# An Intelligent Marine Traffic Evaluation System for Harbour and Waterway Designs

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Marine traffic evaluation system with intelligent movements of traffic is discussed, as one of the applications of **SAFES**(Ship Auto-navigation Fuzzy Expert System). The system **SAFES** is a kind of fast-time simulation system with capability of usual navigation such as course keeping to collision avoidance. The basic features of a navigator are well modelled by fuzzy reasoning or control. Expert system is convenient especially for multi-ship encounter or other complicated rules of a navigator. Combining this fast-time simulation technique with *Monte Carlo* simulation technique, the system for realistic marine traffic simulation is proposed. The system is applied to evaluate the traffic environment and waterway configuration of one of the most congested waterway in Japan. Simulations of four different conditions are carried out for 24 hours respectively and the results are evaluated by the number of *near-miss* etc.

Keywords : Marine Traffic, Safety Evaluation, Collision Avoidance, Navigator's Model, Simulation, Expert System, Fuzzy Reasoning

## 1. Introduction

Harbour and waterway design becomes of great importance, because it affects directly the safety of navigation. Principal dimensions of the supposing ship are the most common factors to be considered, when harbours and waterways are designed. The fundamental manoeuvring performances are, of course, closely related to these factors, but how should we consider the human factor or traffic effects? In this paper, the author will present a new method to simulate more realistic marine traffic and to evaluate the traffic environment. In the system, realistic traffic flow is generated according to the statistic data including arrival intervals, ship speed and size distributions etc. Each ship is operated by a modelled navigator who can order the appropriate course and rudder angles to achieve her own mission. Besides, the modelled navigator has the ability to judge the fear of collision between other ships etc., so she is safely operated by collision avoidance manoeuvre, if necessary. The modelled navigator is realized by utilizing the combination of fuzzy theory and expert system, both of which are suitable for dealing with human activities such as reasoning, judgement, decision-making and knowledge. The system is applied to evaluate one of the most congested seaways in Japan, and hence in the world. If there happenes a collision or near-miss, inspite of best decision or action of the modelled navigator, the sytem counts it as an irresistible fault. After passing the proper time in simulation, the system figures out where the faults occur and how the faults are. Thus we can evaluate the safety of the waterway by a statistical way including the effects of ship performances, waterway configurations, averaged human skills and restriction by traffic control or regulations.

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## 2. Ship Auto-navigation Fuzzy Expert System (SAFES)

This system called **SAFES** from its abbreviation is a kind of knowledge-based simulation system of automatic navigation in multi-ship environment[1]. In this section, brief explanation of the system will be introduced with some results of the applications.

### 2.1 Automatic Collision Avoidance Subsystem (ACAS)

As shown in Fig. 1, the kernel of the system is a subsystem called **ACAS**: Automatic Collision Avoidance System[2]. This subsystem has a model of a navigator, who can perform from usual operation such as course keeping and course changing to collision avoidance with a target ship. These functions are all realized by fuzzy reasoning and control as shown in Fig. 2. Figure 3 is an example of collision avoidance with a crossing ship, where (a) is the aboslute trajectories of every 5 minutes and (b) is time histories of heading angle, rudder angle and ship speed. The broken lines in (b) are the commands by the modelled navigator,

