SIMULATION-BASED MASTER PLAN DESIGN AND ITS SAFETY ASSESSMENT FOR CONGESTED WATERWAYS MANAGEMENTS

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ABSTRACT

Designing harbours and ports, the safety issue is the most important. However, it is quite difficult to measure it. In this paper, a way to do it using marine traffic simulator is introduced with some examples. A kind of automatic navigation system called *SAFES* is used in the simulator. It can not only navigate each ship according to her mission given by waypoints, but also avoid other ships or navigational obstacles, if necessary. Combining the system with automatic traffic generator, we can get realistic marine traffic environment. Simulation-based safety assessment using this system was done for several projects including waterfront development and on-land AIS station configuration.

KEY WORDS: Safety assessment, harbor and port design, marine traffic control, waterfront development, marine traffic simulation, VTS, AIS, GPS

INTRODUCTION

When a harbour or a port is designed, safety is, of course, the most important issue. However, it is quite difficult to measure it. We should take care of economics, geographical configuration, environmental (wind, waves, current, tides, sediment etc.) conditions, manoeuvring characteristics of the ships concerned and the way of their operation, environmental and social influences, political issues and of even some historical backgrounds or local traditions. Civil engineers, naval architects and mariners should collaborate and negotiate under certain initiatives by administrative bodies. Civil engineers (project sponsors) and administrative bodies try to cut construction costs. It will lead easily poor navigational environment such as narrower excavated lane for big ships.

For the fundamental requirements in harbour and waterway design, certain international bodies such as PIANC (The Permanent International Association of Navigation Congress) and IAPH (International Association of Ports and Harbors) will play an important role. Actually, PIANC (1980, 1985) has developed guidelines and each country has established its own guidelines such as USACE (U.S. Army Corps of Engineers) (1983). However, they only guideline dimensional boundaries such as channel width and under keel allowance/clearance (UKA/UKC) by size of ships concerned.

From the operators' side, ship handling simulator is now widely used to assess the safety in the specified port or waterway thus designed. CAORF (Computer Aided Operational Research Facility) has assessed several projects in 80s using its full-mission ship handling simulator and is admitted as one of the pioneers in this field. However, the disadvantage is its time and cost including experiments and maintenance.

AN EXAMPLE OF GUIDELINES FOR WATERWAY DESIGN

To demonstrate how general guidelines are made, parts of the Canadian Coast Guard Guidelines will be introduced.

Guidelines For The Safe Design Of Commercial Shipping Channels (Canadian Coast Guard, 2001)

Vessel Parameters

The following parameters are used to represent the vessel concern.

- Length (L)
- Beam (B)
- maximum draught (d)
- speed (vs)

- manoeuvrability – a qualitative determination compared with other vessels, and
- traffic density – level of traffic frequency.

Waterway Parameters

The following parameters are taken into account to design the waterway.
- bottom material characteristics
- depth
- current velocity ad direction
- wind velocity and direction
- wave height, and
- navigational aids/pilot service.

Channel Width

Channel width is determined by the following equation.

Total Width = Design Width + Allowance

Design Width refers to the summation of width requirements for:
- manoeuvring lane
- hydrodynamic interactions between meting and passing vessels in two way traffic
- counteracting bank suction and
- navigational aids (including pilots).

These elements are illustrated in Fig. 1 and weighting factors are tabulated in Tables 1 – 9.

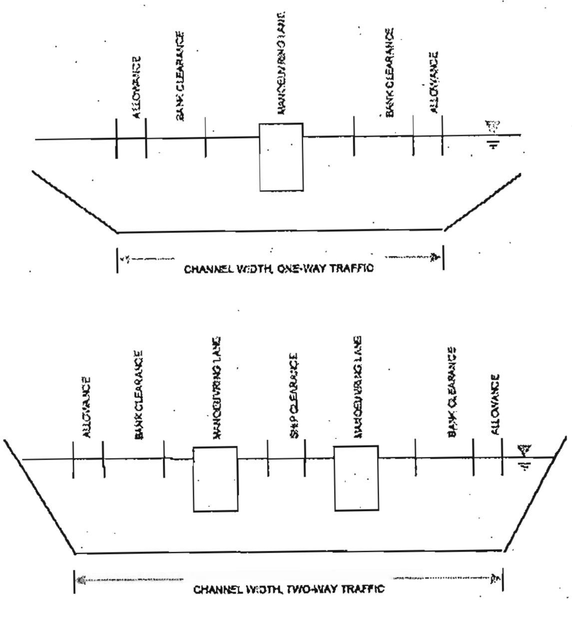

Fig.1 Interior Channel width elements.

