# 해상교통류 시뮬레이션에 의한 해상교통안전관리평가에 관한 연구

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# A Study on Assessment of Vessel Traffic Safety Management by Marine Traffic Flow Simulation

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**Abstruct**

Vessel traffic safety management means the managerial technical measures for improving the marine traffic safety in general terms. The main flow of vessel traffic safety management is that: 1) Traffic Survey, 2) Replay by Marine Traffic Flow Simulation, 3) Quantitative Assessment, 4) Policy Alternatives, 5) Prediction · Verification. In the management of vessel traffic safety, it is most important to establish assessment models that can numerically estimate the current safety level and quantitatively predict the correlation between the measures to be taken and the improvement of safety and the reduction of ship handling difficulties imposed on mariners.

In this paper, the replay model for traffic flow simulation was made using marine traffic survey data, and the present traffic situation became replay in the computer. An attempt was made to rate the current safety of ports and waterways by applying the Environmental Stress model. And, as a countermeasure for traffic management, by taking up the promotion of total traffic congestion in early morning rush hour, the correlation between traffic control rate and the reduction in ship handling difficulties imposed on mariners was predicted quantitatively.

**Key Words:** Marine Traffic Flow, Simulation, Vessel Traffic Safety Management

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## 1. Introduction

Until now, various traffic management measures have been taken in congested waterways such as ports and narrow channels[1][2][3]. But, there has been no research to assess the effect of each marine traffic management measures systematically.

Vessel traffic safety management means the implementation, with the consensus of the relevant people, of tangible measures to improve traffic safety in ports and waterways.

Implementation of safety management policies involves many people including mariners, pilots, port administrators and coast guards. When an organization is to carry out some activity to achieve traffic safety, it is important that all of the people involved are motivated to contribute toward the goal. The key to the success of activities to achieve the traffic safety is that such relevant people are thoroughly motivated to work towards the same objective. What is important in making more relevant people have a greater understanding is the ability to explain to them the logical necessity of implementing the policies.

In the management of vessel traffic safety, it is most important to establish assessment models that can numerically estimate the current safety level and quantitatively predict the correlation between the measures to be taken and the improvement of safety and the reduction of ship handling difficulties imposed on mariners, so as to achieve the mutual understanding of the relevant people. At the same time, it is also important to develop techniques to clearly describe the minimum requirement level and the sufficient levels of safety and difficulty.

In the present paper, the definition of term management and an assessment model using a quantitative analysis method are explained. An example of a scientific approach to vessel traffic safety management technique by taking up the promotion of total traffic control is also introduced.

## 2. Definition of Term Management

The term management used in this context can be described as a way of achieving the goal of an activity by motivating the members of an organization or relevant people[4]. The term management techniques refers to procedures and tools used to motivate them. Common to all management activities, in achieving a goal, is building a strong desire for co-operation and willingness to contribute amongst people or organizations involved.

In the management process for vessel traffic safety, it is essential to achieve a social consensus for implementation of safety policies. And, in the process of convincing the relevant people, we are required to have techniques that explain the logical necessity of implementing tangible measures. Therefore, management techniques can be considered, in more precise terms, to be techniques that explain the logical necessity of policies, and techniques to achieve a social consensus through a scientific approach, while the scientific approach for the management process can be considered as systematizing these techniques using quantitative analysis methods.

Figure 1 shows the systematic process of safety management services. As can be seen from this flow chart of the service, the assessment process is most important. The techniques to promote this procedure are the conclusive factors in studies on maritime safety management. In the process of explaining logical necessity and of achieving social consensus, it is necessary to develop a quantitative evaluation index to predict policy effects, as well as to establish acceptance criteria.

