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ON AN INTELLIGENT HARBOR MANEUVERING SIMULATOR AND ITS APPLICATIONS

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ABSTRACT

To assess the safety of harbor maneuvering in congested waterways, real-time simulation using a simulator with intelligent movements of other target ships is proposed. The system contains a main supervising computer and distributed sub-computers as well as a full-equiped bridge mock-up and visual display. The main computer calculates the own ship's maneuvering motion even to berthing and deberthing. Sub-computers operate other target ships utilizing expert system, generate CGI(Computer Generated Imagery), and communicate signals between the bridge mock-up respectively. The hardware and software requirements as a harbor maneuvering simulator are discussed.

1. INTRODUCTION

Marine simulators are now widely used for training operators, assessing safety and designing ships. The technical developments of CGI (Computer Generated Imagery) and the mathematical model of a ship in various conditions make it possible to apply them to more complicated situations such as in harbors or in narrow waterways. Moreover, requests to these applications grow significantly.

According to these circumstances, most of newly developed marine simulators have been designed to have capabilities necessary for these applications. However, the hardware and software requirements of such simulators are not standardized yet. Kose *et al.*[1].have recently developed a harbor maneuvering simulator, which enables to be used even to berthing and deberthing. We will discuss the requirements. Besides, it is worthy to mention about other aspects of harbor maneuvering through various simulations to full-scale trials.

On the other hand, in harbors and waterways, the operator should also pay attention to other ships' behaviors. Recent development in knowledge engineering also makes it possible to simulate them using expert system. Hasegawa *et al.*[2] has proposed a method to generate realistic traffic flow in congested waterways including each ship's behaviors. In the method, each ship has her own scheduled path in a waterway, but is operated by a modeled operator, who can judge and take suitable actions not only for ordinary operational conditions but also for unexpected situation such as multi-ship encounters,

With combination of these researches and developments, we are now developing a new type of marine simulator calling "intelligent harbor maneuvering simulator", which can be used for more realistic hydrodynamic, environmental and even traffic circumstances. Though we should further pay continuous efforts to improve it from more technical and practical viewpoints, the concept of the intelligent harbor maneuvering simulator is proposing in the following sections.

2. VARIOUS METHODS OF SIMULATION FOR SAFETY ASSESSMENT OF HARBOR MANEUVERING

Among the whole ship navigation, harbor maneuvering is one of the most difficult operation. Usually a skilled pilot of the destination harbor area takes proper instructions instead of the ship master. He knows very well about the geometrical and environmental information of the area. He also has the skills to learn the properties of the ship in a short-term exercise from his long-term experiences.

But there may be the cases when the pilot cannot achieve his superior operation smoothly, if he has less experience, if the ship is unconventional in maneuvering properties, or if the harbor is a newly developed one. In these cases, various approaches to overcome the difficulties are proposed. Gress and French[3] have classified them into the following categories:

Evaluation of safety can be done through or by checking
- Extrapolation of historical casualty data
- Semi-empirical modification and extrapolation of historical casualty data
- Probability of bottom touching
- Full-scale trial
- Man-in-the-loop simulator experiments
- Fast-time simulation
- Collision energy models
- Effects or costs of a particular incident
- Fault tree analysis
- Scaled waterway model experiments
- Queueing model simulating traffic movement

As we are concerned with simulation or simulator methods, we won't describe the detail of each methodology here. Among them, simulation methods are one of the most reliable but, at the same time, costly methods next to full-scale trial. Though it is impossible to carry out a full-scale trial for the condition very dangerous or non-existing, simulator experiments or simulation can be even applied. This is one of the merits of simulation, and the main purposes of simulations can be considered as follows:

- Training of pilots
- Assessing safety of new ships or new harbors
- Analysis of harbor maneuvering from the viewpoint of man-machine system or safety

In this section, we will introduce some case studies, in which various simulation methods were used.

2.1 SIMULATIONS OF ELEMENTAL MANEUVERS

As the procedure to assess safety of the harbor maneuver to a particular port or pier, one of the authors *et al.* have proposed the following steps[4]:

- To make a rational maneuvering plan
- To analyze the plan into elemental maneuvers and to certify the safety for each elemental maneuver
- To assess the safety synthetically by a real-time simulator

Figure 1 shows one of the maneuvering plan proposed for a newly developed pier of VLCCs in Japan. The plan is made through various considerations such as geometrical, environmental and traffic situation with restrictions of weather condition, draft condition and tugboats' assistance.