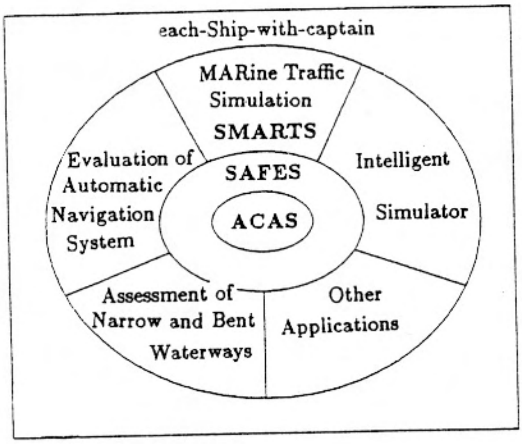


Fig. 1 **SAFES, ACAS** and their applications

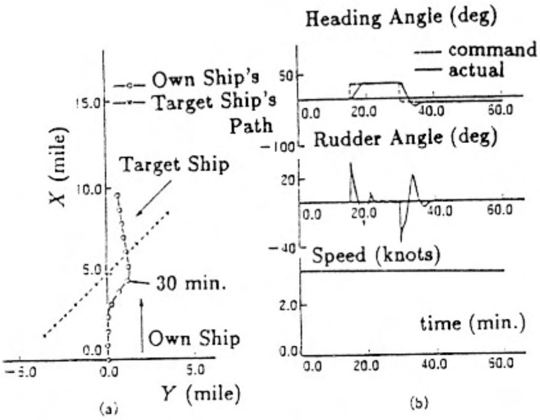


Fig. 3 An example of collision avoidance by **ACAS**

while the solid lines are the actual ones. The own ship was only taught some scheduled points, in this case, at the origin and 15 miles north by the operator and other jobs were all carried out by the modelled navigator as shown in Fig. 3.

### 2.2 Expert system approach to multiship collision avoidance

Though **ACAS** can avoid another ship in various situations according to the International Regulatin for Preventing Collision at Sea, it cannot avoid multiple ships approaching at the same or almost same time. The biggest reason is the fact that there are not rigid rules or regulations for multi-ship encounter. Even if such rules or regulations are provided, it is very difficult to implement them by conventional programming languages such as FORTRAN or PASCAL because of the explosion of combination.

Recent development of knowledge engineering makes it possible. Expert system is a kind of programming structure or style, where *if-then* type rules can be treated without *nesting* by the programmer. A software called *inference engine* evaluates LHS(left-hand side) of each rule according to the present state of dynamically changing memory – called *working memory* in some tools such as OPS5 or OPS83 – and chooses a unique rule for *firing* at that moment. After *firing* this rule – the RHS(right-hand side) of this rule is executed –, the *working memory* changes its contents, so *inference engine* will evaluate each rule again and choose next unique rule. This cycle will be repeated until when no applicable rule exists in the *working memory*. The contents of *working memory* are called *classes* or *elements* containing *variables*, *arrays* or generally *structures*. As the change of *working memory* is equivalent to the creation, modification or removal of these *elements*, and they may force the *inference engine* to *infer*, the definition of *elements* and their structures are very important.

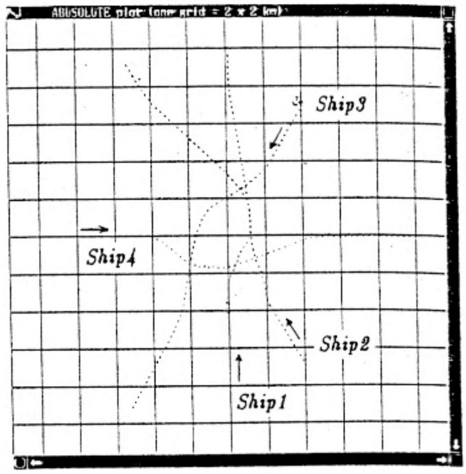


Fig. 5 An example of four-ship encounter by **SAFES**

Koyama and Jin[3] have first applied expert system to collision avoidance with multiple ships, where *target class* plays an important role. In the system **SAFES** similar *element* configurations are introduced, though the strategy itself for multi-ship encounters shown in Fig. 4 is different. Figure 5 is an example of the result for four-ship encouter carried out by **SAFES** and Fig. 6 is a result applied for a narrow waterway design.

For more detail of the navigator's model, the system and its applications, please refer to [1][2][4][5][6].