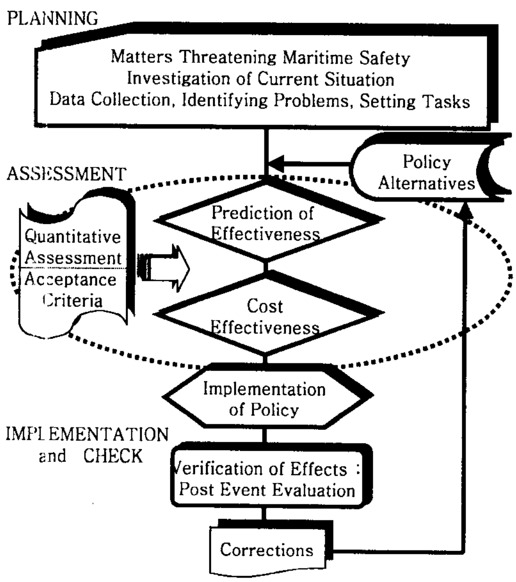


Fig. 1 Flow Chart of Management Services

In the present paper, a quantitative model for evaluating the difficulty of ship handling arising from restrictions in manoeuvring water areas and arising from traffic congestion is proposed. In the model, stress values are introduced as difficulty indices and these values are calculated on the basis of the residual time until a danger becomes a reality. This model also clarifies the acceptance criteria of the stress value based on mariners perception of safety.

## 3. Environmental Stress Model as an Assessment Model

### 3.1 The Environmental Stress Model

Environmental Conditions

The elements of environmental conditions that can be taken into account in the model are as follows:

(1) Topographical conditions such as land, shoals, shore protection, breakwaters, buoys, fishing nets, moored ships and other fixed or floating obstacles.

(2) Traffic conditions such as the density of other ships and traffic flow.

(3) External disturbances such as winds and currents.

Model Structure

The proposed model, which expresses in quantitative terms the degree of stress imposed by topographical and traffic environments on a mariner, is called the Environmental Stress Model(ES model)[5]. The ES model is composed of the following three parts:

(1) Evaluation of ship handling difficulty arising from restrictions on the water area available for manoeuvring. A quantitative index expressing the degree of stress forced on the mariner by topographical restrictions ($ES_L$ value(ES Value for Land)) is calculated on the basis of the TTC(Time to Collision) with any obstacles.

(2) Evaluation of ship handling difficulty arising from restrictions on the freedom to make collision-avoidance manoeuvres. A quantitative index expressing the degree of stress forced on the mariner by traffic congestion ($ES_S$ value(ES Value for Ship)) is calculated on the basis of the TTC with ships.

(3) Aggregate evaluation of ship handling difficulty forced by both topographical and traffic environments, in which the stress value ($ES_A$ value(ES value for Aggregation)) is derived by superimposing the value $ES_L$ and the value $ES_S$.

In the respective calculations of the values $ES_L$ and $ES_S$, a common index was used and the same algorithm was introduced to perform simultaneous aggregate evaluations of ship handling difficulty as experienced in encounters with other ships in ports and narrow waterways.

Calculation of Stress Value

In the most of case at ocean-going navigation, there are no restrictions on the water area available for manoeuvring and there is sufficient TTC, regardless of the ship direction. So no stress is imposed on the mariner and he feels no difficulty in ship handling. In narrow waterways, the water area available for manoeuvring is restricted, and there is little TTC, regardless of the ships direction; therefore, the topographical environment causes the mariner considerable stress and creates difficulty in ship handling. When other ships are present in the vicinity, and there is a danger of collision with other ships according to the direction of sailing, the mariner is put under additional stress. This stress becomes particularly great when there is little TTC, regardless of the direction of the ship.

Based on this concept, the value $ES_L$ and value $ES_S$ are calculated with the common procedure shown below.

(1) Consider the ships course in the range of 180°.

(2) Calculate the TTC for each one degree gradation in the range of ±90° centred on the present course.

(3) Convert the TTC into the mariners perception of safety for each one degree.

The conversion formulae shown in Equation (1) are given by regression equations found through ship handling simulator experiments with 31 subjects and questionnaire 573 answers[6].

$$SJ_L = \alpha \cdot TTC + \beta \qquad (1)$$
$$SJ_S = \alpha \cdot TTC + \beta$$

Where, $SJ_L$(Subjective Judgement for Land): Subjective judgment of mariners in relation to TTC with obstacles. $SJ_S$ (Subjective Judgement for Ship): Subjective judgment of mariners in relation to TTC with ships. The scales of the subjective judgment consist of numeric values with seven steps from 0 (extremely safe) to 6 (extremely dangerous). $\alpha$, $\beta$: Coefficients determined by the size of own ship (in case of $SJ_L$ value) or by the combination of the size of own ship and target ship (in case of $SJ_S$ value).

