Simulation of Automatic Ship Navigation and Vessel Traffics

1st Report: Design of Simulation System*

By

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ABSTRACT:

A new type of a computer system suitable for the simulation of ship navigation and vessel traffics is proposed.

The simulation system is composed of a network system of two kinds of computers, one for numerical calculations using FORTRAN and the other for logical processing using LISP, with graphic displays.

Realistic representation of environmental conditions, such as nature conditions and vessel traffic conditions, is effective on judgment and decision-making for ship operation and also on the subjective evaluation of the results.

In order to develop a complete system, the concept and the composition of the simulation system are introduced with some typical simulation results in the first report.

1. INTRODUCTION

A ship navigation in a heavy vessel traffic, such as in narrow channels, ports and harbors, is kept safe by skillful judgments and operations of experts on ship operations. An automatic navigation system in which experts' judgments and operations[2] can be realized has been studied by many workers. Various kinds of marine traffic simulations have been also made. Some of them represent the marine traffic as a macroscopic traffic flow[1], and the others represent detailed

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movements and operations of the individual vessels[5,7]. The evaluation of the automatic navigation system is, however, very difficult because of complex conditions for navigation and fuzzy definition of the navigation safety and complex functions of the ship itself[3]. A real time and realistic simulation by a computer system is, therefore, useful for the evaluation, because it can realize such various ship environments as nature conditions, other ships and navigation aids[4]. The present paper mentions the design of such a simulation system.

First of all, the definition of an automatic navigation system should be confirmed[2,8]. It is considered that an automatic navigation system consists of various kinds of functions as follows;

(1) observation of its environments, such as nature conditions and other ships,
(2) communication with other ships or navigation aids,
(3) processing and recognition of the observed data,
(4) judgment and decision-making for keeping the navigation safety and achieving its objectives,
(5) routing according to its decision,
(6) ship maneuvering controls.

All ships in the simulated vessel traffics have these functions, although the simulation levels of the functions of the ships are different with each other.

The simulation system should contain not only the functions of the automatic navigation system but also physical functions such as governing motions of ships according to physical laws and environmental functions such as setting nature conditions or controlling vessel traffics. Those functions are so organically related with each other that the simulation system should be constructed in a multiprocess form and has common data as a simulated world. The concept of the simulation system is shown in Fig. 1

On the other hand, as a programming language FORTRAN is suitable for numerical calculation and LISP (or an "AI" tool) for logical processing, computers which perform advanced logical processing had better be connected with a main computer chiefly performing numerical calculations through a network system.

The composition of the simulation system is introduced with some examples applied to vessel traffics in Tokyo Bay in the following chapters.

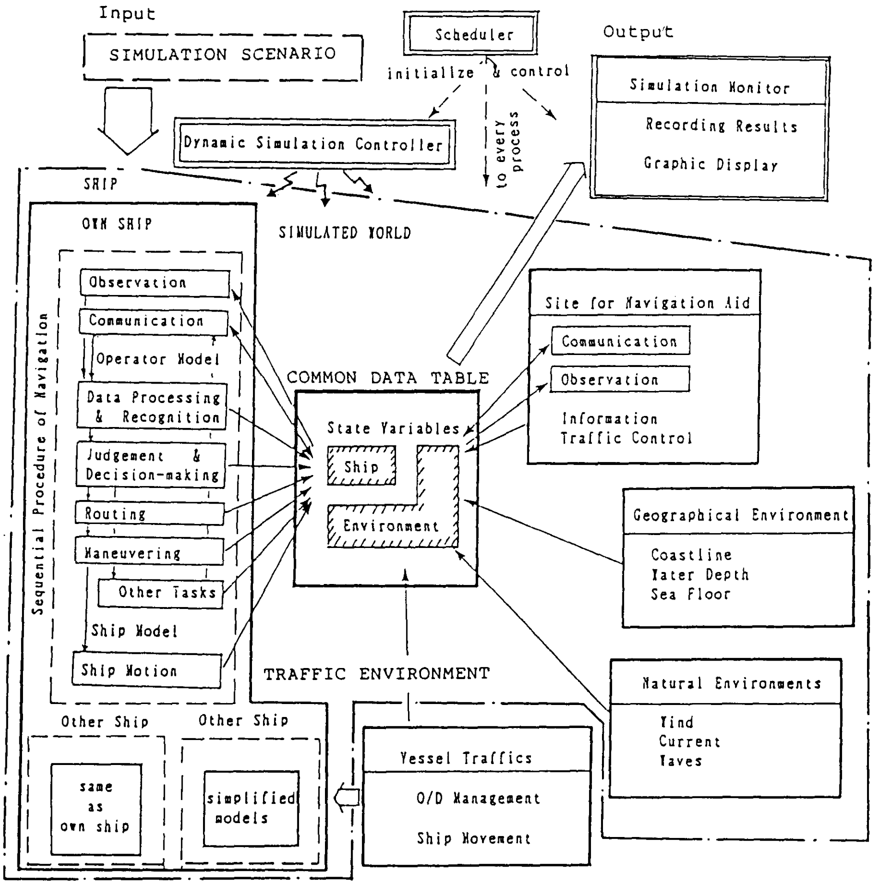


Fig. 1 Concept of simulation System

2. COMPOSITION OF THE SIMULATION SYSTEM[6)]

The simulation system is made in the form of a network system as shown in Fig. 2. The main computer takes a part of simulation control and performs most of processes which realize nature conditions and vessel traffics including the automatic navigation ships. One of sub-computers takes a part of logical processing processes such as those simulating a navigation aid and highly skilled judgment for navigation. Another sub-computer can be added and substituted for any functions in the main computer. The graphic work station shows a 3-dimensional view from the bridge of any particular ship. Graphic displays are used for simulation monitors such as an ARPA (Automatic Radar Plotting Aids) and other meters in a bridge.