The maneuvering plan is composed of the following simple component maneuvers or elemental maneuvers.

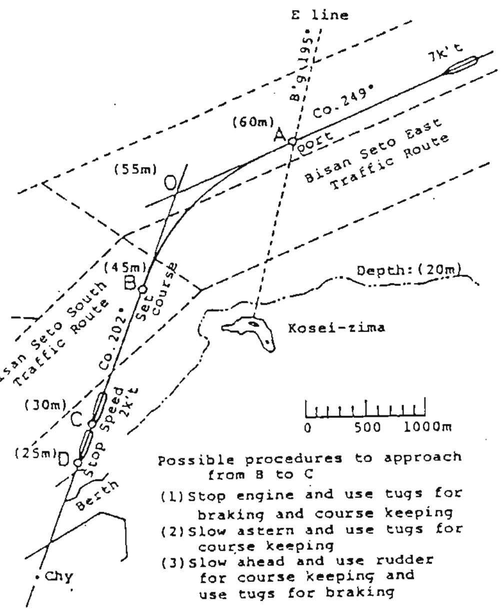


Fig. 1 A maneuvering plan to a berth

Table 1 Patterns of elemental maneuvers in harbor maneuvering plans of 21 different ports[5] (mainly with tugboats' assistance)

(unit: case)

No	Kinds of elemental maneuvers		berth in	berth out
1	Course-keeping	at constant speed	42	0
		with accelerating	0	46
		with decelerating (incl. stopping)	64	0
2	Course-changing	at constant speed	10	1
		with accelerating	0	29
		with decelerating	25	0
3	Turning-around-a-point	at bow	28	18
		at stern	0	20
		at midship	4	24
4	Shifting	laterally	39	36
		obliquely	0	1

(1) Course-keeping at constant speed
(2) Course-changing at constant speed
(3) Reducing speed to stop the ship with course-keeping
(4) Turning around bow at almost zero advance speed
(5) Shifting laterally to the pier

Of course, the actual maneuver cannot be separated completely into these elemental maneuvers and most of phases overlap each other, but it will be convenient to evaluate the maneuver if the maneuver can be treated as the combination of these simple maneuvers. Table 1 is the summary of the results of analyzing other harbor

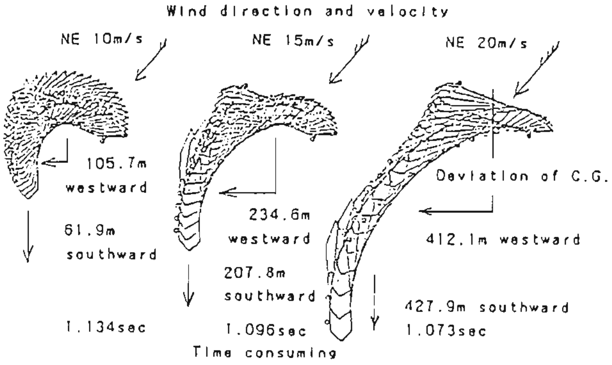


Fig. 2 Simulations of tug-assisted turn under different wind velocities[6]

maneuvering plans of 21 different ports in Japan[5]. Unexpectedly and fortunately, it is proved that there are not many varieties in maneuvering patterns.

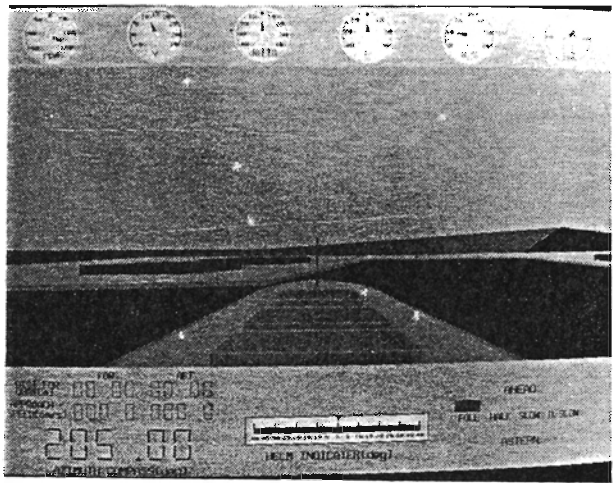
As each elemental maneuver itself is very simple, we can roughly judge the validity of the maneuvering plan by checking each maneuver is acceptable in the following aspects:

- to be reasonable from the viewpoint of ship handling
- to be reasonable regarding the navigational aids available, including tugboats
- to be reasonable from the viewpoint of ship hydrodynamics
- not to be difficult under a certain condition of wind, current or other external forces

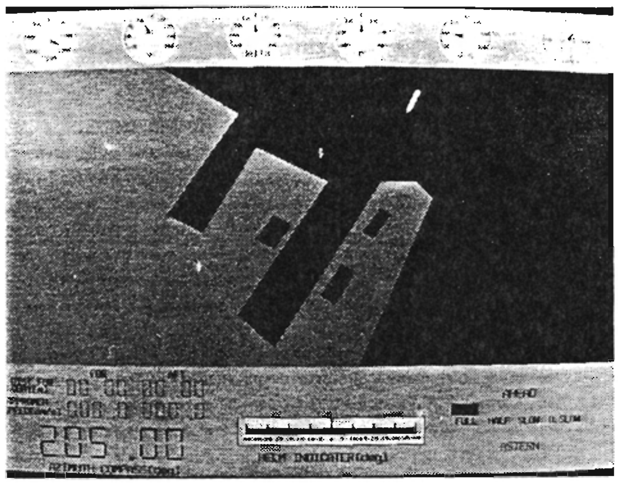
Figure 2 is an example of the simulations of tug-assisted turn under different wind velocities[6]. From these simulations, we can evaluate, for instance, the maximum allowable wind velocity or the radius of the turning basin.

2.2 MANUAL CONTROL SIMULATIONS USING A DESKTOP SIMULATOR

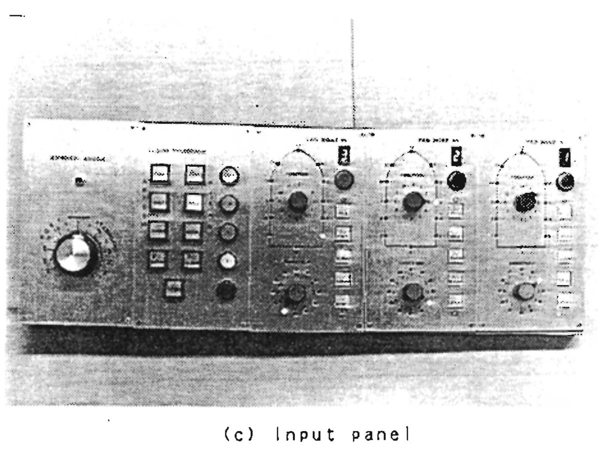
A desktop simulator is defined here as a computer simulation system with input/output interface with an operator. The output interface is usually graphic display with a bird's-eye view or a perspective view from the bridge. It is desirable to be 'equiped' with a compass etc. and to be easily 'operated' by a steering wheel or an engine telegraph. These features of a desktop simulator can rather easily realized with full utilization of recent development of computer graphics and user-friendly interface. Indeed, most desktop simulators now available are installed in personal computers. In Fig. 3 CRT displays and the input panel of the desktop simulator of Hiroshima University are shown. In a desktop simulator, the system response will not always required to be real-time, however, the time scale should be carefully chosen so that operator's actions won't be affected. Before the completion of a harbor maneuvering sim-



(a) CRT display(perspective view)



(b) CRT display(bird's eye view)



(c) Input panel

Fig. 3 Desktop simulator of Hiroshima University

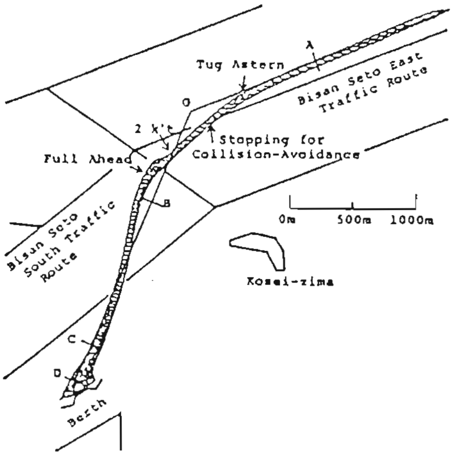


Fig. 4 An example of simulator experiment using a prototype desktop simulator[4]

ulator, we have made another real-time desktop simulator, where the total safety assessment of the maneuvering plan as shown in Fig. 1 was carried out[4]. An example of the simulator experiment is shown in Fig. 4.