(4) Sum the values $SJ_L$, $SJ_S$ within the range of courses ±90° to find the stress values as follows:

$$ES_L = \Sigma[SJ_L]_i$$
$$ES_S = \Sigma[SJ_S]_i \qquad (2)$$
where, $i = -90 \sim +90$

Classification of Stress Value

If there is no danger in all directions, the SJ(Subjective Judgement) value of 0 extends over 180° (-90° ~+90° ), so this becomes zero as the minimum stress value. If there is an immediate danger, regardless of the ship's direction, the SJ value of 6 extends over 180° , so $6\times180 \fallingdotseq 1000$ is assigned as the maximum stress value. The stress ranking is set up by classifying the range of stress values as 0 to 1000, as shown in Table 1.

Table 1 Stress Ranking and Acceptance Criteria

| SJ: MARINERS' JUDGEMENT | ES VALUE $\Sigma[SJ]_i$ | STRESS RANKING | ACCEPTANCE CRITERIA |
|---|---|---|---|
| 0 Extremely safe | [0] | NEGLIGIBLE | ACCEPTABLE |
| 1 Fairly safe | | NEGLIGIBLE | ACCEPTABLE |
| 2 Somewhat safe | | NEGLIGIBLE | ACCEPTABLE |
| 3 Neither safe or dangerous | [500] | MARGINAL | UNACCEPTABLE |
| 4 Somewhat dangerous | [750] | CRITICAL | UNACCEPTABLE |
| 5 Fairly dangerous | [900] | CATASTROPHIC | UNACCEPTABLE |
| 6 Extremely dangerous | [1000] | | |

The rank of stress can be classified according to the extent to which a dangerous situation causes a particular SJ value in the range of ±90° around the present ships course. In the model, a situation giving the same SJ value, regardless of direction, was taken as the standard situation. The relationship between each stress ranking and the acceptable level was found through ship handling simulator experiments and a questionnaire.

The ES model, therefore, allows us to judge how great a stress value will be when it is no longer acceptable and to point out the disadvantages of the topographical and traffic situation in ports and waterways.

Calibration of Model Output

To verify the outputs of ES model, a calibration was attempted using a ship handling simulator. In trials, several scenarios in which the ship encountered other ships in a curved, narrow waterway were prepared. $ES_A$ values were calculated from the results of trials, and pulse of heartbeat of the mariner subjected to the simulation trial was measured at the same time. The correlation between the stress values derived from the ES model and the indices of physical stress obtained from the spectral analysis of the change of heartbeat is shown in Figure 2. In this Figure, the physical stress index means heartbeat number.

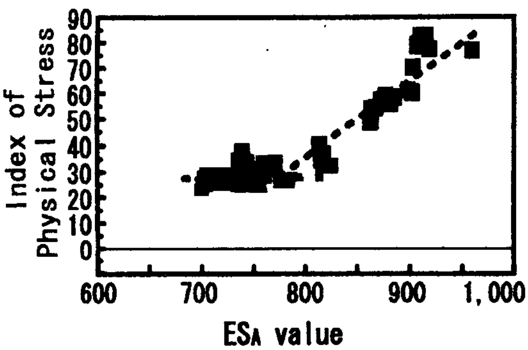


Fig. 2 Calibration of Model Output

It is demonstrated the validity of the model that the index of physical stress increases as the $ES_A$ value increases (in the unacceptable area to a value of more than 750).

### 3.2 Latent Environmental Stress (L-ES) Value

Individual uncertainty due to different skills or personalities of mariners is inevitably included in the manoeuvring process, such as the decision making on the timing and the action when taking a collision avoidance manoeuvre. To clarify the ship handling difficulty of ports and waterways, human factors such as the skill or the personality of a mariner must be excluded from the evaluation process.

The L-ES(Latent Environmental Stress) value is, therefore, introduced to avoid the influence of individual differences in skills and personalities among mariners, and to guarantee the universality of the results when evaluating ship handling difficulty. L-ES values are obtained by calculating the stress value, assuming that own ship sails at a fixed speed along a fixed route without making any collision avoidance manoeuvres against encountering ships. This is intended to avoid concealing information on stress levels that each encounter would naturally impose on the mariner by taking collision avoidance actions against other ships

### 3.3 Output Example of L-ES Value

Figure 3 shows an overview of three scenarios with different patterns of encounter. In all scenarios, own ship (3,500TEU container ship) encounters other ships in succession as it passes through a narrow waterway on course 000° at a speed of 12 knots. L-ES values were obtained for each scenario by calculating the ES value, assuming that the own ship sails at a fixed speed along a fixed route without making any collision avoidance manoeuvres.