Processes representing rapid physical phenomena, such as movements of

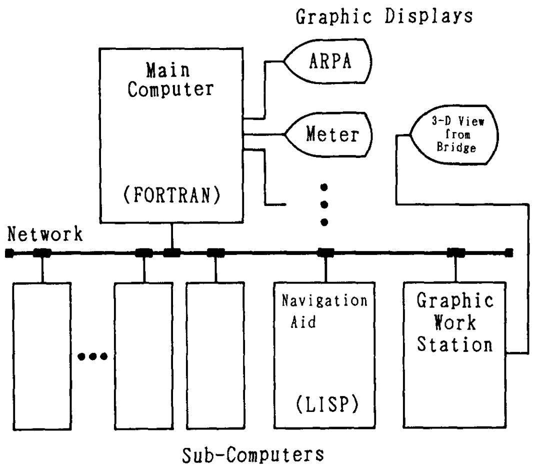


Fig. 2 Composition of Simulation System

ships, are more frequently performed than those representing gradual changes in nature conditions and etc.. Moreover, there are some processes which represent much more gradual changes, such as a process representing a network

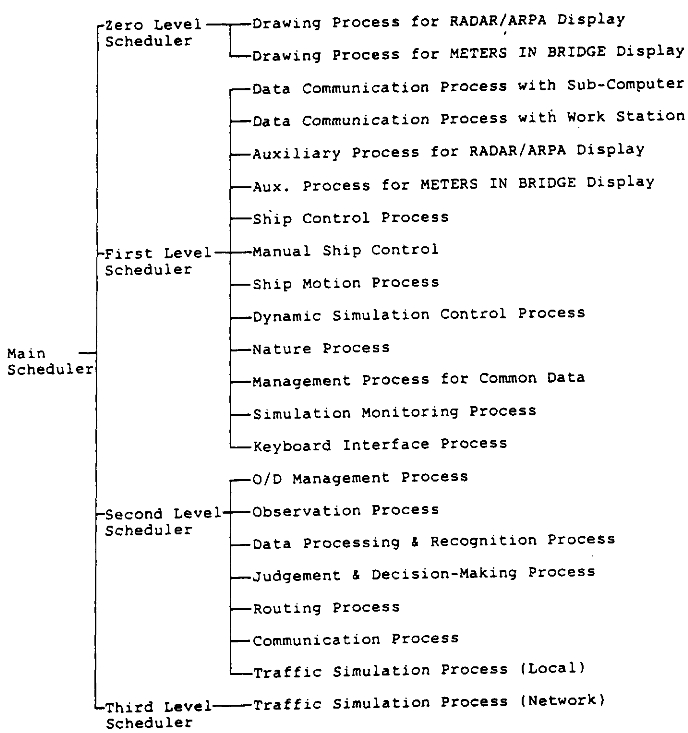


Fig. 3 Scheduling System of Processes in Main Computer

control of vessel traffics. Monitoring processes are also performed at an independent interval. The simulation system, therefore, has a scheduling system, which divides the processes into four groups as shown in Fig. 3 and drives the processes beloging to each group at an independent time interval, respectively. Processes are also classified into five groups according to their functions as shown in Fig. 4, which are those for simulation control, data communication between computers, displays, ship navigations and setting of environmental conditions.

A simulation scenario decides the simulation by indicating a simulation area, ship environments, models of all functions and etc. in the form of a scenario element, respectively.

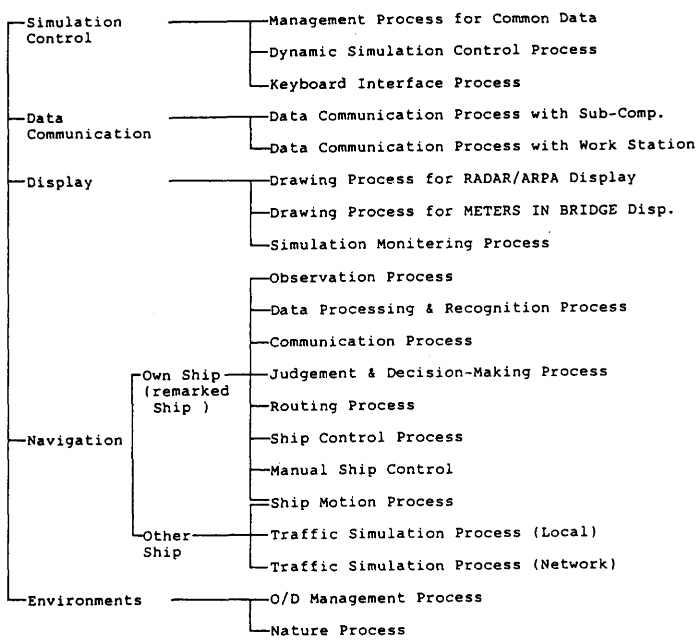


Fig. 4 Classification of Processes in Main Computer by Their Functions

3. APPLICATION IN TOKYO BAY

A simulation scenario shown in Fig. 5 which represents a ship navigating in Tokyo Bay is applied to the simulation system. The scenario includes nature conditions and vessel traffic conditions as shown in Table 1.