## 3. each-Ship-with-captain Marine Traffic Simulation System (SMARTS)

### 3.1 Macro simulation

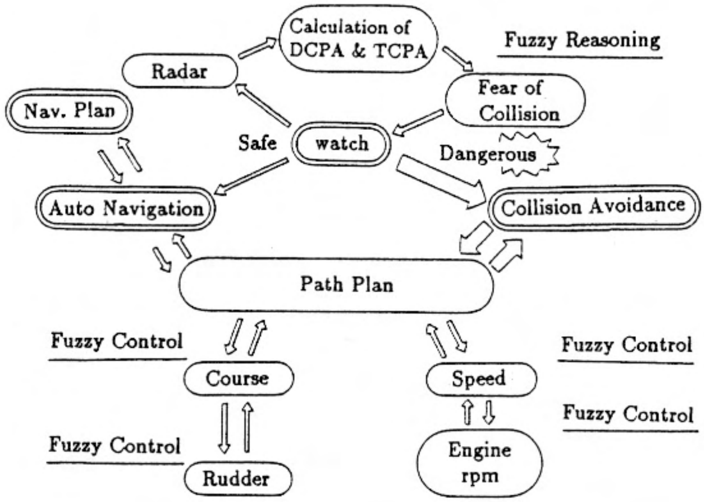


Fig. 2 System structure of **ACAS**

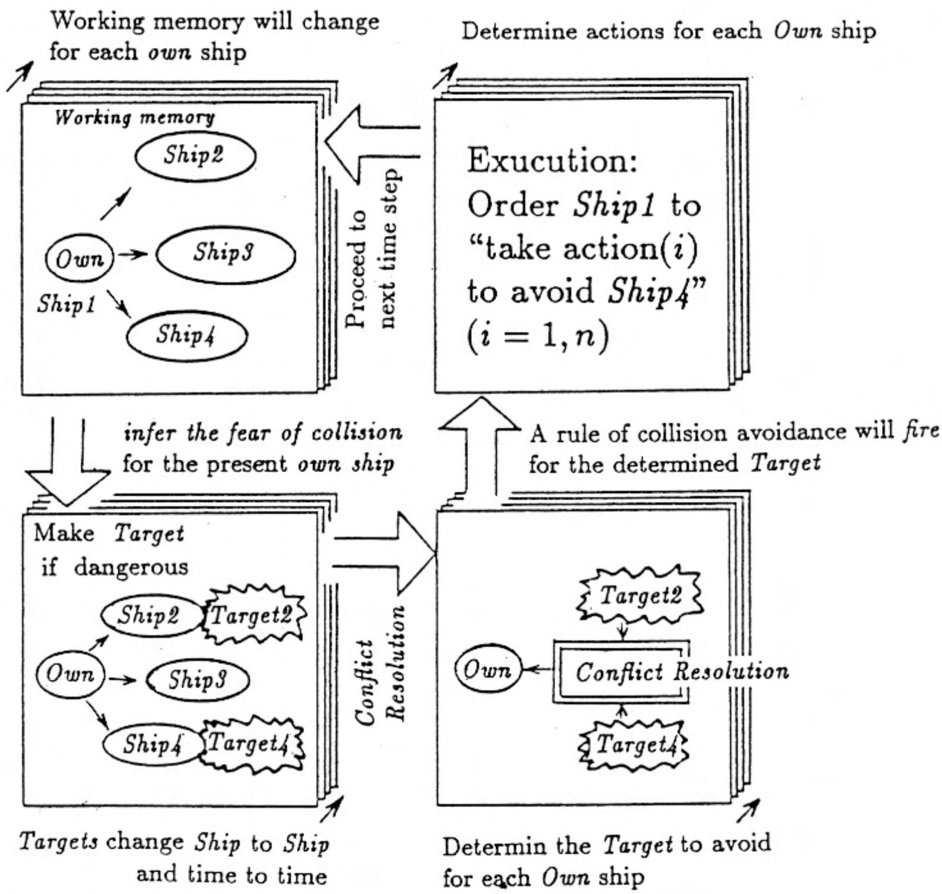


Fig. 4 Strategy for multi-ship encounter in **SAFES**

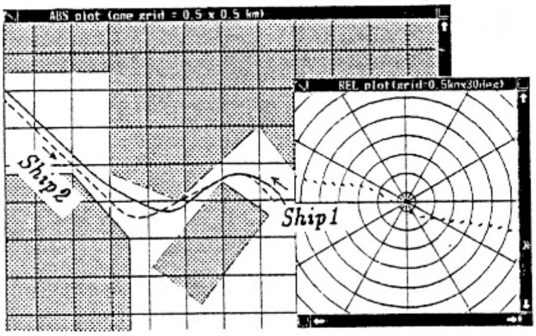


Fig. 6 An example of narrow waterway design by **SAFES**

Marine traffic simulation has been carried out for long time in Japan using so-called network simulation[7]. The main purpose of the simulation is the quantitative evaluation of the traffic and its future prediction for harbour and waterway designs. In this method, the traffic routes are modelled by networks of *links* (segments of navigation path divided at the points – called *nodes* – connecting other *links*) and each ship will sail from point A to point B through several *links* via *nodes*. This is the reason why this method is called so. As it should generally deal with quite many ships, each ship's manoeuvring properties are neglected or simplified, utilizing a queueing model. This method is also called *macro simulation* from this point.

