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Advanced marine traffic automation and management system for congested waterways and coastal areas

Kazuhiko Hasegawa[1]

Abstract: One of the most advanced marine traffic automation and management systems is introduced. The system has been developed to assess safety issues in congested waterways and coastal areas. It contains automatic traffic generation sub-system, automatic track-keeping sub-system, automatic collision avoidance sub-system and AIS simulation sub-system. The system is already applied not only for Tokyo Bay, one of the most congested waterways in the world, but also in river navigation area in Europe. The largest area simulation is finally done for Malacca and Singapore Straits. Through these simulations the system was refined and some practical applications using the system are also introduced. AIS simulator is the one of the latest features of the system implemented, and future prospective directions will be suggested.
Keywords: port and harbour design, waterway design, congested waterways, safety assessment, ship automation, marine traffic generation, automatic collision avoidance, modelling of ship operator, AIS, broadcast communication at sea, communication conflict and garble, Tokyo Bay, Malacca and Singapore Straits

INTRODUCTION

Harbour, port or waterway design is the mission to determine its configuration etc. to satisfy the required functions considering the given geographical and other restrictions within the given expense. Once it is constructed, it is very hard to modify it due to the change of the ship size etc. From the viewpoint of the safety issue, it had better designed initially with certain margin, but it is not realistic. So it is normally designed proportional to the size of the typical ship in the subject area (*e.g.* PIANC, 1980, 1985). Therefore, it is very important to assess its safety from a planning stage of its construction or in occasion of any additional project. Full-mission ship handling simulators are developed for this purpose and utilized for various actual projects (*e.g.* Puglisi, 1985). They can project virtual view from a wheel house on a mock-up of a ship bridge and human operator(s) will navigate *the ship* just as in the real world. Panama Canal expansion plan was validated by this kind of ship handling simulator experiments and executed successfully (Puglishi *et at.* 1984, U.S. Maritime Administration. 1986). However, it costs much to develop a full-mission ship handling simulator, to prepare and validate complete mathematical model suitable for the subject ship (*e.g.* Eda *et al.*, 1986),

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1 Professor, Department of Naval Architecture and Ocean Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka, 565-0871, Japan, member of JASNAOE, JIN, JIME, IFAC Marine-TC, IEEE, etc. Email: hase@naoe.eng.osaka-u.ac.jp

and to conduct the simulator experiments with multiple ship masters/pilots to reduce the unsteadiness of the human behaviours.

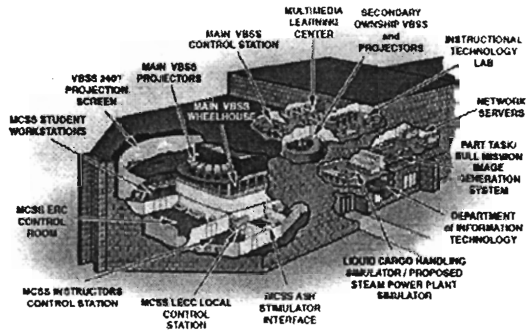

Fig. 1. Example of full-mission ship handling simulator (CAORF, established in 1975)

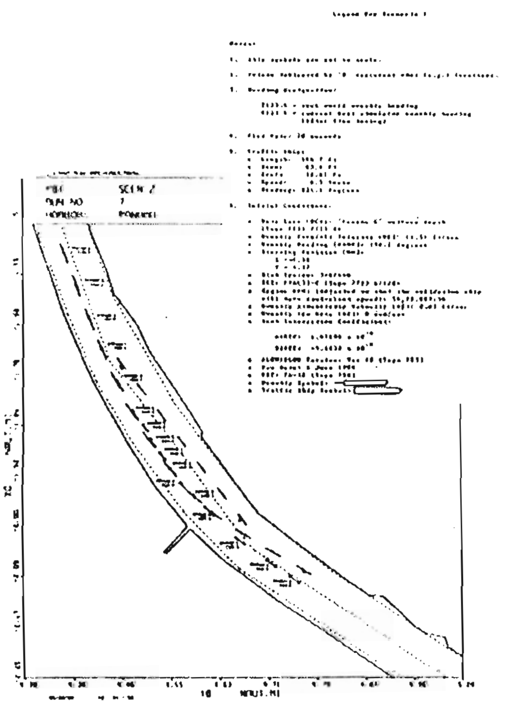

Fig. 2. Safety assessment using ship handling simulator (CAORF – Panama Canal Gaillard Cut expansion project) (Puglisi *et al.*, 1984)