There are conditions constant in time such as water depth data and sea floor

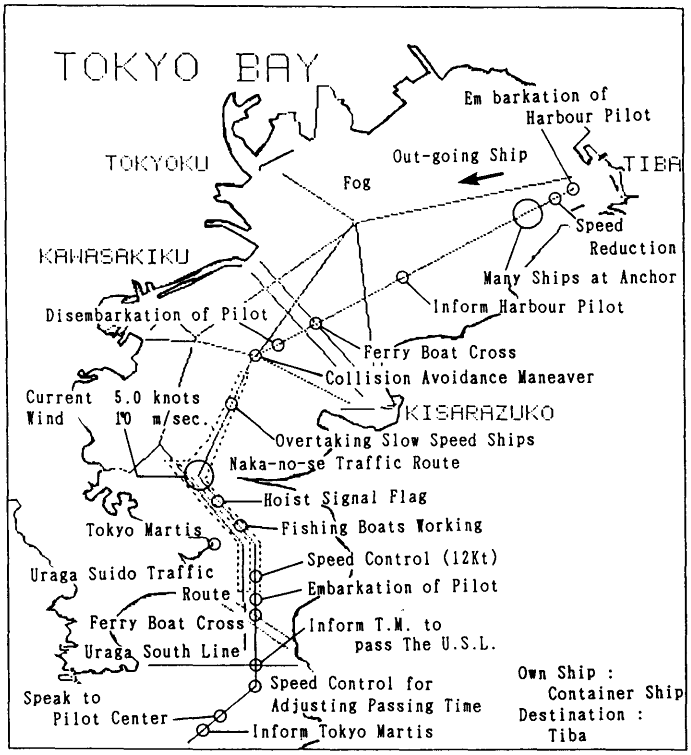


Fig. 5 Simulation Scenario in Tokyo Bay

Table 1 Environmental Factors for Navigation

Factor	Element
Nature Condition	Calendar Season, Moon Age, Day/Night Weather at Sea, Wind, Current Tidal Level, Waves, Weather Visibility
Geographical Factor	Coastline, Water Depth Sea Floor Condition
	Route, Buoy
Traffic Factor	Encountered Ship (Traffic Density)
	Traffic Control, Rules
	Traffic Signal, Navigation Aid
	Harbor Facilities
Else	System for Preventing Disasters and Saving Lives Policy of Economy, Circulation, etc.

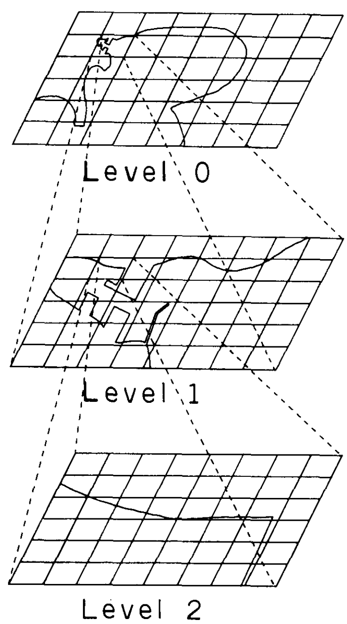
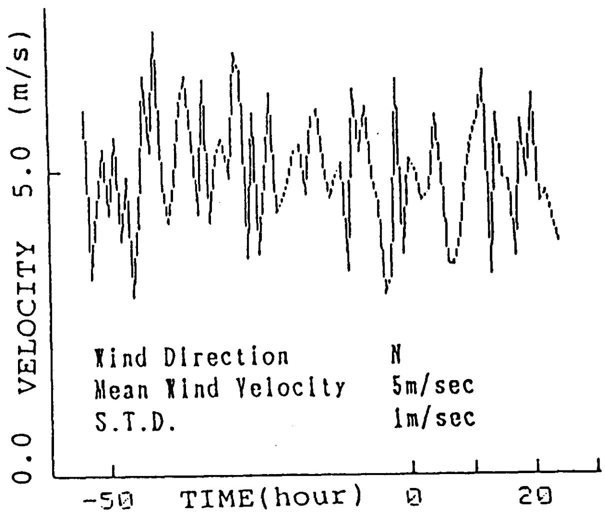
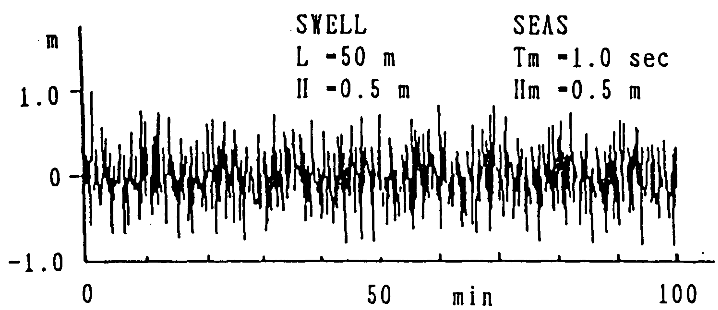