Figure 4 shows the calculated L-ES values for the three scenarios. The dotted line shows the L-ES$_L$ value that expresses the degree of ship handling difficulty due to topographical restrictions, the fine solid line shows the L-ES$_S$ value that expresses the degree of ship handling difficulty due to traffic congestion, and the thick solid line shows the L-ES$_A$ value that expresses the aggregate evaluation result of ship handling difficulty forced by both topographical and traffic environments.

Encounters with other ships in a topographically restricted narrow waterway would impose great stress on mariners.

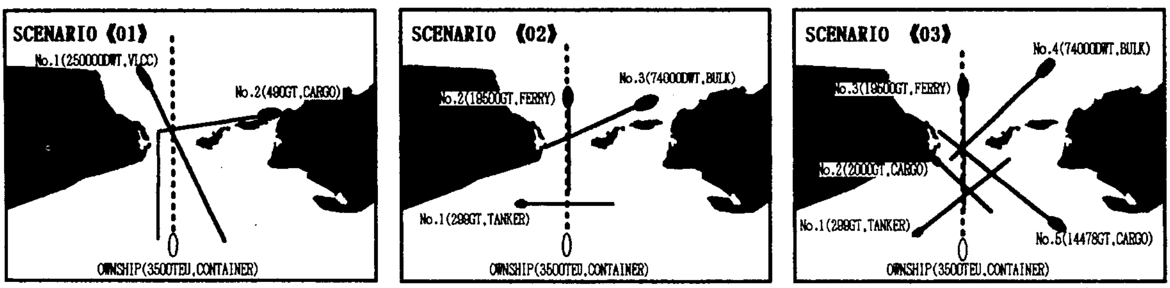


Fig. 3 Three Scenarios

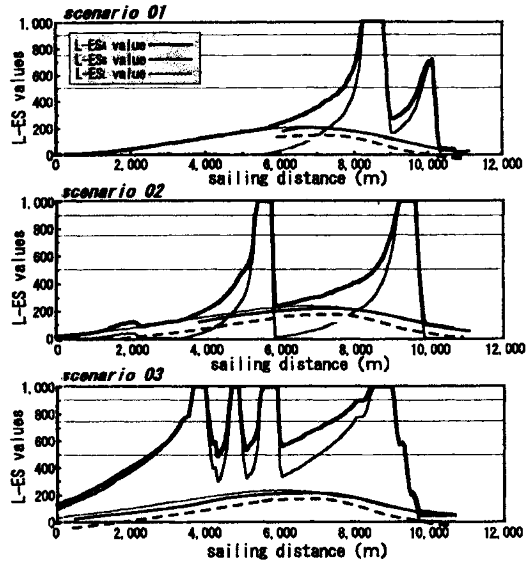


Fig.4 Results of L- ES Values

Accordingly, L-ES<sub>A</sub> values are significant when the degrees of ship handling difficulty in different ports and waterways with different environmental conditions are contrasted. Figure 5 shows the frequencies of stress classified into four ranks for each scenario based on the calculated L-ES<sub>A</sub> values.

According to the mariners acceptance criteria of the stress value based on a mariners perception of safety shown in Table 1, L-ES<sub>A</sub> value of 750 or more corresponds to unacceptable. The percentage of unacceptable (L-ES<sub>A</sub>≧750) suggests higher difficulty in ship handling. The percentage of negligible (L-ES<sub>A</sub>≦500) suggests the ease of ship handling.