### 3.2 Micro simulation

On the other hand, there are already proposed some differrent methods for simulating marine traffic regarding each ship's manoeuvring properties[8] or navigational behaviours such as collision avoidance[9]. They are generally called *micro simulation*.

### 3.3 Knowledge-based micro simulation

The author proposed a method for generating more realistic traffic flow called **SMARTS** (each-Ship-with-captain MARine Traffic Simulation)[10] as one of applications of **SAFES**.

This method is belonging to the category of *micro simulation* from the above explanation, but it may be categorized as the combination of knowledge-based simulation with *Monte Carlo* simulation. As you can easily imagine, a subsystem, which is also a collection of rules, of automatic generation and removal of traffic vessels is added to the system **SAFES**.

### 3.4 Automatic traffic flow generation

The following traffic data can be treated in **SMARTS**: arrival interval, ship speed, ship size and manoeuvring data.

### 3.5 Graphic display and animation system

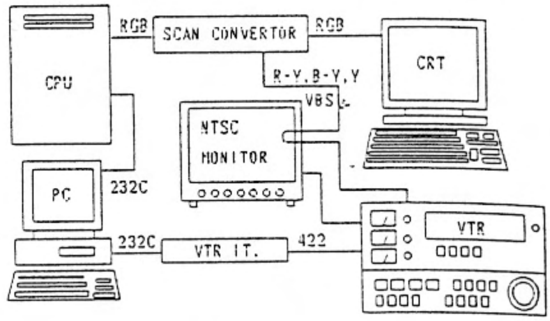


Fig. 8 Automatic video recording subsystem

The graphic display is divided into five windows as shown in Fig. 7. **VIEW** window is a perspective view from an appropriate place and provide to *watch* the traffic. **ABS** window is the bird's eye view of the present state of the tested area. **ABS trace** window is the same with the **ABS** window, but with all traces of each ship. **Casualties** window is the provided for the evaluation of the traffic and will be explained in the next section. **Console** window contains the the system information and statistical result of the present state. In the actual windows ships of the same route and same type of casualties have coloured same, so we can easily distinguish them.

The author also utilizes the automatic video recording system for making the animation of the simulation result directly from the graphic display as shown in Fig. 8. We can check the simulation result at proper time scale as well as hardcopies of the graphic display and the file containing the necessary information.

## 4. Application of SMARTS

The proposed system **SMARTS** was applied to the actual project to assess the most effective way of improving the navigational safety and convenience. The considering waterway is the crossing part of *Bisan Straits Waterway* and *Mizushima Waterway*, where about 1,000 vessels are passing in a day.

### 4.1 Simulation conditions

The waterway configuraton is slightly modified from the original as shown in Fig. 9, where hatched area is the original waterway and ‡-shaped waterway is the modelled one. A, B, C and D are the name of each gate of arrival vessels and the arrows indicate the direction of sailing: *i.e.* route A and B are one-way traffic, while C and D are two-way traffic. Route A and B are the main traffic connecting Osaka area to west Japan, whose traffics are about 300 vessels in a day each. Route C and D are the connecting route from *Bisan Straits Waterway* to *Mizushima*