Table 1 Manoeuvrability coefficients for various vessel types.

Vessel	Manoeuvrability	Manoeuvrability Coefficient	Manoeuvring Lane Width
Naval fighting vessels, Victory class freighters	Excellent	1.3	1.3 B
Tankers, new ore ships, Liberty class freighters	Good	1.5	1.5 B
Old ore ships, damaged vessels	Poor	1.8	1.8 B

Table 2 Additional width requirement for traffic density

Traffic Density*	Width Requirement
Light (0 - 1.0 vessel/hour)	0.0 B
Moderate (1.0 - 3.0 vessel/hour)	0.2 B
Heavy (> 3.0 vessel /hour)	0.4 B

Table 3 Additional width requirement for prevailing crosswinds

Wind Severity	Width Requirement for vessel Manoeuvrability		
	Excellent	Good	Poor
Low (< 15 knots)	0.0 B	0.0 B	0.0 B
Moderate (15-33 knots)	0.3 B	0.4 B	0.5 B
Severe (> 33 knots)	0.6 B	0.8 B	1.0 B

Table 4 Additional width requirement for prevailing cross current

Current Severity	Width Requirement for vessel Manoeuvrability		
	Excellent	Good	Poor
Negligible (< 0.2 knots)	0.0 B	0.0 B	0.0 B
Low (0.2 - 0.5 knots)	0.1 B	0.2 B	0.3 B
Moderate (0.5 - 1.5 knots)	0.5 B	0.7 B	1.0 B
Severe (> 1.5 knots)	0.7 B	1.0 B	1.3 B

Table 5 Additional width requirement for bank suction

Vessel Manoeuvrability[3]	Width Requirement - Severity		
	Low	Medium	High
Excellent	0.5 B	0.75 B	1.0 B
Good	0.75 B	1.0 B	1.25 B
Poor	1.0 B	1.25 B	1.5 B

Table 6 Additional width requirement for navigational aids

Navigational Aids	Width Requirement
Excellent	0.0 B
Good	0.1 B
Moderate with infrequent poor visibility	0.2 B
Moderate with frequent poor visibility	0.5 B

Table 7 Additional width requirement for cargo hazard

Cargo hazard level	Width Requirement
Low	0.0 B
Medium	0.5 B
High	1.0 B

Table 8 Additional width requirement for depth/draught ratio

Depth/Draught Ratio (D/d)	Width Requirement
D/d > 1.50	0.0 B
1.15 ≤ D/d ≤ 1.50	0.2 B
D/d <1.15	0.4 B

Table 9 Additional width requirement for bottom surface

Bottom Surface	Width Requirement	
	D/d > 1.5	D/d < 1.5
Smooth and soft	0.0 B	0.1 B
Smooth or sloping and hard	0.0 B	0.1 B
Rough and hard	0.0 B	0.2 B

Uncertainty of Categories and Factors

Manoeuvring Lane, for example, refers to the calculated value of the largest of the most frequently expected vessel type according to Table 1. The manoeuvring characteristics of vessels are here categorized only into three – excellent, good and poor. The reason of the factor values by these three is unknown. Traffic density is also categorized into three and traffics over 3 vessels per hour are assumed same. It cannot be directly applicable for heavily congested waterway such as Tokyo Bay or Osaka Bay.

Similar guidelines are prepared for other channel parameters such as side slope, channel depth, bends and bridge clearance.