### 3.4 Rating Table

The degree of ship handling difficulty can

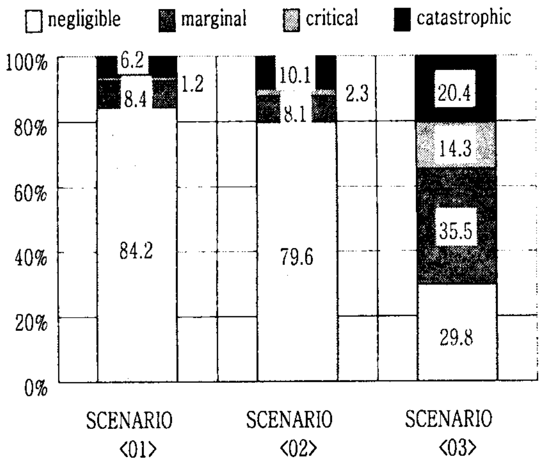


Fig. 5 Frequency of Each Stress Ranking

be judged from the combination of the percentage of unacceptable (L-ES<sub>A</sub>≧750) and the percentage of negligible (L-ES<sub>A</sub>≦500) found from the calculations of L-ES<sub>A</sub> values. The higher the percentage of unacceptable (L-ES<sub>A</sub>≧750) is the greater the ship handling difficulty is, and the lower the percentage of negligible (L-ES<sub>A</sub>≦500) is, the less the ship handling difficulty is. However, even under the same unacceptable (L-ES<sub>A</sub>≧750) condition, the higher the percentage of negligible (L-ES<sub>A</sub>≦500) is, the less the ship handling difficulty is.

As shown in Figure 6, the Rating Table used to identify ship handling difficulties of ports and waterways is divided into sections by combinations of the percentage of unacceptable (L-ES<sub>A</sub>≧750) and negligible (L-ES<sub>A</sub>≦500). The horizontal axis shows the percentage of unacceptable (L-ES<sub>A</sub>≧750), segmented for each 20% level. The vertical axis shows the percentage of negligible (L-ES<sub>A</sub>≦500), segmented into 40% and 80% levels.

The Rating Table is divided into nine stages by these combinations, labeled from [A++] to [E] according to the degree of ship handling difficulty.

Ship handling simulator experiments were carried out to identify what label on the Rating Table(Fig. 6) from the viewpoint of ship handling difficulty. Thirty-two ship masters participated in the experiment. In the simulator experiment, several scenarios simulating different environmental conditions of ports and waterways with various levels of difficulties were prepared. As a result of discussions based on the output data of L-ES values through the ship handling simulator experiments and its comparison with the subjective judgments of mariners, it was agreed that label [A] or higher was required for ensuring navigational safety of ships of 3,000GT or more. However, it was concluded that label [C] could be required for smaller ships of 1,000GT or less, because of the good manoeuvrability of ships of these sizes[7].

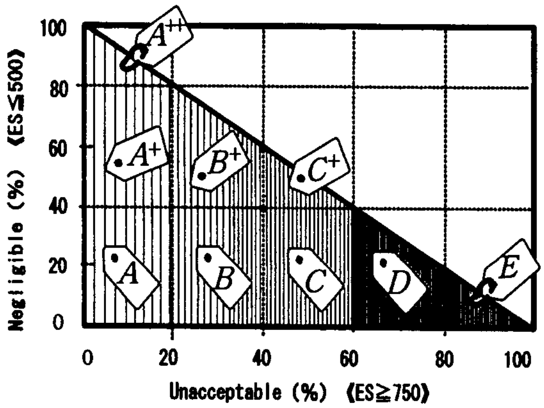


Fig. 6 Rating Table

## 4. Evaluation of Safety on a Rating Table

### 4.1 Calculation Conditions

Two major ports in Japan were selected as samples for rating quality from the viewpoint of ship handling difficulty. One was port of A and the other was port of B. Traffic density in both ports was quite high. In port of A about 33 ships were observed per hour during the rush hour in early morning, and the traffic density in port of B had about two times the density of that in port of A during the same period.

L-ES values were calculated on the assumption that the own ship sails at a fixed speed along the fixed route without making any collision avoidance manoeuvres. Three sizes of ship were set for own ship: 300GT, 3,000GT and 10,000GT. The sailing routes and the speed deceleration patterns of the own ship were standardized and the traffic flow conditions for the simulation were modeled on data obtained from marine traffic observations in the early morning rush hour in both ports.

Marine traffic simulations were conducted under the above calculation conditions, and 50 trial navigations were conducted for each size of own ship sailing in the traffic flows produced on a computer. The traffic flow encountered by own ship is different in each navigation trial, because the next own ship is made to start after the previous own ship reaches a berth.

L-ES values of each trial were calculated by applying the ES model to the ship handling process in each trial of navigation, and L-ES values representing the ship handling difficulties in the port were obtained by taking mean values of these output results of 50 trial navigations on a distance basis.