2.3 FAST-TIME SIMULATIONS USING HUMAN MODEL

When proposing a maneuvering plan, planners usually discuss also some other alternative plans. If they cannot conclude the most preferable plan from them by document study or interview from experts, simulator experiments will be planned. Even if the desktop simulator is handy and less costly than a full-mission simulator, we cannot conduct so many experiments with different maneuvering plans in a limited amount of time and expense. There are also the cases when we cannot fix what kinds of scenarios are suitable for the intention of the experiments.

Fast-time simulation including human model becomes important mainly from the above reasons. If an appropriate human model is obtained, the fundamental part of safety assessment, namely, the parametric studies can be done by fast-time simulations.

Figure 5 is an example of fast-time simulation using SAFES[2], where a modeled pilot ordered suitable instruction for track-keeping, track-changing and even collision avoidance. In this case, it is very difficult to setup enough width waterway, because of many small islands around here. So two-way traffic as shown in Fig. 5 and one-way separated plans are compared by this fast-time simulation and it is found that it is possible to navigate alone in either case but one-way traffic is sometimes very dangerous at some meeting situations.

2.4 REAL-TIME SIMULATIONS

According to these investigations, real-time simulation using a full-mission simulator is usually carried out for the selected cases.

A harbor maneuvering simulator of Hiroshima University[1] is specially designed suitable for harbor maneuvering. Figure 6 shows the layout

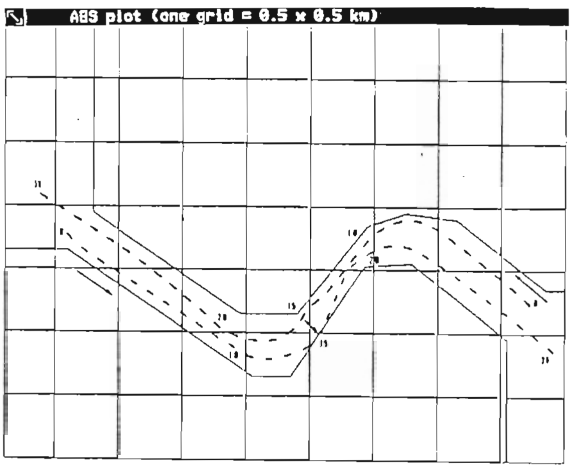
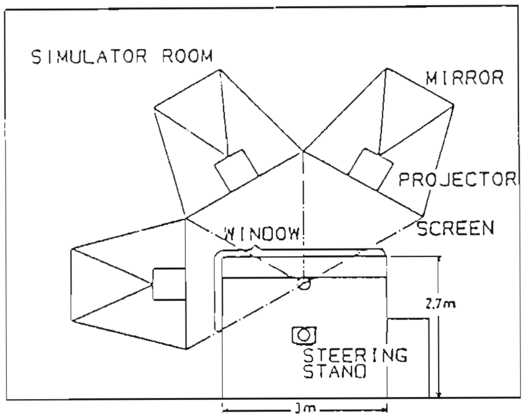
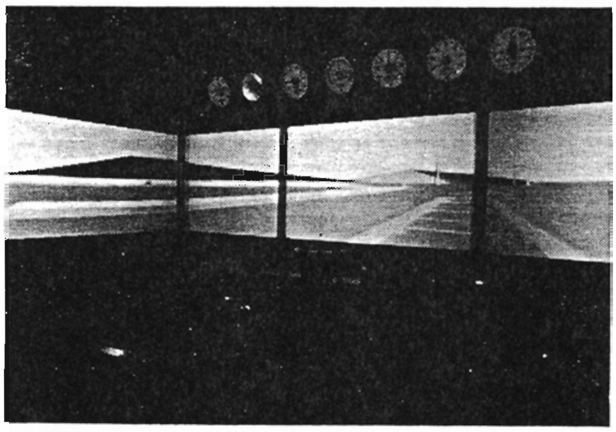