Before the full-mission ship handling simulator is developed, so-called macro model simulation, or a kind of stepwise simulation just like a board game was used, where human operators are involving as players. It simulates event-oriented behaviours of human beings, but contains some lack of reality, because of discrete time simulation. Fast-time simulators (e.g.

MARIN, unknown) using autopilot or a kind of captain/pilot model to replace human operators are also developed for this purpose, but in most cases the captain's model is not yet qualified as to be regarded as a real one.

The author is engaging on these historical developments for more than 30 years from one of the oldest analogue-computer-driven ship handling simulators in the world to, probably, the most advanced human-model-driven marine traffic simulator. There will be another chance to describe these historical researches, but in this occasion, as a keynote lecture, he will show the latest result of his contributions in this field.

MARINE TRAFFIC SIMULATOR

The idea of marine traffic simulator was already given from the stage of stepwise discrete simulation, but probably developed here and there in the world according the rapid development of computer (*e.g.* Yamada *et al.* 1976 and Kobayashi *et al.*, 1980).

We need to consider several functions necessary for a marine traffic simulator.

Traffic Flow Generator

This is the part generating the traffic flow based on the statistical data, normally specifying the average arrival time of a ship to each gate, the type, speed and other specifications of the ship generated. In the gaming area, it contains at least two gates, namely, an entry – called origin, and an exit – called destination, but not limited. For each origin, it is given so-called an OD table, which specifies the distribution percentage of each destination from each origin respectively. It is sometimes very hard to define OD table for the subject area, if there is no statistical data by gate observation of radar analysis. Table 1 is an example (Hasegawa *et al.*, 2001).

Table 1. An example of OD table (Osaka Bay) (Hasegawa, 2001)

OD		Ship(%)						
Origin	Destribution	Type A	Type B	Type C	Type D	Type E	Type F	Type G
West Kobe and Suma	West Kobe and Suma	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Lane No.1	0.4	0.4	0.2	0.0	0.0	0.0	0.0
	Lane No.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	Lane No.3	0.2	0.2	0.7	0.0	0.0	0.0	0.0
	East Lane of Mole No.7	0.2	0.2	0.4	0.0	0.0	0.0	0.0
	Amagasaki Lane	3.1	3.5	3.9	0.5	0.0	0.0	0.7
	North Lane	5.2	1.9	4.1	5.9	0.0	0.0	0.0
	Main Lane	12.5	9.3	6.5	12.9	6.9	5.6	2.9
	South Lane	5.3	1.6	1.1	2.7	0.0	0.0	0.7
	Sakai Lane	22.5	2.7	3.9	0.5	0.0	0.0	0.0
	Hamadera Lane	7.9	2.0	2.2	0.2	0.0	0.0	0.7
	Izumiohtsu Lane	14.7	1.7	0.4	0.2	0.0	0.0	0.0
			0.7	0.2	0.0	0.0	0.0	0.0

Ship Dynamics
In the field of ship manoeuvrability, sophisticated hull, propeller and rudder forces and moment with their interactions should be taken into account. MMG model is widely reputed for this purpose and several variety of the model exists for its form and for the applicable situation including ship type, speed, propeller/rudder type and other restrictions like shallow water (*e.g.* Kose 1982, Yoshimura 1986). However, in case of marine traffic simulator, simplified Nomoto's KT model (Nomoto 1960) is recognized as feasible enough for the purpose of reducing computation time of multiple ships movement each time. Therefore it can be said that from the viewpoint of ship dynamics, marine traffic simulator is a kind of macro simulation. However, in the case of shallow water navigation or restricted waterway navigation appropriate choice of mathematical model is strongly recommended, taking an account of the accuracy required and the number of ships in the gaming area. Further discussion is still going on both in the communities of ship manoeuvrability (*cannot assign individual references, but many*) and ship handling simulator operators and vendors about the standardisation of the mathematical model, practical prediction method of its coefficients and/or the model documenting guideline (Endo, 2008).