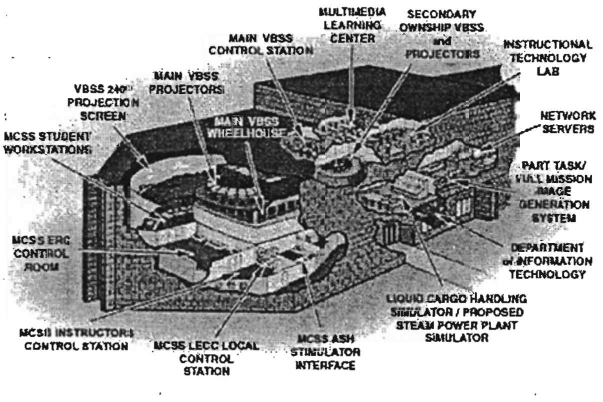

Fig.2 Example of full-mission ship handling simulator (CAORF, established in 1975)

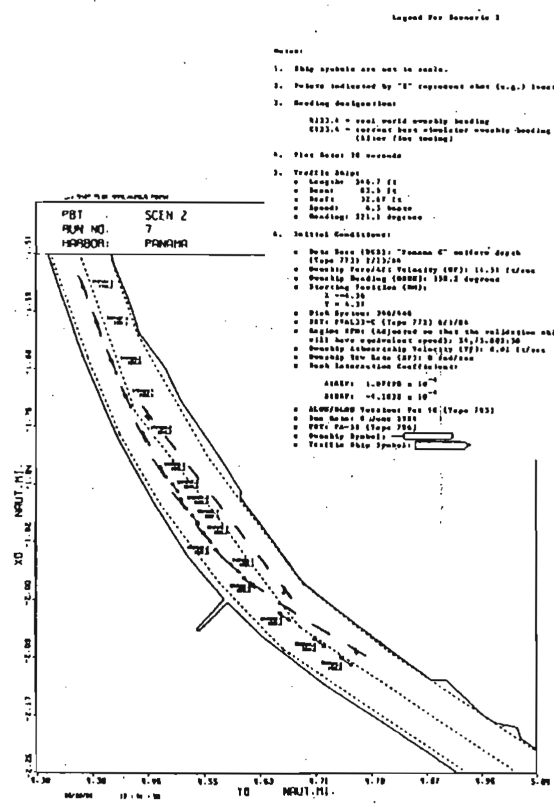

Fig.3 Safety assessment using ship handling simulator (CAORF – Panama Canal Gaillard Cut expansion project) (Puglisi *et al.*, 1984)

SAFETY ASSESSMENT USING SHIP HANDLING SIMULATOR

In 1980s, it's a kind of boom to construct ship handling simulator in the world. Rapid development of computer and computer graphics, CGI (Computer Generated Imagery) can make it possible for realistic large angle full-mission ship handling simulator. It was originally targeted for training of ship masters and still now the major activities are done for this purpose. These days they are used for education and licencing, too.

Most of them are thus facilitated in marine colleges or training centres, but a few simulators are mainly used for research purpose. CAORF simulator is one of them and one of pioneers of CGI based simulator. Several projects for harbours and waterways development were validated using this simulator. One of the biggest projects was Panama Canal width expansion project (Puglisi *et al.* 1984). The expansion plan based on the certain guidelines were confirmed and validated by Panama Canal pilots in reality. The mathematical model for bank suction and ship interaction is also very carefully prepared including model ship experiments in SSPA, Sweden and tuning of numerous coefficients.

Similar works were done in various projects in the world and at this moment, it is regarded as the best way to validate the waterway design.

Disadvantages of ship handling simulator are;

1) man-power, time and cost
2) subjective evaluation (depending upon person and relatively poor repeatability), and
3) physical and psychological influence (visual information processed differently *etc.*).

MARINE TRAFFIC SIMULATOR/SIMULATION

Kose and Hasegawa (1990) have proposed an idea of intelligent ship handling simulator utilizing expert system based automatic navigation system. Normally in ship handling simulators the own ship is modeled precisely, but other ships are simply modeled according to the waypoint navigation. For some dangerous situation, the instructor can change their heading angle or speed manually.