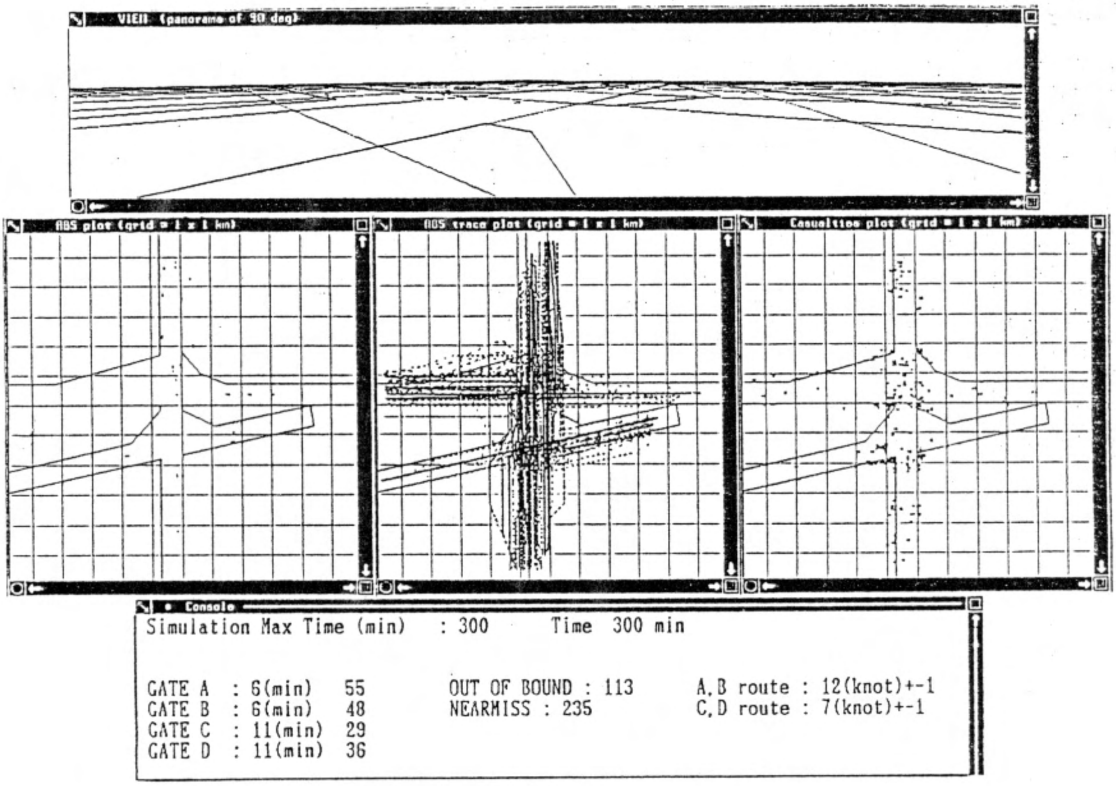


Fig. 7 An example hardcopy of the result of **SMARTS**

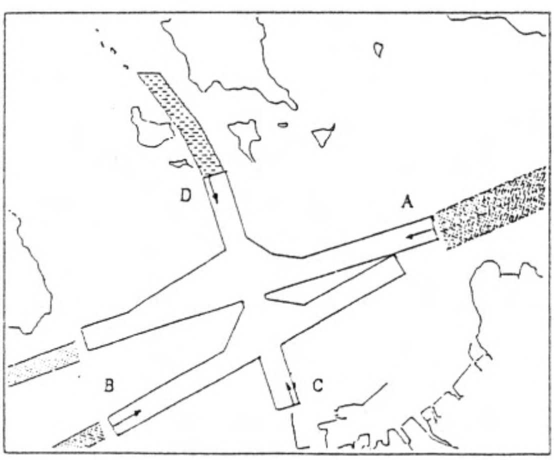


Fig. 9 Modelled waterway for marine traffic simulation

where chemical plants or a car carriers' terminal are located. In the actual waterway there is no route from *Bisan Straits Waterway* to gate C, and southbound vessels turn to *Bisan Straits Waterway*.

Distributions of arrival interval, ship speed and size are given according to the actual field investigation[11]. Distribution of ship size are given as shown in Table 1, where small ship is defined as the ship of less than 1,000GT, medium ship as the ship of between 1,000GT and 10,000GT and large ships as the ship of over 10,000GT. For each ship size, several type ships are provided and small scattering was added to each type ship.

Simulation of 24 hours traffic was carried out for four cases as shown in Table 2 to check the effects on traffic density, standard deviation of ship speed and the contour configuration of the crossing section.

### 4.2 Results of simulation

The results are summarized in Figs.10~13 and Table 3. We can roughly evaluate the effect of traffic density etc. on the number of *near-miss* and *out-of-bound*. *Near-miss*ed point is plotted when the modelled navigator feels the encounter *very dangerous* by *fuzzy* reasoning of *fear of collision*. As this value is reasoned from TCPA (Time to the Closest Point of Approach) and DCPA (Distance of the Closest Point of Approach), it cannot be declared the distance itself, but we can easily suppose the stress of navigators there. The detail data of each *near-miss* and *out-of-bound* are logged into a file. So we can check it afterward. However, now the development of a method to analyze the log file automatically is planned.

