

A Proposal on the Navigation Supporting System for improving the Marine Traffic Safety

Hyong-Ki Lee* · Chang-Hyun Jung** · Gil-Young Kong*** · Young-Soo Park†

*,† Ship Operation Training Center, Korea Maritime University, Busan 606-791, Korea

** T.S. HANBADA, Korea Maritime University, Busan 606-791, Korea

*** Division of Navigation System, Korea Maritime University, Busan 606-791, Korea

Abstract : In near future, more congested and dangerous marine traffic environment due to the rapid marine traffics increase and ship handling difficulty by enlargement of ship size is predicted. In this paper, an navigation supporting system proposal made to enhance the safe navigation by providing the collision avoidance informations to the navigator via marine traffic environment assessment. Proposed navigation supporting system displays results of marine traffic environment assessment, degree of the dangers and gives reason of danger which is enhance situational awareness of navigator. For this purpose, results of marine traffic environment assessment which is obtained via real time assessment sent to the designated server and through the connection with navigation supporting system navigator being enable to see all those informations on the computer screen. Navigator would utilize those information to make a decision in the difficult waterways and thus safe navigation could be enhanced.

Key words : Marine traffic environment, Collision avoidance informations, Navigation supporting system, Internet, Safe navigation

1. Introduction

Vessels navigating in restricted areas such as narrow channels, port area or main traffic way encounter with other vessels and/or obstacles. It impose ship handling difficulty to navigator. Due to developments in recent decades international trade and consequently marine transportation is drastically increased. As a result marine traffic increasing, ship size getting bigger and more dangerous marine environment occurred. Moreover continuity of this development is expected which at the end will impose more ship handling difficulty to the officers who navigates in the difficult waterways such as narrow channels, ports and any other restricted areas.

In this paper it is aimed to enhance safe of navigation by providing detailed navigation evaluation information to navigator which is acquired by the assessment of navigating marine environment.

Proposed navigation supporting system displays surrounding marine traffic environment, level of ship handling difficulty, potential dangerous and shows collision avoidance courses on computer screen in order to improve marine traffic safety in the difficult waterways.

2. Construction of navigation supporting system

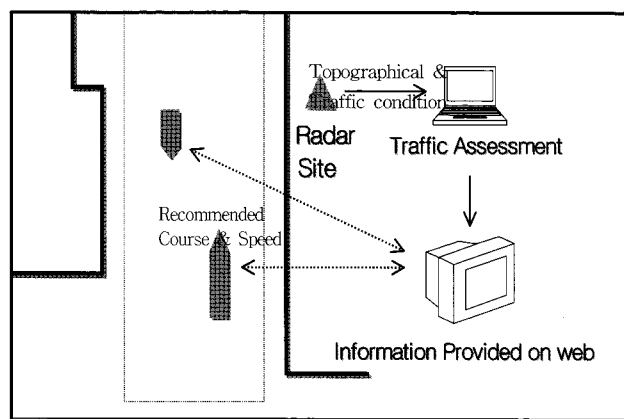


Fig. 1 Data transmission diagram of the system1

Fig.1 shows the information flow of navigation supporting system constructed in this paper to improve the marine traffic safety. First, the radar site in the ground installed to grasp the marine traffic flow and obstacles in the selected area. Afterward, once a minute captured image of the radar screen and informations about marine traffic flow and topographical environment send to server of marine traffic analysis system in real-time. In the server informations such

* Hyong-ki Lee, hyongki@hhu.ac.kr, 051)410-4201

** hyon@hhu.ac.kr, 051)410-4206

*** kong@hhu.ac.kr, 051)410-4273

† Corresponding author : Young-Soo Park, youngsoo@hhu.ac.kr, 051)410-4474

as speed, course and size are evaluated by the Environment Stress Model which is a quantitative assessment model expressed the difficulty of ship-handling due to surrounding marine environments. Based on the results of assessment, system gives detailed risk information about surrounding navigation area. Those information are promulgated to the ships navigating in the selected area via web and displayed on navigation support system which is installed on the ship.

3. Environmental stress model as an assessment model

3.1 Environmental Stress Model

1) 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

2) Model Structure

The ES model 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 ; Inoue, 2000). 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 maneuvering. 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.

3) Calculation of stress value

In the most case of ocean-going navigation, there are no restrictions on the sea for maneuvering 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 area available for maneuvering 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 taken 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 procedures as shown below;

- ① Consider the ship's course in the range of 180° .
- ② Calculate the TTC for each one degree in the range of $\pm 90^\circ$ centered on the present course.
- ③ Convert the TTC into the mariners perception of safety for each one degree.