Fig. 5 An example of fast-time simulation by a modeled pilot



(a) Layout around the bridge



(b) A view from the bridge

Fig. 6 Harbor maneuvering simulator of Hiroshima University

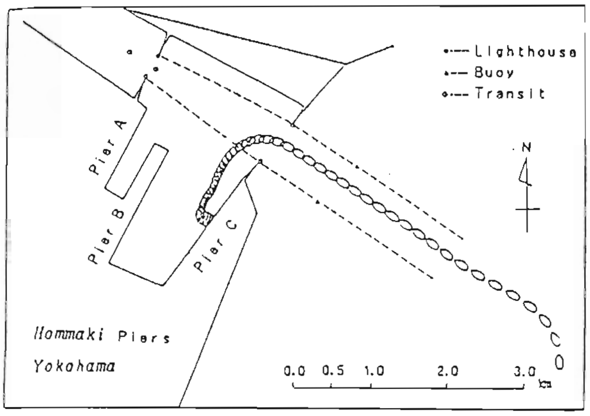


Fig. 7 An example of berthing using a harbor maneuvering simulator

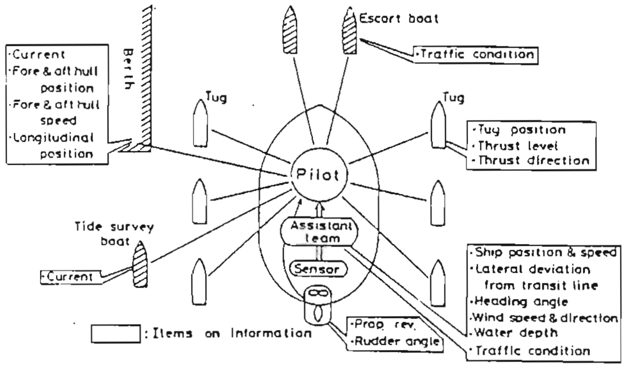


Fig. 8 Harbor maneuvering system for a large tanker

around the bridge and a view from the bridge of the simulator. Though it is said that a ship handling simulator is preferably equiped with a screen of large diameter and in wide horizontal range of angle, because a ship master or a pilot usually moves wide area in the bridge. However, a short distance to the screen is more convenient when berthing or deberthing. Tugboats operation is carried out through an interphone to a simulator operator, who sets the pilot's order to tugboats instead.

Figure 7 is an example of the result of a berthing maneuver using this simulator. Figure 6(b) is a scene of the approach to the harbor entrance. It is found to be useful for training pilots and assessing the safety.

Once, the safety evaluation was made through such a simulation, we sometimes misjudge the result is also valid in the actual navigation. However, we should remember even this simulation cannot represent the real world completely. Mathematical model in low speed and/or in shallow water is included, but it stands on some simplifications or assumptions. External forces are also idealized. Besides, in the actual navigation, around 20 personnels make a team when berthing or deberthing.

2.5 ONBOARD VERIFICATION

Onboard verification was planed to investigate these effects or as a final stage of the whole assessment.

In the actual navigation, a pilot has to deal with quite many informations and instructions during a harbor maneuvering as roughly shown in Fig. 8. We can thus easily imagine that he feels an extreme stress during performing the mission. Indeed, as shown in Fig. 9 and Table 2, we have observed various kinds of unexpected or confused instructions or events[7]. These erroneous behaviors may often induce further human errors and, as a result, they might be a trigger of an occurrence of a hazard. We should, therefore, carefully conclude the total evaluation of safety.