The intelligent ship handling simulator can do it instead. Authors have developed marine traffic simulator/simulation system since then (Hasegawa, 1990b).

Ship Auto-navigation Fuzzy Expert System (*SAFES*)

Hasegawa has first launched the system in 1987 (Hasegawa, 1987). The system can solve any collision avoidance manoeuvres, but with one target ship. Expanding the system using expert system, Hasegawa (1990a) has developed automatic multiple-ship collision avoidance system, which is called ***SAFES***. It can handle any number of ships in the gaming area. At that time in Japan, "Intelligent Ship" project was conducted, so several similar systems are developed by several institutions and researchers. Hasegawa has further developed the system to meet narrow channels (Hasegawa, 1993). The system was validated at the first model ship experiments with multiple target ships (Hasegawa, 2002).

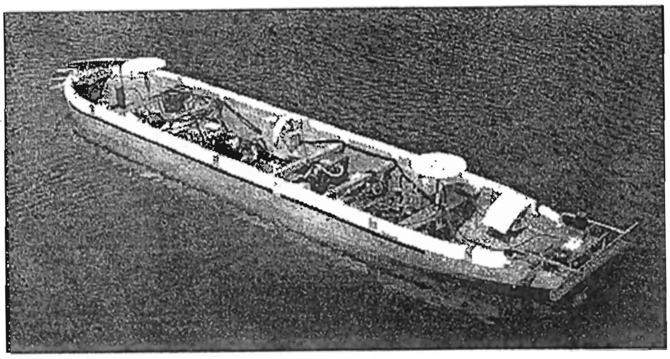

Fig.4 Model ship used at the multiple-ship collision avoidance experiment (Hasegawa 2004b)

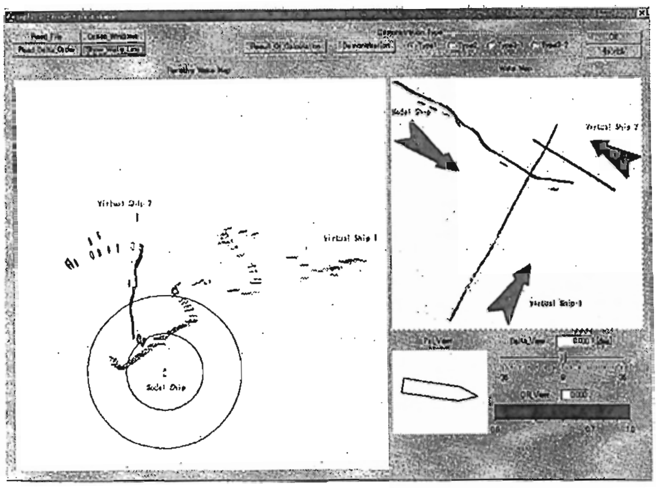

Fig.5 Automatic collision avoidance model experiment with two target ships (Hasegawa, 2002, 2004b)

each-Ship-with-captain MARine Traffic Simulation (***SMARTS***) System

The system was first developed for a project to assess the safety navigation in #-shape crossing lanes in Japan (Hasegawa, 1990b). It combines ***SAFES*** which can navigate any ship in the gaming area with automatic traffic generation system. Details are described also in Hasegawa (2000, 2001, 2004b).

The simulation can be done according to the OD table based on the various distribution statistics including ship type, speed and manoeuvring characteristics. So, it is easy to modify such as traffic density.