## 4.2 L-ES Values in Ports

Figure 7 shows the $L\text{-}ES_L$, $L\text{-}ES_S$ and $L\text{-}ES_A$ values calculated for port of A and port of B. In both ports, the $L\text{-}ES_L$ values increase just before the ship passes the breakwater entrance at a point at 5,000m in port of A and at a point at 6,000m in port of B , because of topographical restrictions. As can be seen in Figure 7, no remarkable differences are seen in the outputs of $L\text{-}ES_L$ values, regardless of own ship size. This is probably a reflection of the mariners perception of safety, attempting to reduce stress due to topographical restrictions to permissible extents by operating larger ships at slower speeds.

However, there are significant differences in $L\text{-}ES_S$ values between each size of own ship. It can be deduced that mariners onboard larger ships have more ship handling difficulty imposed when taking collision avoidance actions because of the poor manoeuvrability of these sizes of ship. Regarding with the $L\text{-}ES_A$ values, it can be seen that great stress is imposed over the entire area of water in port of B compared to port of A, and the stress is greater with larger ships.

## 4.3 Ratings

Figure 8 shows a comparison of the frequency of stress classified into four ranks for each size of ship based on calculated

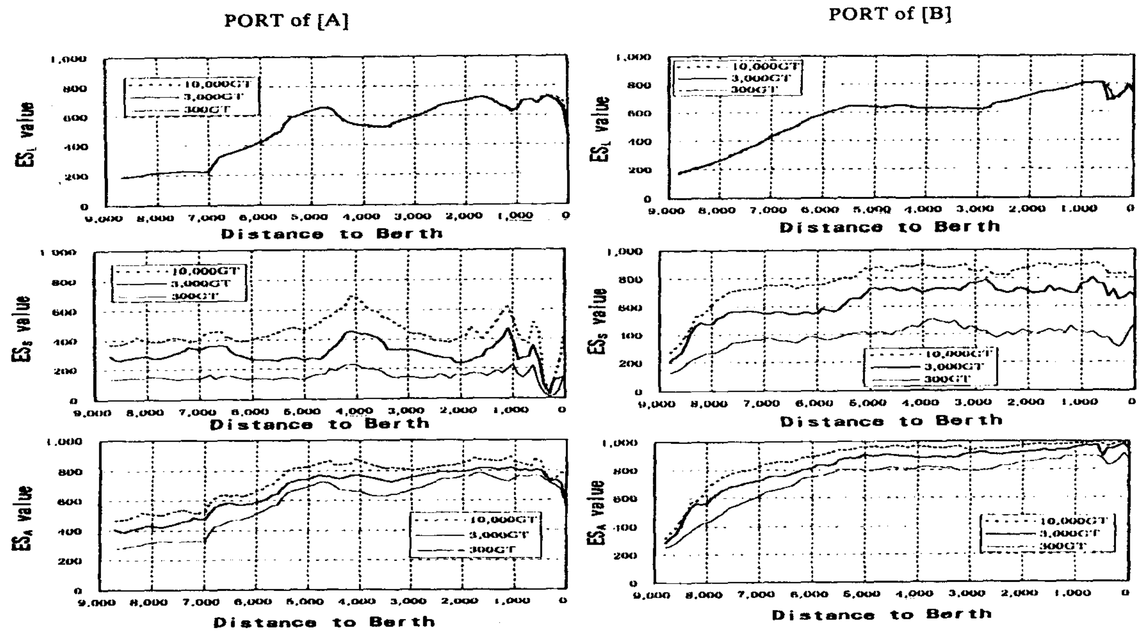