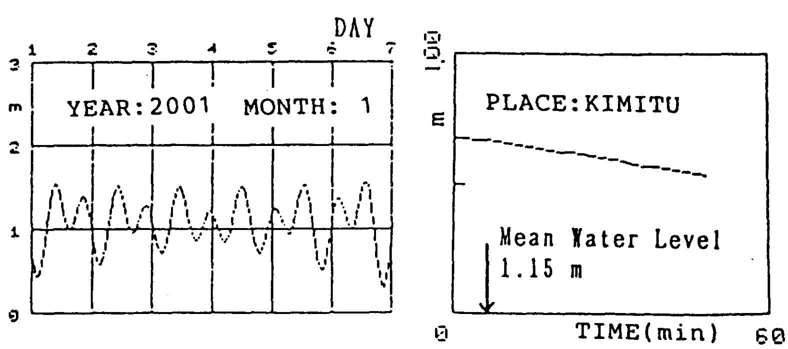
Fig. 6 Hierarchical Data Structure



(a) Wind



(b) Wave



(c) Tidal Level

Fig. 7 Example of Time History of Nature Conditions

conditions. Although both ship motions and decisions for ship operation are not so much affected by the water depth in the deep region, more detailed water depth data are needed in the shallow region than in the deep, and if all the data were memorized in the same form of a fine mesh size, a great deal of real memories would be needed in a computer. The water depth data and the sea floor conditions are, therefore, supplied in the form of a hierarchical mesh data as shown in Fig. 6. The mesh sizes in each level are 5km × 5km, 500m×500m and 50m×50m, respectively. Photo 1 shows the first level, 500m×500m mesh, data of water depth near Kannon-saki with the whole data of Tokyo Bay at the upper right corner.

Other nature conditions have individual time histories, respectively. An example of the time histories is shown in Fig. 7. Some nature conditions which show gradual changes in the horizontal plane such as winds and waves are supplied in the form of regions divided coarsely into polygons as shown in Fig. 8. Some intermediate conditions are supplied in the form of a constant mesh as shown in Fig. 9.

Photo 2 shows the wind data in coarsely divided regions. Gust winds can be also realized within any polygon declared by means of a graphic editor. The wind data are supplied also in the form of a constant mesh, 2km×2km, as shown in Photo 3, where the wind velocity is shown by a color spot according to its magnitude and the wind direction is shown by an arrow.

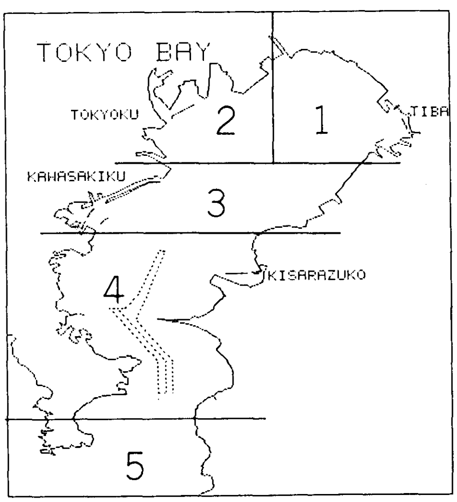


Fig. 8 Data Structure Divided Coarsely into Polygons

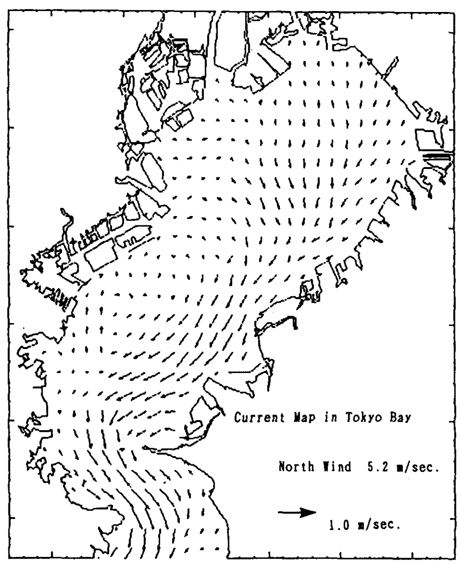


Fig. 9 Constant Mesh Data Structure

The current data are supplied in the form of a constant mesh (2km×2km) as shown in Fig. 9, which are calculated with tidal wave data and wind data during the preceding 24 hours.

Vessel traffics in the simulated Tokyo Bay are controlled according to the realistic O/D (Origin and Destination of ship) data which is based on the annual report of ports and harbors of Japan in 1978.