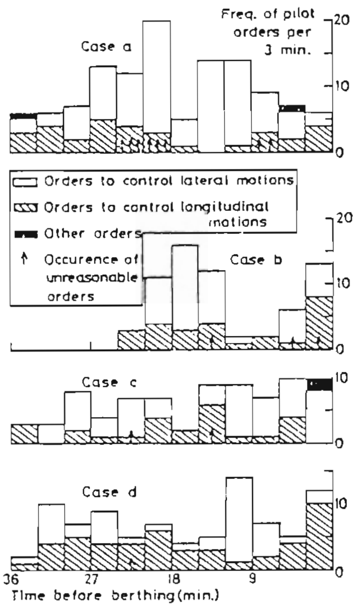


Fig. 9 Frequencies of pilot orders and occurences of unreasonable orders

Table 2 Percentages of wrong decision-makings or orders

Items of wrong or insufficient events	%
Jamming in transceiver communication	34
Wrong or insufficient grasping situations of own ship, control devices and external circumstances	19
Wrong or insufficient decision-making by a pilot	8
Wrong or insufficient communicating or executing for pilot's orders	39

3. SAFETY ASSESSMENT FROM THE VIEWPOINT OF MARINE TRAFFIC

When designing a new waterway or a harbor, we should consider the maneuvering performance of the ship under consideration, environmental conditions and human effects, and simulator is a tool to assess them totally as described in the previous section. Though it can also consider a few pre-scheduled or instructor-operated other ships, it is generally difficult to take into account of congested traffic. It may sometimes affects the pilot's behaviors unnegligibly.

In this section, some simulation methods to deal with traffic environment will be described.

3.1 MACRO SIMULATION OF MARINE TRAFFIC

So-called network simulation[8] is an application of Monte Carlo simulation, which deals with marine traffic as a queueing problem. Though maneuvering properties and pilot's behaviors of each ship are neglected or simplified (this is the reason why this method is also called as macro simulation), we can evaluate the qualitative and quantitative state of marine traffic and its future prediction.

In Japan since this method was proposed around 1975[9], it has been used in many projects of port design or safety assessment[10]. There are some variations or modifications to consider ship dynamics etc., but it is generally difficult to evaluate the effect of each ship's maneuvering properties and operational behaviors.

3.2 MICRO SIMULATION OF MARINE TRAFFIC

Micro simulation is also an application of Monte Carlo simulation as same as macro simulation, but without neglecting each ship's maneuvering properties and/or pilot's decision processes. Kobayashi and Koyama[11] have used this method to investigate the availability and the effect of the change of traffic density or method in a marine traffic control system to control safety navigation in #-shape crossing lanes. In the proposed system, each ship is requested to pass the crossing points during the appointed time, adjusting her speed (each ship going straight should pass the crossing lanes twice). So it was necessary to calculate each ship's speed by a suitable mathematical model. Nagasawa[12] has proposed a method to simulate marine traffic with regarding collision avoidance maneuvers. In congested waterways and harbors, path-keeping, speed control and collision avoidance are all unnegligible to achieve safety navigation, so micro simulation will be of great importance.

3.3 KNOWLEDGE-BASED SIMULATION OF MARINE TRAFFIC

Knowledge-based simulation is one of the latest methodologies in simulation to simulate a complicated system/plant with or without human's behaviors. Because collision avoidance or berthing maneuver is suitable for an expert system approach[13], it is natural to apply it to micro simulation of marine traffic.

Combining the macro, micro and knowledge-based simulation, we can carry out more realistic marine traffic simulation as shown in Fig. 10, where 24 hours of simulation with totally 555 vessels was carried out. This is an application of SAFES[2], and in the figure all traces of each ship and the points of "near-miss" and "out-of-bounds" are marked to evaluate the average ship paths and the probability of casualties. Besides, as the properties of so-called engineering workstation(EWS) or graphic worksta-