It is said that each ship is forced to take averagely collision avoidance manoeuvres 3 times during sailing this waterway, and these simulation results support this feeling. Although we should

Table 1 Distribution ratio of ship size

| route | A | B | C | D |
|---|---|---|---|---|
| small ship | 66 | 60 | 30 | 30 |
| medium ship | 11 | 12 | 2 | 2 |
| large ship | 1 | 1 | 1 | 1 |

Table 2 Simulation conditions

| simulation condition | | I | II | III | IV |
|---|---|---|---|---|---|
| item | route | | | | |
| average interval of arrival (min) | A, B | 6 | 6 | 6 | 6 |
| | C, D | 11 | 20 | 11 | 11 |
| average ship speed (knots) | A, B | 12 | 12 | 12 | 12 |
| | C, D | 7 | 7 | 7 | 7 |
| standard deviation of speed (knots) | A, B | 1 | 1 | 0.2 | 0.2 |
| | C, D | 1 | 1 | 0.2 | 0.2 |
| contour configuration | | org. | org. | org. | mod. |

org.: original, mod.: modified

Table 3 Simulation results

| simulation condition | | I | II | III | IV |
|---|---|---|---|---|---|
| item | route | | | | |
| Number of Ships passing | A | 218 | 222 | 218 | 218 |
| | B | 221 | 207 | 221 | 221 |
| | C | 123 | 67 | 123 | 123 |
| | D | 127 | 59 | 127 | 127 |
| No. of Near-miss | total | 903 | 485 | 555 | 610 |
| No. of Out-of-bound | total | 424 | 208 | 312 | 274 |

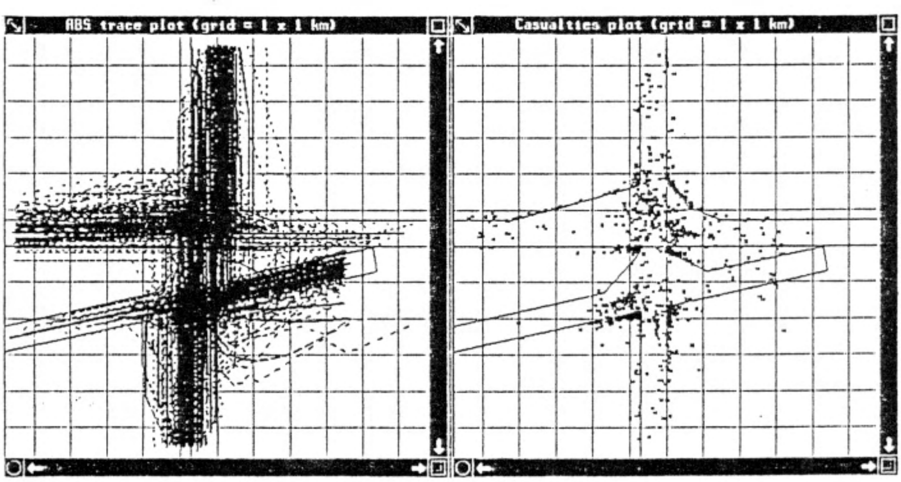


Fig. 10 Result of simulation
(case I, 24 hours)

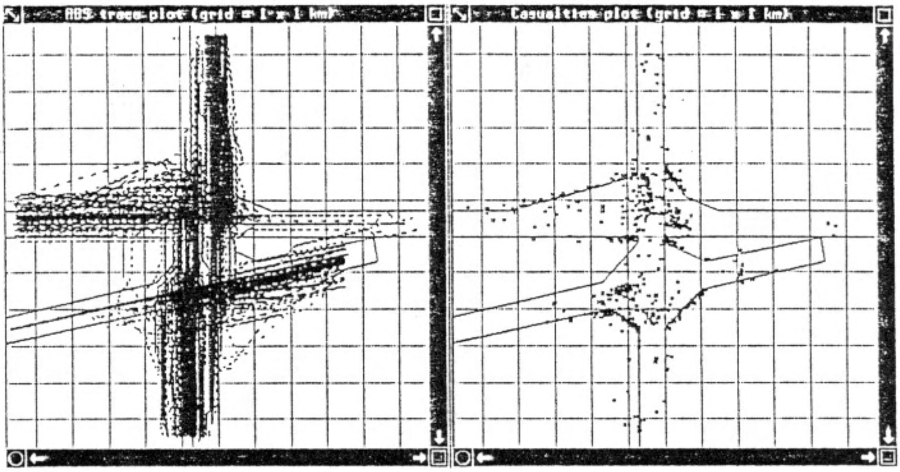


Fig. 11 Result of simulation
(case II, 24 hours)