Fig. 7 Calculated Results of L-ES Values in Both Ports

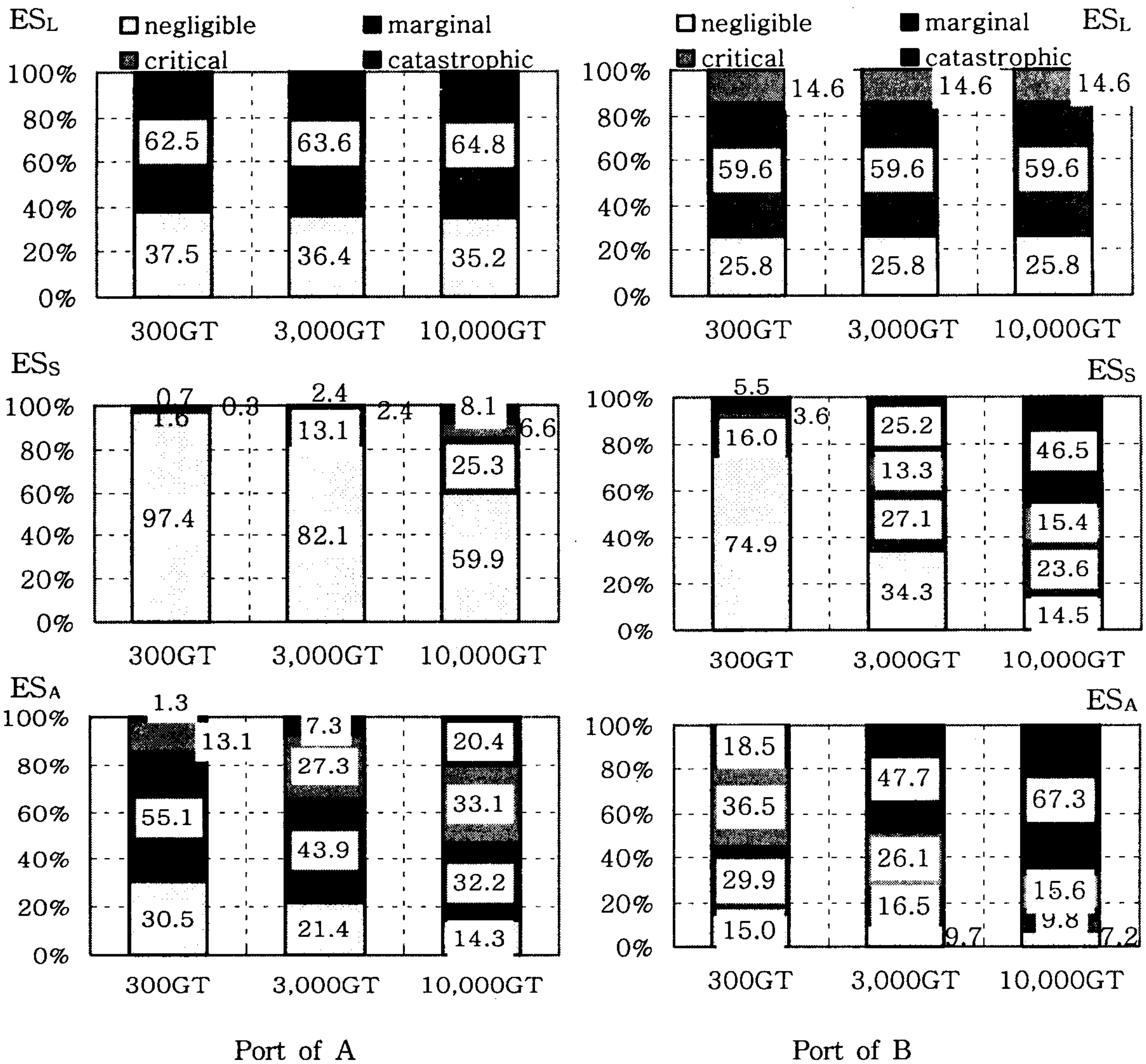


Fig. 8 Frequency of Each Stress Ranking in Both Ports

$L\text{-}ES_A$ values. To identify the quality of the two ports from the viewpoint of ship handling difficulty, the results were plotted on the Rating Table shown in Figure 9, paying attention to the percentage of unacceptable ($L\text{-}ES_A \geqq 750$) and the percentage of negligible ($L\text{-}ES_A \leqq 500$) drawn from Figure 8. The quality of port of A can be ranked as label [B] for a ship size of 3,000GT and as label [D] in port of B. The quality for a ship size of 10,000GT can be ranked as label [C] in port of A and as label [E] in port of B.

## 5. Effectiveness of Total Traffic Control

According to the calculated results of L-ES values in Figure 8, the stress imposed on mariners is extremely high in port of B, the reason why the level of quality are not so desirable in ports of B is because traffic congestion is coupled with topographical restrictions to increase ship handling difficulty.

It could, therefore, be said that safety measures should be taken to resolve the traffic congestion in the early morning rush hour in the port. It would be desirable to take countermeasures that emphasize vessel traffic safety management such as promoting total traffic control.