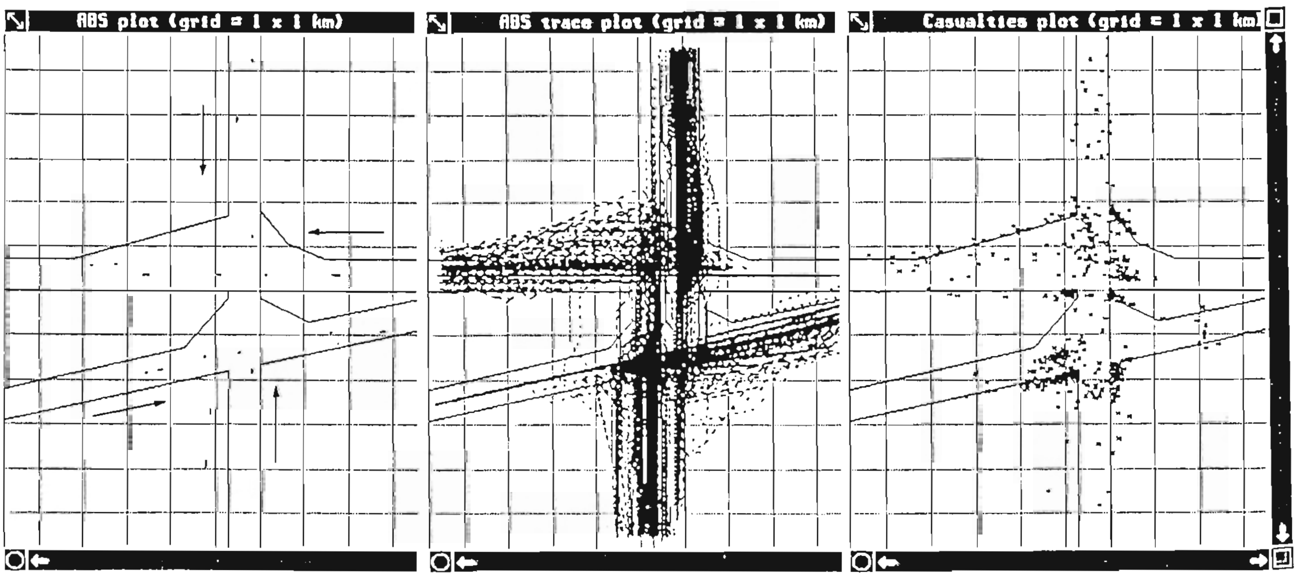


Fig.10 A result of knowledge-base marine traffic simulation

tion(GWS), we can also easily provide a relative radar-type view and a perspective view from a fixed point or from the bridge of an appropriate ship. In the actual system, graphic hardcopy is taken every, *e.g.*, one hour and every refreshed graphic display can be recorded into video tape using a scan converter and a VTR controller as well as an output file consisting several statistical data, casualties data etc. As all the processes are done automatically, we can check the simulation result visually or numerically after the simulation.

4. INTEGRATION TO AN INTELLIGENT HARBOR MANEUVERING SIMULATOR

4.1 THE AIM OF THE SIMULATION

Through our experiences in various marine simulations as described above, we have established an idea of an intelligent harbor maneuvering simulator. As is easily imagined, it can realize hydrodynamic, environmental and traffic conditions as well as capability even to berthing and deberthing. Though the simulator itself is not realized yet, we will discuss the hardware and software requirements. The similar idea is also proposed by Colley *et al.*[14].

4.2 Hardware and Software Requirements

The simulator may consist of the following subsystems:

- Bridge Mock-up
- Main Computer for supervising the whole system and calculating the own ship motion
- Sub computer(s) for judging and calculating other ships' behaviors and motions
- Visual Display Subsystem
- Interface Subsystem

All setup in the bridge mock-up of a harbor maneuvering simulator is necessary and enough for an intelligent harbor maneuvering simulator. Besides, as we have already discussed in 2.4, the window-attached screen with reverse projection is suitable for harbor operation.

As for the duty of the main computer, no special tasks are added, but the supervising task will be heavier, so high performances in calculating speed, real time interrupts and network communication are redquired.

Hydrodynamic model of the own(manned) ship should be able to simulate the maneuvering under such conditions as:

- normal speed and in deep water
- low speed including slow astern with ahead or astern propeller revolution
- in shallow water
- bow and stern thrusters
- pull and push forces of tug boats
- fender forces (if possible)
- wind and current forces

The load of the sub computer for movements of other ships is also growing. Although every ship should be an 'own ship' in marine traffic simulation, in this case, only neighbor ships of the manned ship at each moment are required to behave intelligently and precisely. For other ships existing on the screen or the radar image are supposed to be a part of the background scenery, so we may provide less grade of intelligence and hydrodynamic model. This means that we should provide two grades of pilot and hydrodynamic models respectively, and that the supervising computer sets the flag for each target ship according to the situation to the manned ship and the sub computer calculates each ship's behavior and movement according to the flag.

In the high grade of pilot model, we should prepare various kinds of knowledge, regulations and experiences of pilots. Figure 11 is a sample heirarchical structure of the knowledge base which should be installed in a knowledge-based of the pilot model.