Modelling of human behaviours
It is the most important parts in the marine traffic simulator. Simplified marine traffic simulator may use very simple autopilot, if it has track-keeping ability, when the user disregards the confliction with other traffic. Once other traffic is taking into account, we need certain model to replace a ship master/pilot. The most heuristic part of the human behaviour is the decision-making process to avoid collision against other ships or any navigational restrictions. There are many researches concerning to automatic collision avoidance system coping for from a-ship-to-a-ship to multiple-ship encounter situations. In 1980s there was a peak boom of so-called artificial intelligence in the field of computer science. Multiple-ship collision avoidance problem is a good target for this kind of research, because;

- ✓ There are only very simple rules regulated against one target ship (IMO, 1972).
- ✓ However, it cannot be directly applicable in the real world, because of confliction among multiple targets, and
- ✓ It requires certain expertise which is not describable.
- ✓ Ship master/pilot can solve it appropriately at last, but
- ✓ It will be one of the most stressful tasks, if the traffic density exceeds to some extent.

Besides, not like missile attack system, there are no uniquely-determined operation, in other words, there is no well-defined evaluation function. Therefore and coinciding the rapid development of newly-born algorithms such as fuzzy logics, artificial neural network, genetic algorithm and so on are applied as well as expert system or knowledge-based approach.

The author has developed the system combining fuzzy reasoning for collision risk recognition and expert system for conflict resolution for decision-making. Fig. 3 shows an example of the collision avoidance manoeuvre for multiple-target situation (Hasegawa, 2004a). The system was validated to work in model ship experiments as shown in Figs. 4 and 5 (Hasegawa, 2002, 2004b, 2004c).

Marine Traffic Simulator, Implementation, Validation and Its Applications
The system is applied for congested waterway areas such as Tokyo Bay, Osaka Bay and Ise

Bay (entrance to Nagoya). Fig. 6 shows an example of the result for Tokyo Bay where the left-hand side shows the result of the present state and the right-hand side shows the result after Haneda Airport runway expansion were done.

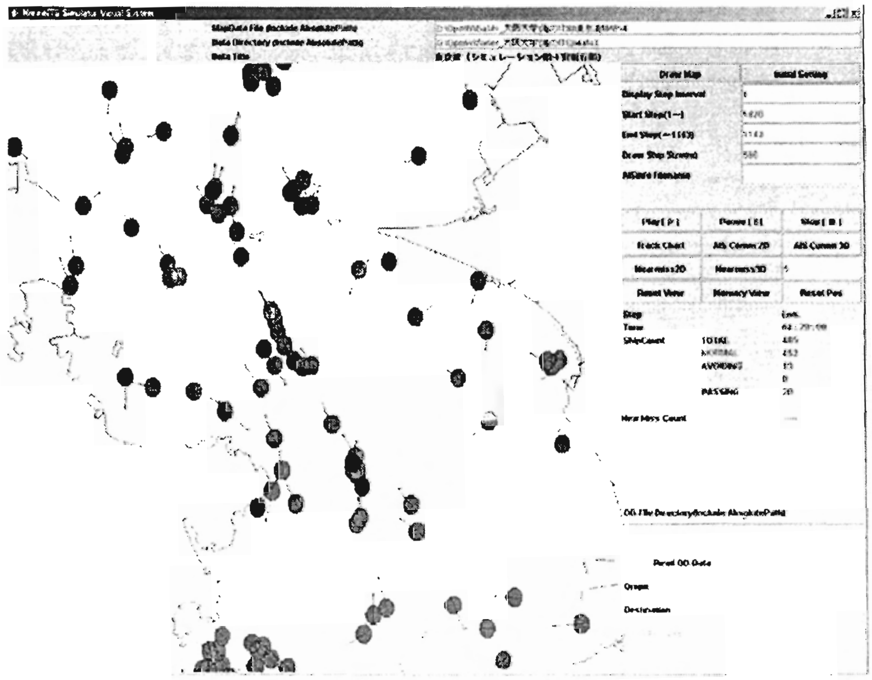

Fig. 3. An example of multiple-target collision avoidance manoeuvres (Hasegawa, 2004a)