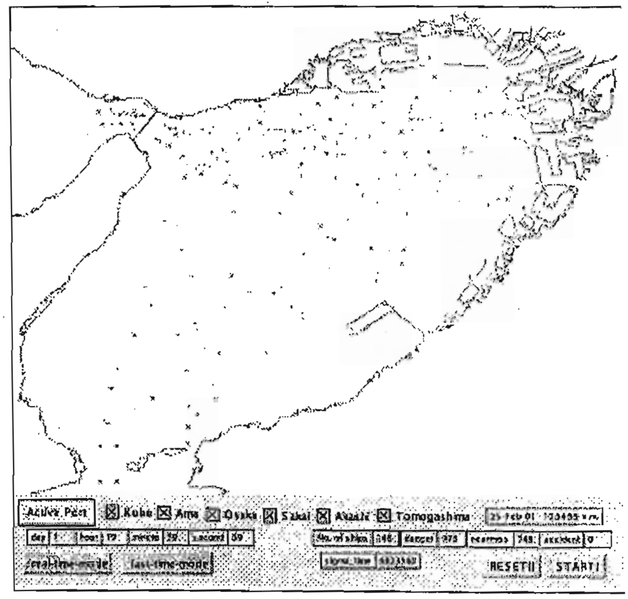

Fig. 5 Marine traffic simulation using SMARTS (Osaka Bay) (Hasegawa, 2001, 2004)

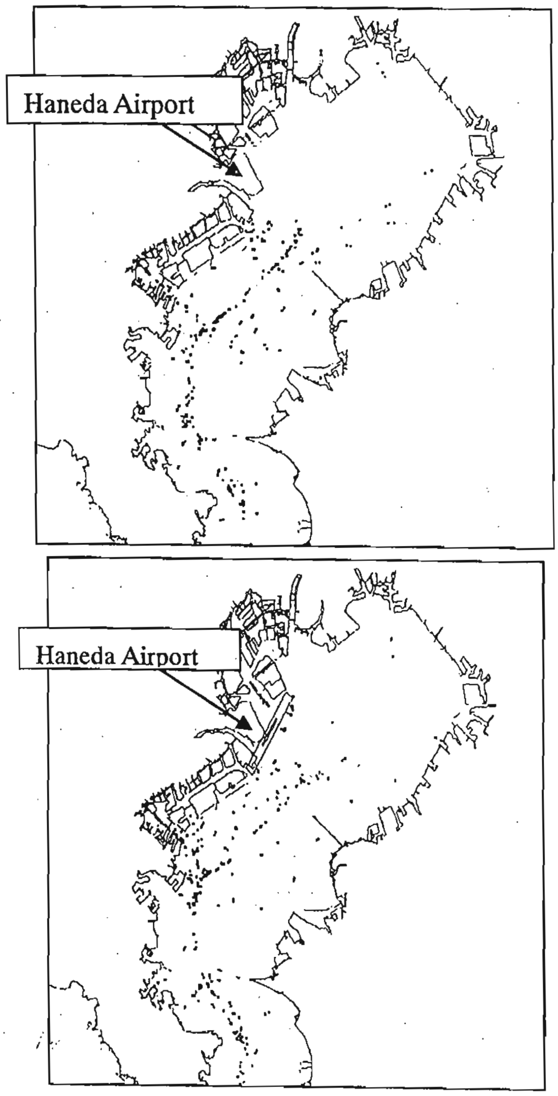

Fig. 6 Near-miss points before (upper) and after (below) of runway expansion (Haneda Airport, Tokyo)

SEVERAL APPLICATIONS

The system can be utilized in various applications. Hasegawa (1997, 1998) has proposed Virtual VTS using the kernel of this system as communication and advisary system to support navigation. Now this V-VTS system can be practically realizable using AIS as a communication tool.

Hasegawa *et al.* (2000) have applied it to the estimation of AIS report number. It is further applied to the confliction of AIS slot reservation (Hasegawa *et al.*, 2004b).

Hasegawa *et al.* (2004b) have assessed the Haneda Airport (Tokyo) runway expansion project. There are several master plans and it will affect only for a local navigation lane. However, using this system, the effect is not limited in the area, but it affects wide area as shown in Fig. 6 (Hasegawa *et al.* 2004b).

Hasegawa (2004a) summarizes the system and several applications here introduced.

CONCLUSIONS

Introducing harbours, ports and waterway design, marine traffic simulation system is explained. The main conclusions are summarized as follows:

1. PIANC guidelines are the first step to offer the initial design stage.
2. Ship handling simulator still plays an important role to assess the initial design.
3. More effective and quantitative assessment can be done using marine traffic simulation.
4. Further applications can be expected such as intelligent ship handling simulator, AIS report and conflict estimation etc..

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