Display subsystem should be more and more powerful to be able to create enough number of target ships and their graphical reality. The quantity treated by interface subsystem may be also two times to three times greater than a harbor maneuvering simulator, but if sufficient communication speed is available, no specail problem may occur.

4.3 Future Applications

As we have not yet completed the proposed simulator with intelligent target ships's movements, it is regret that we cannot show here an actual result of the applications. However, we are planning to utilize the proposed simulator for such cases as:

- training of pilots in congested waterways
- assessing the safety in congested waterways
- planning waterways or harbors

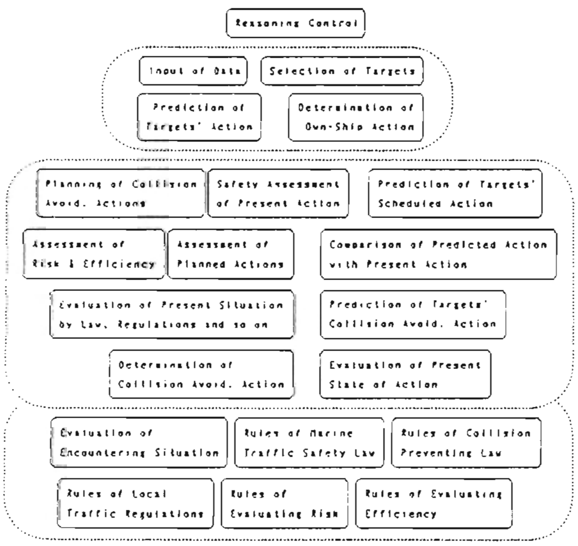


Fig. 11 Hierarchical structure of knowledge base

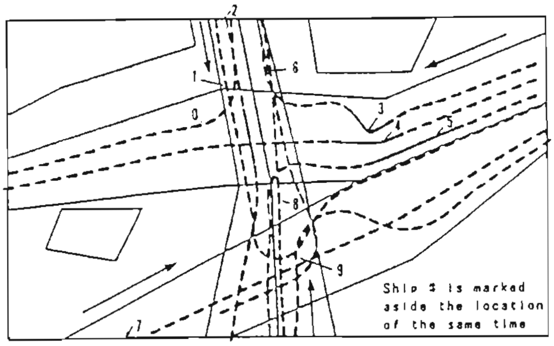


Fig. 12 A scenario to be applicable to an intelligent harbor maneuvering simulator

- designing vessel traffic control system
- designing automatic navigation system and its evaluation

Figure 12 itself is a result of knowledge-based marine traffic simulation with 10 ships, and it can be a good example of a scenario. The tested pilot should across the lane vertically with regarding some crossing ships, meeting ships and some course-changing ships. He should, of course, avoid any collision and sail within the lane. He can expect the normal actions of target ships and even if he misses the suitable operations(timing, ammplitute, manner etc.), the target ships will act differently according to the pilot's operations.

Using an intelligent harbor maneuvering simulator, we can conduct the simulator experiments more naturally. Knowledge-based simulation itself is thus useful to make scenarios of an intellient harbor maneuvering simulator and, on the contrary, knowledge base of knowledge-based marine traffic simulation can be checked by comparing with the simulator's results.

5. CONCLUDING REMARKS

Simualation technology has been rapidly changed according to the development of computer hardware and software. In the field of marine simulators, during past 20 years analog computer with point-light source projection has completely changed to digital computer with CGI. Maybe in the next decade, this tendency will accelerate to be more and more high-speed and compact computer with more and more realistic computer graphics. In this paper, we have showed another possibility of great change in marine simulators, *i.e.*, knowledge-based simulation and an intelligent simulator.

Though we did not describe the hydrodynamic aspects, we have also established more realistic and reliable mathematical model developed as the cooperative works of MMG, JAMP and MSS groups in Japan. (Please refer to appropriate papers in this proceedings.)

There still remain many problems to make use of the proposed intelligent harbor maneuvering simulator for actual applications. However, we believe that the problems concerning to the computer hardware and software will be solved in the very near future. The true problem is rather the financial support. We send our sincere thanks to all persons and organizations who support and encourage our researches.

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