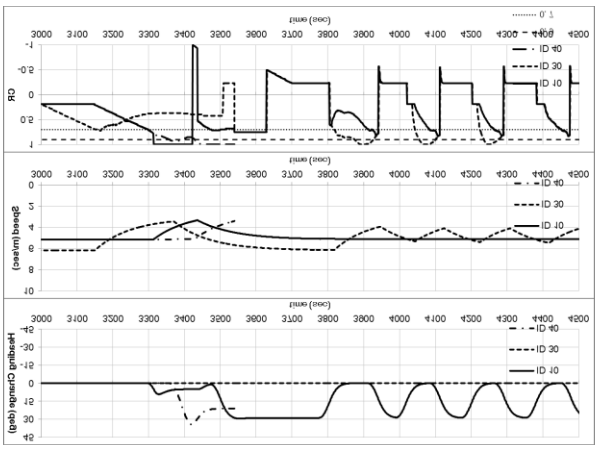

Fig. 12　Heading change, speed and CR for special case 21

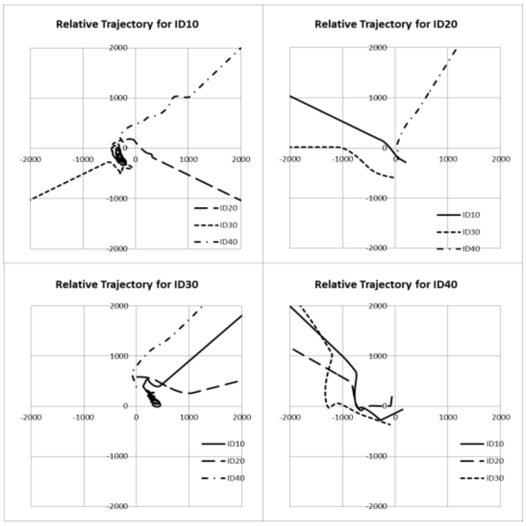

Fig. 13 Relative Trajectory for special case 21

From the relative trajectory, we can also understand the procedure for the collision and how strange the behaviors are between the ship ID 10 and ID 30.

Besides the two cases above, our system succeeds for most of other cases. Only a few imperfections of avoiding actions and even collisions exist in some very special encounters like overtaking and hold-on situation. This means our system can deal with most of the dangerous situations, in which some ships don't follow the COLREG.

From all the simulation we have conducted, we can conclude that Imazu problem could be used for building an evaluating standard for judging the collision avoidance ability of an automatic system. Here, an evaluating standard, which consist of 5 levels, is put forward:

Level 0: collision happens in two ships' encounter

Level 1: No collision happens for the case of two ships' encounters.

Level 2: No collision happens for the case of simple multiple ships' encounters.

Level 3: No collision happens for all the higher number cases (start from case 12) of Imazu Problem.

Level 4: No collision happens for all the 22 cases of Imazu Problem even if some ships don't follow the COLREG.

As for our MTSS, it succeeds in all the 22 cases of Imazu problem when all the ships have the collision avoidance ability. For the special cases of Imazu problem, except some very severe cases, in which collision happens due to the very irrational behaviors of ships, MTSS succeeds to instruct ships to avoid collision successfully and properly.

According to the above standard, we can understand that our system is at level 3, but hasn't reached level 4 yet. Therefore, we can conclude that our system is at very high level for collision avoidance, but still with some rules need to be improved or modified.

4. Conclusions

In this paper, several simulation of Imazu Problem has been done. Main conclusion can be drawn as follows:

1) Imazu problem can be used for evaluating the automatic collision avoidance system.
2) A standard for evaluating collision avoidance ability has been proposed.
3) The collision avoidance ability of MTSS has been evaluated by the standard.
4) MTSS is already very intelligent and effective for collision avoidance but still can to be improved or modified.

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REFERENCES

1) K. Hasegawa.: Automatic Collision Avoidance System for Ship Using Fuzzy Control. Proc. Eighth Ship Control Systems Symposium (SCSS) (2), 34-58, June, 1987

2) K. Hasegawa: Some Recent Researches on Next Generation Marine Traffic Models and Its Applications, Proc. The International Workshop on Next Generation of Nautical Traffic Model (IWNTM'2012), pp.25-31, Shanghai, China, Sep. 21-24, 2012.

3) K. Hasegawa, J. Fukuto, R. Miyake, M. Yamazaki: An Intelligent Ship Handling Simulator with Automatic Collision Avoidance Function of Target Ships, Proc. International Navigation Simulator Lecturers Conference, (INSL17), pp.F23-1-10, Rostock, Germany, Sep. 3-7, 2012.

4) K. Hasegawa. et al.: Ship Auto-navigation Fuzzy Expert System (SAFES) (in Japanese). J. Soc. Naval Architecture, Japan (SNAJ) (166), 445-452, Dec., 1989.

5) K. Hasegawa. et al.: Maritime Traffic Simulation in Congested Waterways and Its Applications. Proc. The 4th Conference for New Ship and Marine Technology (New-STech 2004), 195-199, Oct., 2004.

6) R. Miyake, J. Fukuto and K. Hasegawa: publication of Automatic Collision Avoidance Function on a Ship Handling Simulator to the Congested Sea Areas (In Japanese). Proc.20th JSME Transportation and Logistics Symposium (TransLog 2011), Dec., 2011.

7) H. Imazu: Research on Collision Avoidance Manoeuvre (in Japanese). PhD Thesis, University of Tokyo, Japan, 1987.

8) K. Inoue: Modelling of Mariners' Senses on Minimum Passing Distance between Ships in Harbour (in Japanese). J.JIN (90), 297-306, March 1994.

9) H. Imazu, T. Koyama: The Optimization of the Criterion for Collision Avoidance Action (In Japanese). Japan Institute of Navigation Proceedings No. 71, pp.123-130, 1984

10) H. Imazu, T. Koyama: The Optimization of the Criterion for Collision Avoidance Action (In Japanese). Japan Institute of Navigation Proceedings No. 71, pp.123-130, 1984

11) K. Hasegawa, E. Fu: Marine Traffic Simulator and its Application of Safety Assessment in Huangpu River of Shanghai. The 15th Academic Exchange Seminar between Shanghai Jiao Tong University and Osaka University, Oct. 2010.