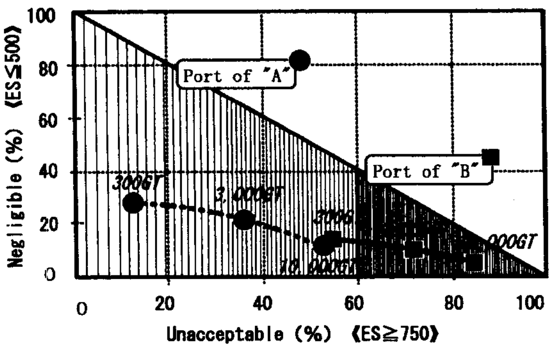


Fig. 9 Ratings for Both Ports

In this sense, an analysis was made to verify the effectiveness of promoting total traffic control in port of B, by employing the same evaluation procedure and the same calculation conditions for the simulation described in the previous chapter. Here, a ship size of 10,000GT was set for own ship. Figure 10 shows the frequencies of stress classified into four ranks in each traffic-control-rate based on calculated L-$ES_A$ values.

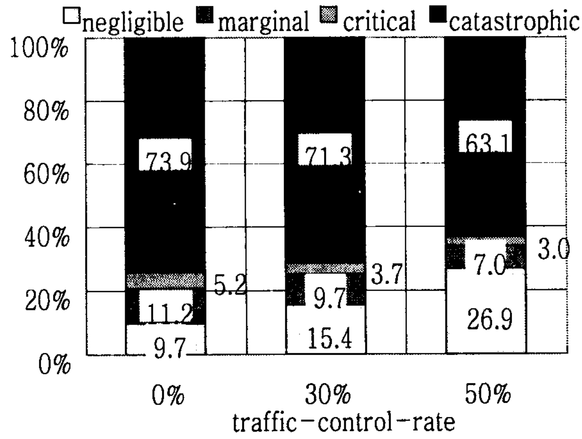


Fig. 10 Frequency of Each Stress

The results are plotted on the Rating Table shown in Figure 11, paying attention to the percentage of unacceptable (L-$ES_A$ $\geqq$750) and the percentage of negligible (L-$ES_A$$\leqq$500) drawn from Figure 10. The plots are superimposed on the Rating Table in Figure 9 to show the effectiveness of promoting total traffic control from the viewpoint of reducing of ship handling difficulty.

As can be seen in Figure 11, under the condition that the traffic-control-rate is fifty percent, ship handling difficulty for own ship size of 10,000GT can be improved to the rank of label [D], which seems to be nearly label [C]. If the navigational safety in port of [B] is desired to be ranked as label [A] or higher, further enhancement of traffic-control-rate seems to be necessary. This analytic evaluation, thus, allow us to find acceptable and maximum traffic volume to ensure navigational safety in ports and waterways from the viewpoint of ship handling difficulty. This suggests that an impact of traffic flow should be taken into account in a channel design process.

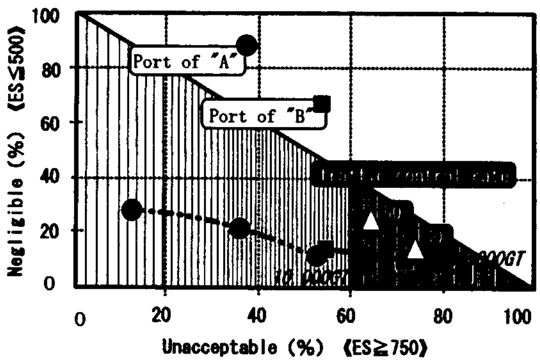


Fig. 11 Effectiveness of Total Traffic Control

## 6. Conclusion

The most important points for administrators in relation to making plans for ensuring safety in ports and waterways is that the safety level to be achieved and the aims or the effective traffic countermeasures are clarified.

It has been very difficult to point out the goals and the assessment process for achieving navigational safety in ports and waterways. This paper suggests how to solve these issues. It became clear that:

(1) a systematic safety management process based on a quantitative analysis provides important hints for safety management

(2) an analysis based on information obtained in the evaluation process for rating the quality of ports and waterways by employing the ES model is effective tool for the management service.

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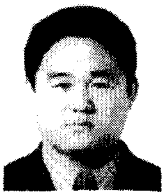

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