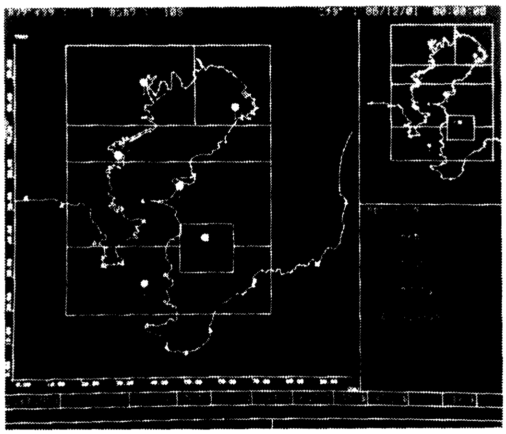


Photo 2 Example of Wind Data in Coarsely Divided Regions

4.RESULTS AND DISCUSSION

A schematic over view of vessel traffics shown in Photo 4 is an example of the simulation applied in Tokyo Bay.

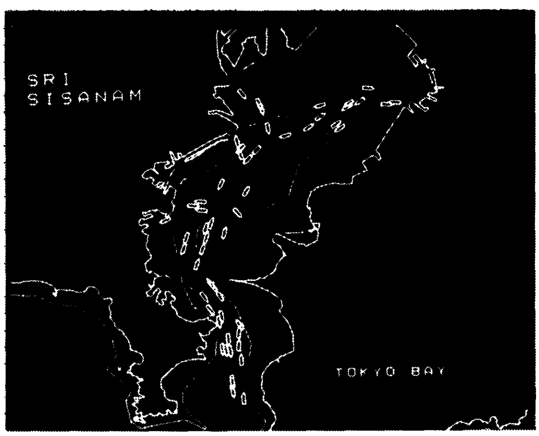


Photo 4 Schematic Over View of Vessel Traffics in Tokyo Bay

There are two kinds of view points from which results of the simulation are analyzed. One is a macroscopic view as a vessel traffic flow, and the other, a microscopic one as ship operations and the resulting motions. The ship distribution in Tokyo Bay at an instance of another example is shown in Fig. 10. Trajectories of ships are shown in Fig. 11.

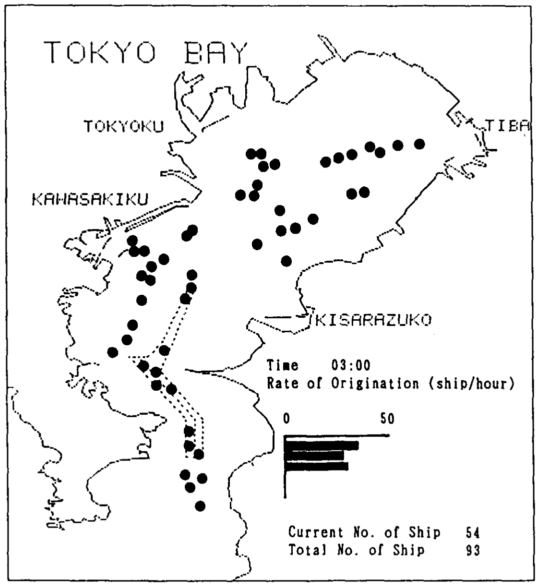


Fig. 10 Example of Ship Distribution in Tokyo Bay

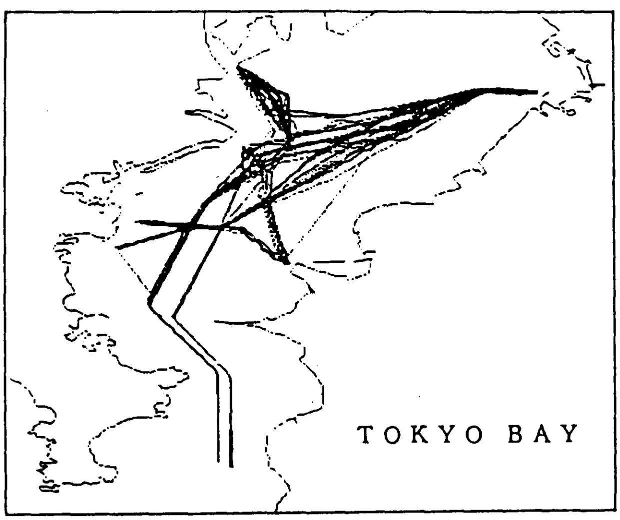


Fig. 11 Trajectories of Ship Navigation

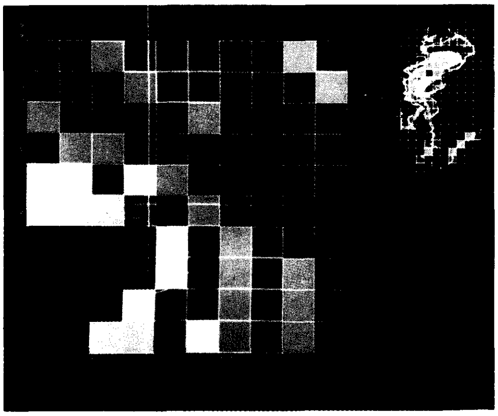


Photo. 1 Water Depth Data near Kannon-saki.

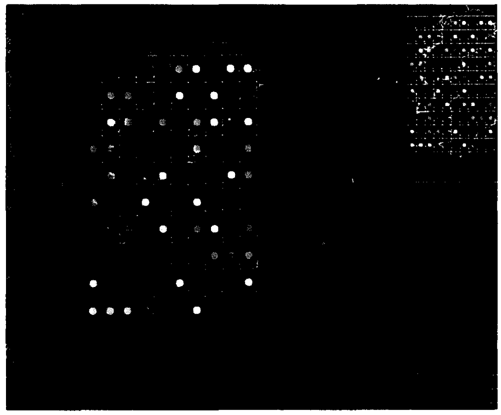


Photo.3 Example of Wind Data in Constant Mesh.