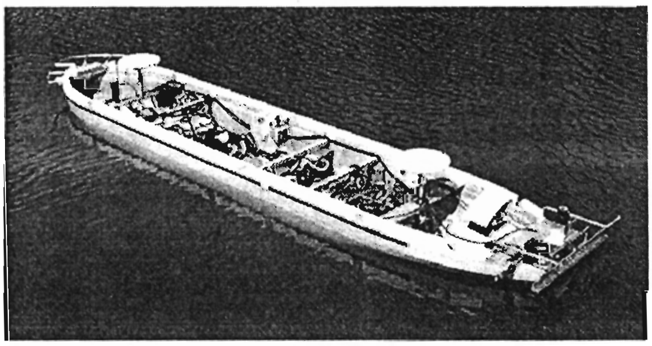

Fig. 4. Model ship tested for collision avoidance experiment (Hasegawa, 2002, 2004b, 2004c)

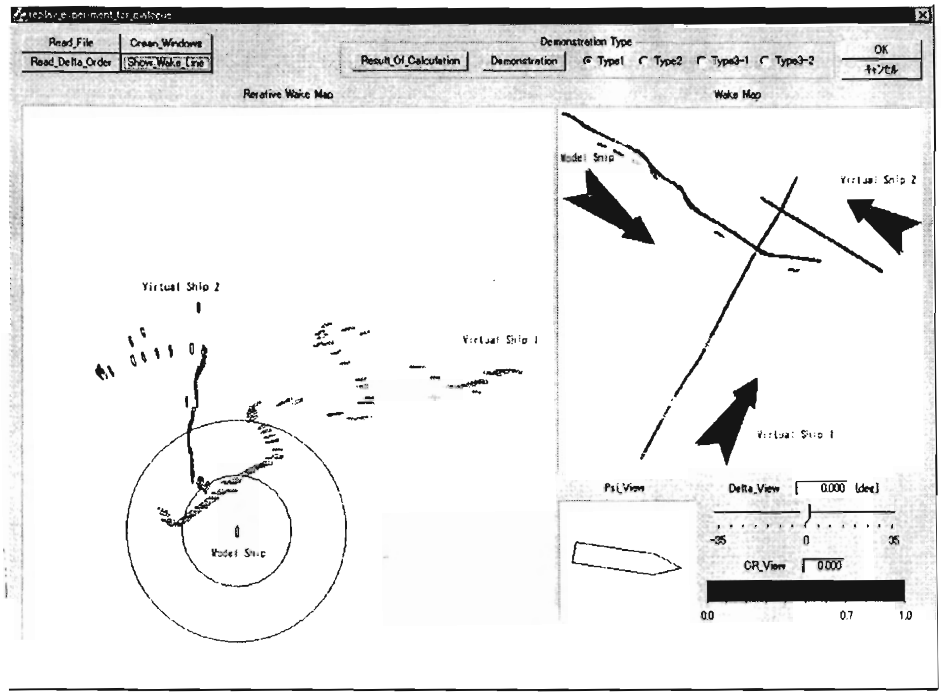

Fig. 5. An sample result of automatic collision avoidance of a model ship with two other virtual target ships (Hasegawa, 2002, 2004b, 2004c)