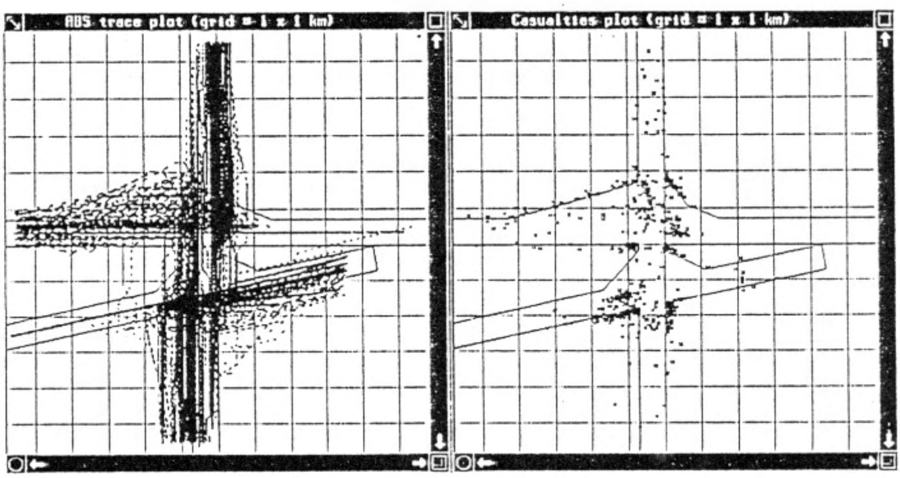


Fig. 12 Result of simulation
(case III, 24 hours)

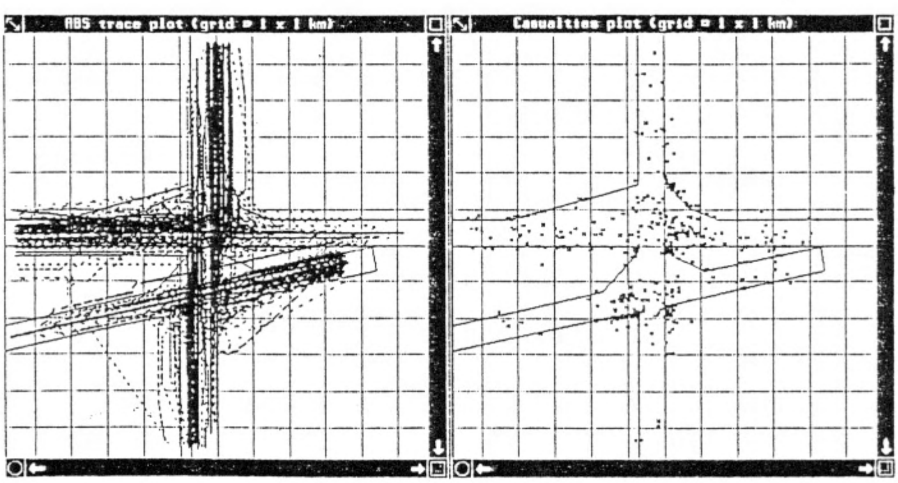


Fig. 13 Result of simulation
(case IV, 24 hours)

further revise the knowledge base to realize more natural movement of each ship, the author would like to stress the effectiveness of the marine traffic simulation method **SMARTS**.

## 5. Conclusions

Through the research and the actual application, the following conclusions can be derived.

1. In the assessment of navigational safety in harbours or waterways, not only the traffic frequency and density, traffic movements such as collision avoidance should be considered for more reliable prediction of the traffic environment.

2. The proposed system **SMARTS** is the tool for this purpose, and it can be applicable to the actual waterway design.

3. Continuous efforts should be paid to improve the system, especially on the following points.

   (a) Adding more realistic rules fitting to the actual navigational operation.

   (b) Finding more efficient way of reasoning to determin the most dangerous ship(s) to reduce simulation time.

   (c) Finding more effective parameters etc. to evaluate the simulated traffic environment.


## Acknowledgements

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[1]The title was translated by the author.