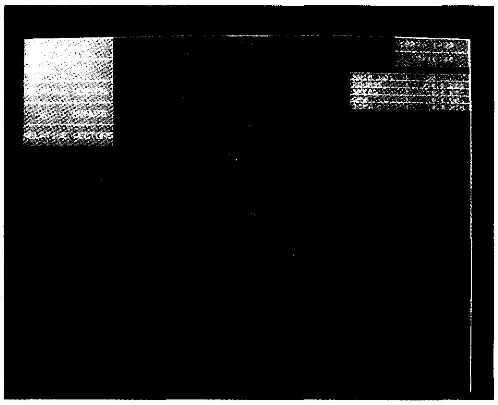


Photo.5 Example of Display of ARPA-like View.

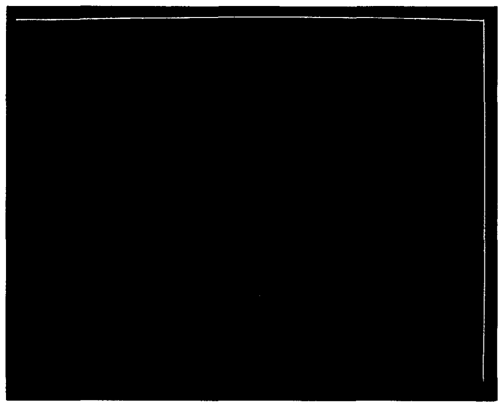


Photo.6 Example of Display of Meters in Bridge.

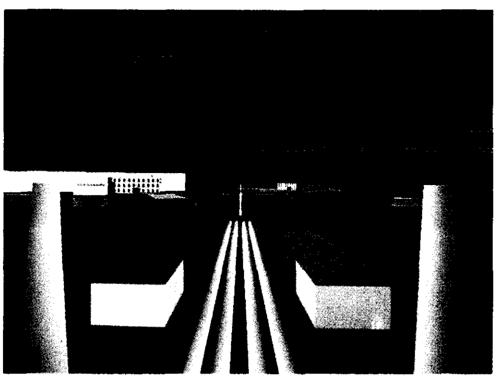


Photo.7 Example of 3-Dimensional View from Bridge.

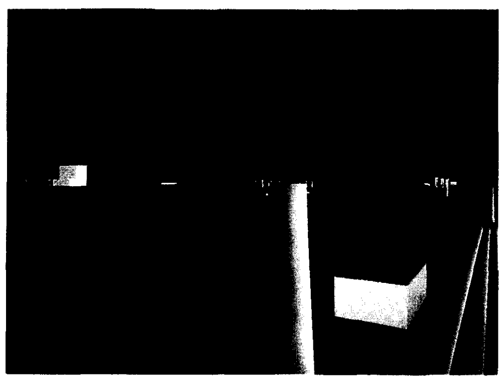


Photo.8 Example of Bird's Eye View.

In order to enable the microscopic analyses, collision avoidances, the obedience to laws and regulations for navigation and the precise ship motions are taken into account in the application.

Collision avoidances at multiple encounters with ships are possible with one of our algorithms. Some typical examples are shown in Figs. 12 to 14, in which courses of all ships are set to collide with each other in case of no course changes. Fig. 12 shows a single encounter with a ship crossing from the right. Figs. 13 and 14 show multiple encounters with ships; one crossing from the left and one crossing from the right backward. These figures show almost the same situation but a crossing angle of the right backward ship. As ship trajectories in the examples are varied according to parameters in the algorithm and the