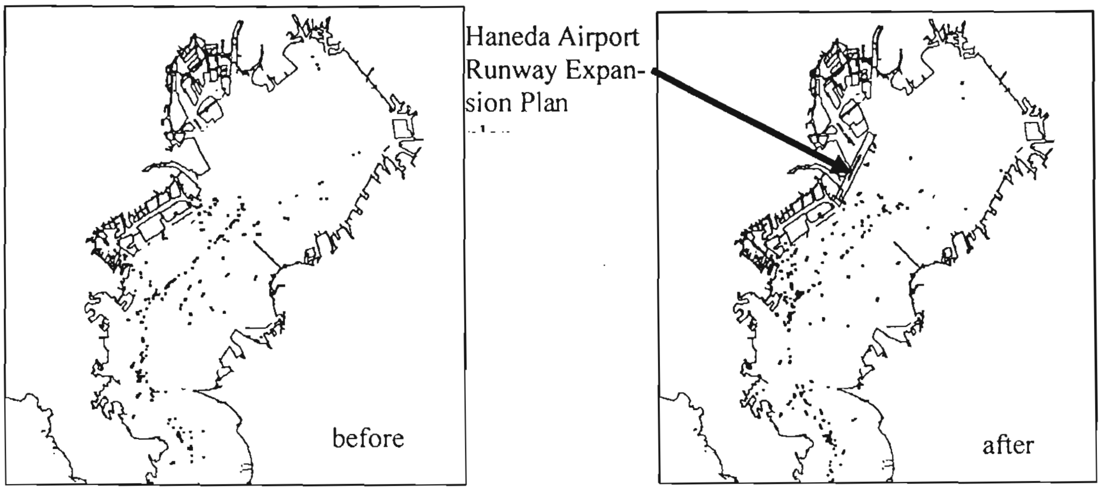

Fig. 6. An example of marine traffic simulator applications to assess the influence of waterfront development "Haneda Airport runway expansion project" in Tokyo Bay (Hasegawa, 2004c)

Marine Traffic Simulation of Malacca and Singapore Straits

The system is modified to be easily applied for any given waterway area, several improvements were applied. One implementation is for European river transportation (Watanabe *et al.*, 2008) and the other is for large scale simulation for Malacca/Singapore Straits. Fig. 7 shows an example result for Singapore Straits.

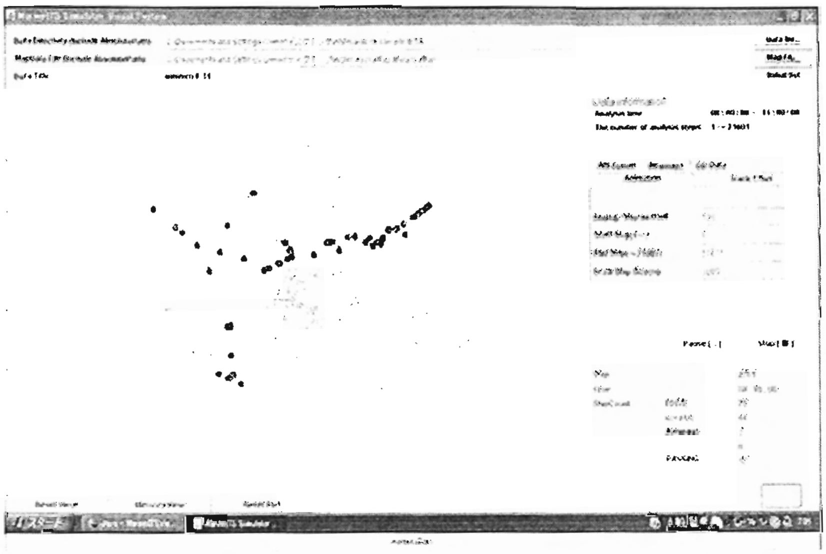

Fig. 7. An example of marine traffic simulation in Singapore Straits

AIS SIMULATOR

AIS (Ship-borne Automatic Identification System) is a system that enables a ship to get information about encountered ships, such as their position, course, speed, name etc. automatically by VHF radio transmission. The system is expected to contribute the improvement of marine traffic control and safety. In some congested waterways overloaded transmission of AIS may bring some transmission conflicts and garbles.

IMO and other bodies like port authority, VTS/VTIS (Vessel Traffic (Information) Centre) , coast guard and so on of each country is considering to utilize AIS for other usage like integrating into VTIS system, Class B AIS implementation etc.

The main problem to predict AIS transmission traffic is the fact that it depends on each ship's position, speed and movement! Therefore there is a big demand to develop AIS simulator. Hasegawa and his research group developed AIS Simulator and integrated it into Marine Traffic Simulator (Hata *et al.* 2006, 2007a, 2007b, Hasegawa *et al.* 2008).