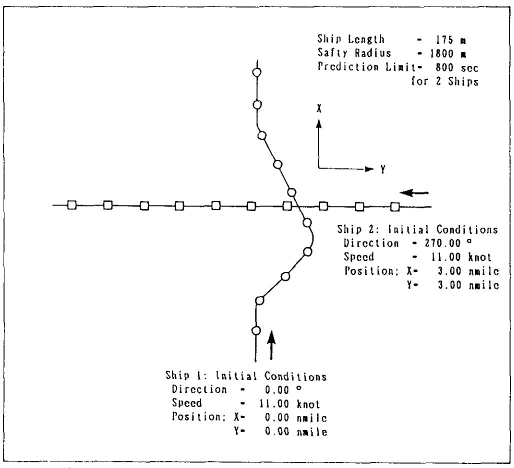


Fig. 12 Example of Single Encounter with Ship

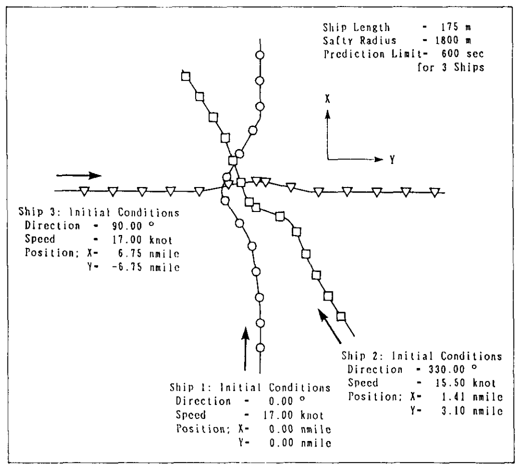


Fig. 13 Example of Multiple Encounters with Ships

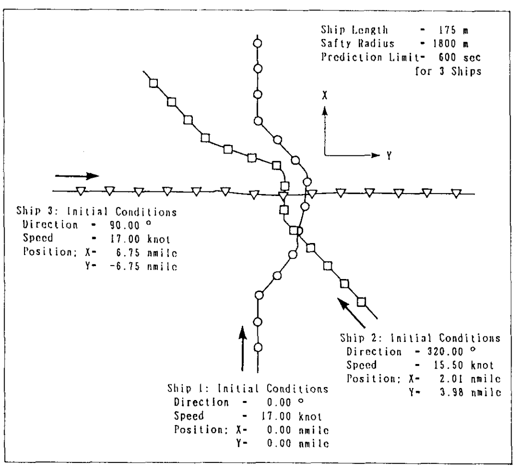


Fig. 14 Example of Multiple Encounters with Ships

situation of encounters, parameters can be tuned by systematic simulations.

A highly skilled judgment such as that according to laws and regulations and etc. concerning navigation can be also realized in the application by using a concept of an expert system which consists of an inference engine, a production memory, a working memory and a man-machine interface shown in Fig. 15. In the simulation, not a man but the automatic navigation system itself consults with the expert system. The expert system indicates appropriate judgments referring to the related laws and regulations. Examples of the inferences and results are shown in Fig. 16 and Table 2, in which one ship is going to cross a narrow channel and the other is navigating in the channel. Although the application of a law or a regulation needs special knowledges and experiences, quite reasonable results shown in Table 2 are acquired through inferences

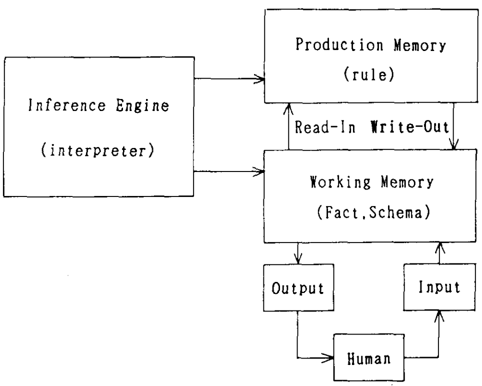


Fig. 15 Concept of Expert System

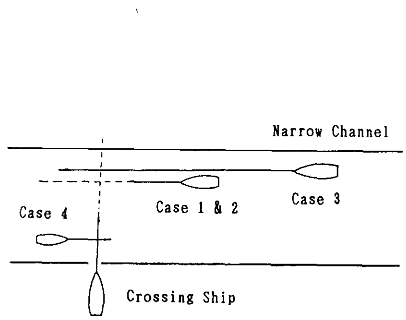


Fig. 16 Situations of Test Cases

Table 2 Test Conditions and Results

Case		1	2	3	4
Condition	Crossing Ship	Cargo Ship	Cargo Ship	Cargo Ship	Cargo Ship
	Passing Ship	Cargo Ship	LNG Carrier	Container Carrier	Cargo Ship
Result		Permitted	Prohibited	Prohibited	Prohibited
Reason For Prohibition		——	Dangerous Cargo	Dangerous Speed	Too Close

directly related to the regulation and trees of judgment generated by the inferences shown in Fig. 17.[9)]

The precise ship motion is affected by environmental conditions such as water depth, winds and current. The effects of these conditions are also taken into account in the simulation. Some typical examples are shown in Fig. 18 and 19. Fig. 18 shows a shallow water effect that a radius of turning increases with the decrease of water depth. Fig. 19 shows a wind effect that a ship trajectory is blown down by an ordinary wind and that a ship becomes uncontrolled by a strong wind.

The results of the simulation can be evaluated numerically or statistically by the recorded ship trajectories etc., and they can be also evaluated subjectively by means of graphic monitors indicating an ARPA-like view (shown in Photo 5), meters in a particular ship (shown in Photo 6) and a 3-dimensional view from a bridge of a particular ship (shown in Photo 7) or any spatial view point (shown in Photo 8). The simulation is driven by a scenario which contains data for ships' movements, environments and simulation parameters. Preparation and edition of the scenario, therefore, is quite important for the simulation and simulation system design. Various kinds of data bases and a graphic editor of the scenario are equipped to the system. By Photo. 9, functions of the editor are explained. There can be seen vertical and horizontal cursor lines driven by the mouse of the computer graphic terminal.