Fig. 8 shows an example of integrated AIS simulator conducted for Tokyo Bay.

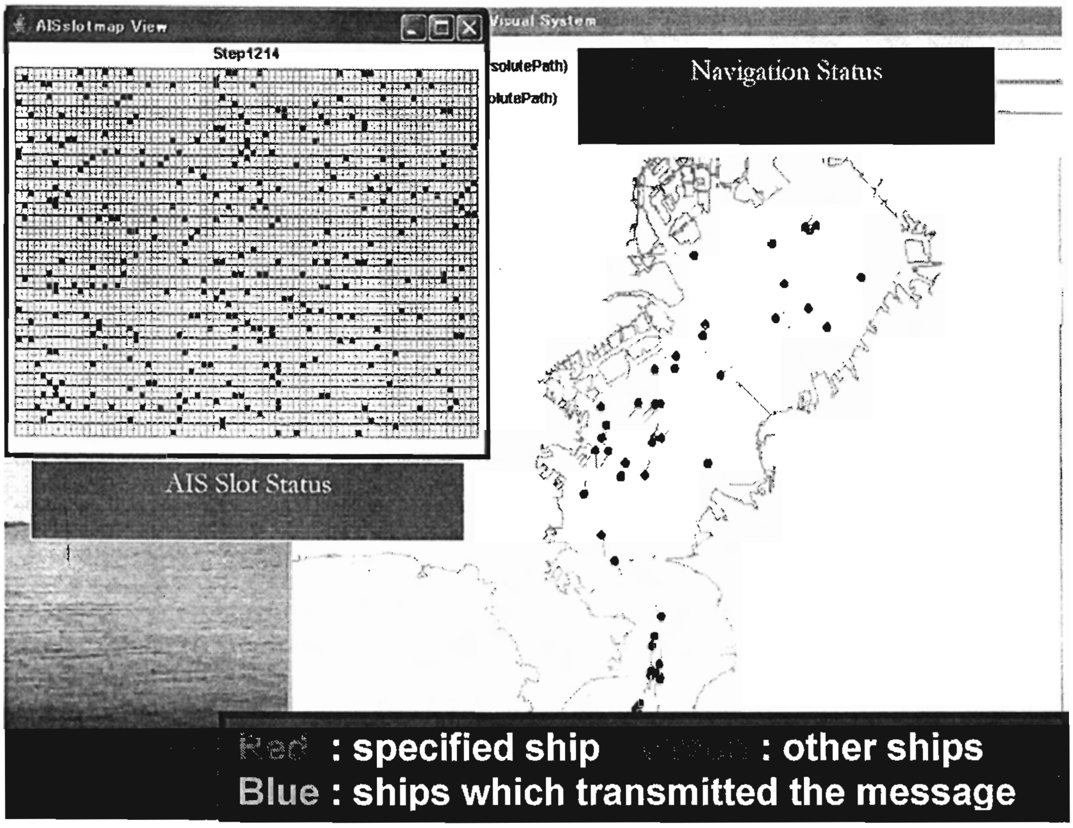

Fig. 8. An example of integrated AIS simulator into marine traffic simulator

CONCLUDING REMARKS

The way to contribute safer planning and construction of harbour, port or waterways from its historical development is briefly reviewed including introducing marine traffic simulator and AIS simulator. There are still many problems remaining for assess the safety issue in this field, but the role of simulation is increasing.

Model experiments, on the other hand, are still very important, especially, for new types of ships to identify their manoeuvrability and controllability. Captive model tests are essential for this purpose, but free-running tests play an important role to confirm the overall performance. CFD will be most promising tool in the near future to replace with model experiments even in the field of ship manoeuvrability, but accumulation of experiment data of any kind of ships will be of greater worth.

Assessing the safety issue using a ship handling simulator is established technique, as well as for education and training purposes, but the results are always subjective and there is no established protocol to validate the results.

Marine traffic simulator is a tool to replace human operator as its model and exclusive combination of the scenarios or situations can be evaluated objectively, including taking an account of capability to tune operator's skill.

AIS simulator, by-product, will be a common and standard tool for future AIS applications and harbour, port and waterway management system.

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