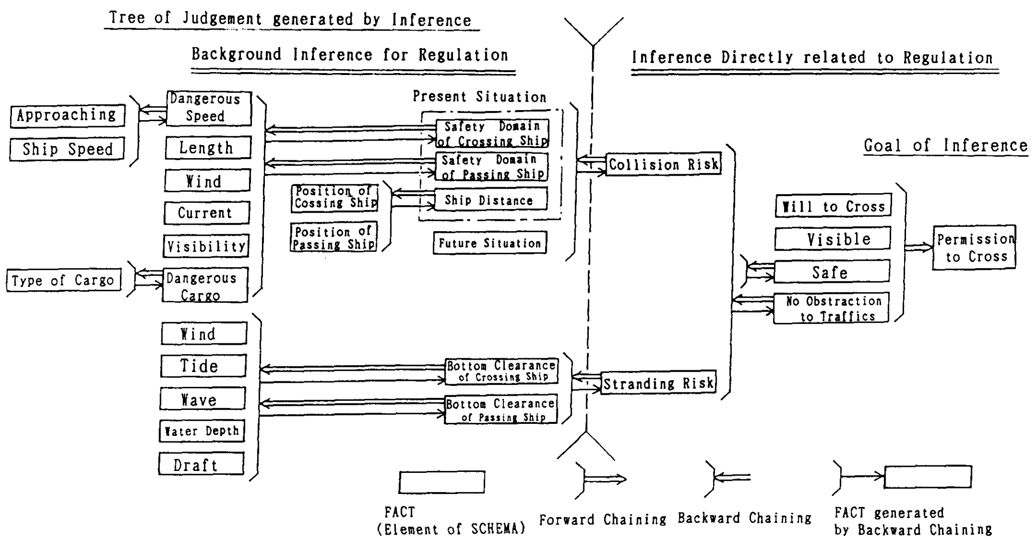


Fig. 17 Example of Structure and Flow of Inference

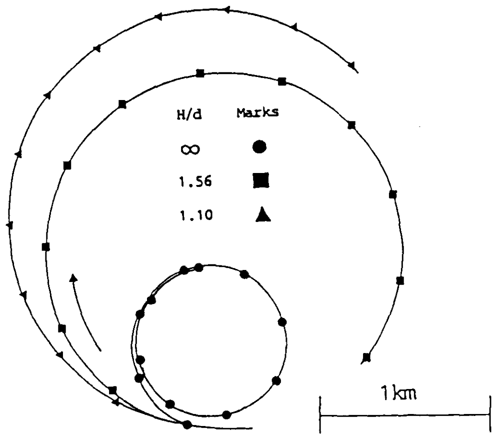


Fig. 18 Shallow Water Effects

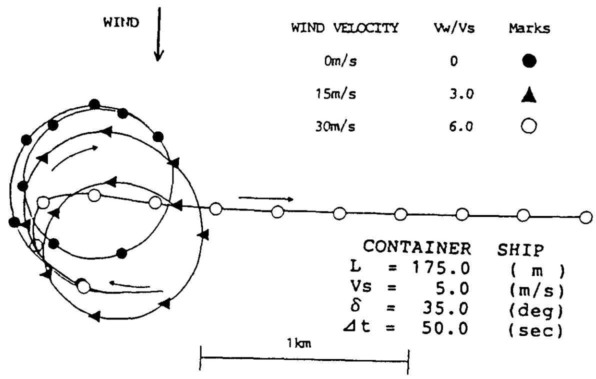


Fig. 19 Wind Effects

By using the cross point of the cursor lines, a polygonal area can be set, and menu of the editor can be selected. In the bottom of the photo, menu of functions of the editor are listed in Japanese. For example, 1) arbitrary scale of graphic display, 2) mesh size, 3) slow motion browse, 4) comments, etc.. In the right hand down corner of the photograph, secondary menu of the editor is shown, where, 1) addition, 2) alter, 3) delete and 4) end of edition, are written in Japanese. In the right hand upper corner, the whole region is displayed with marked subregion, which is shown in the main graphics of the display.

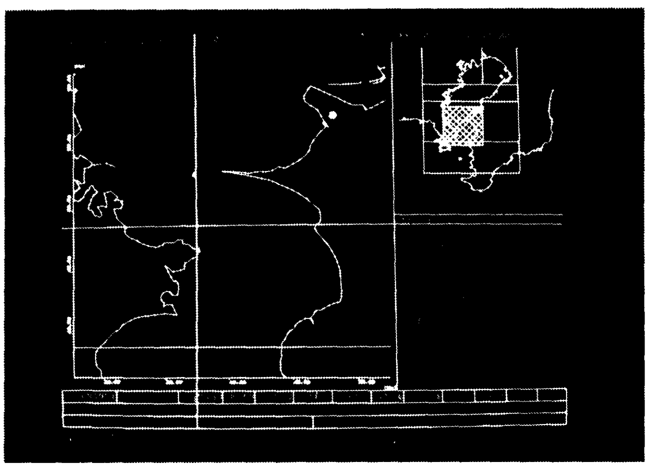


Photo 9 Example of Scenario Editor

5. CONCLUSION

The results of the application of the simulation system is quite reasonable.

Although the present system simulates ship navigation only, various simulations for anchoring and coming alongside a pier and etc. could be performed if the system should be modified properly and equipped with sufficient data. The proposed design of the system is, therefore, considered to be useful for the simulation of vessel traffics including the automatic navigation.

ACKNOWLEDGMENT

The simulation system used in the present study is constructed under the cooperation of the Japan Ship Research Association and Ship Research Institute. Photos 5 to 8 are those of computer graphics developed by Ishikawajima-Harima Heavy Industries Co., Ltd..

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