The conversion formula shown in equation(1) are given by regression equations found through experiments of ship handling simulation with 31 subjects and questionnaire 573 answers(Inoue et al, 1998).

$$\begin{aligned} SJ_L &= \alpha \cdot TTC + \beta \\ SJ_S &= \alpha \cdot TTC + \beta \end{aligned} \quad (1)$$

Where SJ_L (Subjective Judgement for Land) is subjective judgment of mariners in relation to TTC with obstacles. SJ_S (Subjective Judgement for Ship) is 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). α and β is 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 of SJ_L and SJ_S within the range of course $\pm 90^\circ$ to find the stress values as follows;

$$ES_L = \sum [SJ_L]_i \quad (2)$$

$$ES_S = \sum [SJ_S]_i$$

Where, $i = -90^\circ \sim +90^\circ$

Table 1 Stress ranking and acceptance criteria

SJ : Mariner's Judgement		Evaluate $\sum [SJ]_i$	Stress Ranking	Acceptance Criteria
0	Extremely safe	[0]	Negligible	Acceptable
1	Fairly safe			
2	Somewhat safe			
3	Neither safe or dangerous	[500]	Marginal	Unacceptable
4	Somewhat dangerous	[750]	Critical	
5	Fairly dangerous	[900]	Catastrophic	
6	Extremely dangerous	[1000]		

4) 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 6×180=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.

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.

5) 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 or 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 Fig. 2. In this figure, the physical stress index means the number of heartbeat.

It was 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.

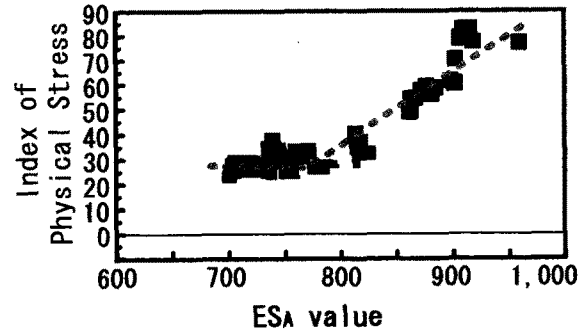


Fig. 2 Calibration of model output

3.2 Latent environmental stress (*L-ES*) value

Individual uncertainty due to different skills or personalities of mariners is inevitably included in the maneuvering process, such as the decision making on the timing and the action when taking a collision avoidance maneuver. To clarify the difficulty of ship handling in ports and waterways, human factors such as the skills or the personalities of a mariners 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 the ship handling difficulty. The *L-ES* value is obtained by calculating the stress value, assuming that own ship sails at a fixed speed along a fixed route without making any collision avoidance maneuvers against encountering ships. This is intended to avoid concealing the informations of stress levels that each encounter would naturally impose on the mariner by taking collision avoidance actions against other ships.

4. How to display recommended course from *L-ES* value

4.1 Example of *L-ES* value output

Fig.3 shows an overview of three scenarios with different

patterns of encounter. In all scenarios, own ship (3,500 TEU 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 from 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 maneuvers.

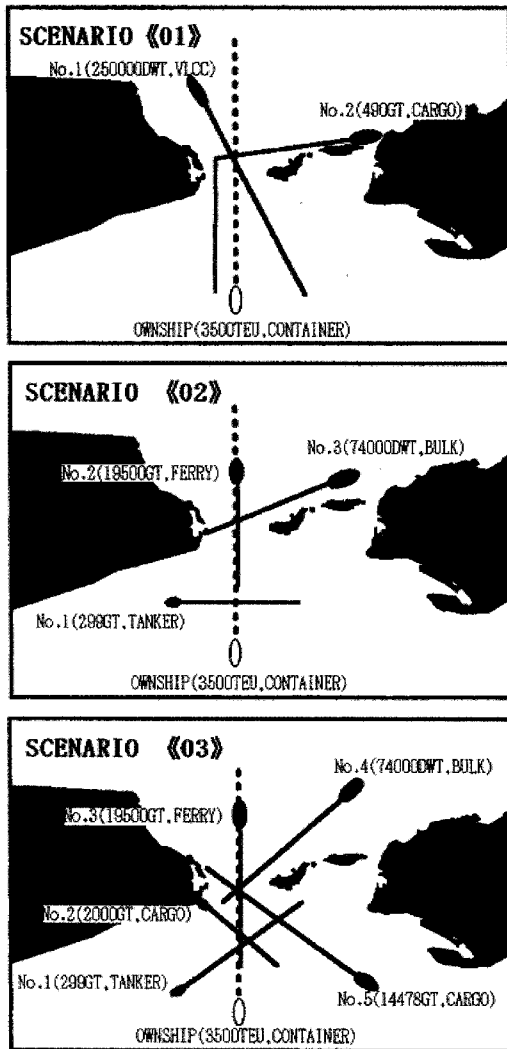


Fig. 3 Overview of three scenarios

Fig.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. Accordingly, $L-ES_A$ values were significantly different as to the degrees of ship handling difficulty in different ports and waterways with different environmental conditions.

Stress classified into four ranks for each scenario based on the calculated $L-ES_A$ values. According to the mariners acceptance criteria of the stress value based on a mariners perception of safety shown in Table 1, The $L-ES_A$ value of 750 or more corresponds to unacceptable. The percentage of unacceptable ($L-ES_A \geq 750$) suggests higher difficulty in ship handling. The percentage of negligible ($L-ES_A \leq 500$) suggests the ease of ship handling.

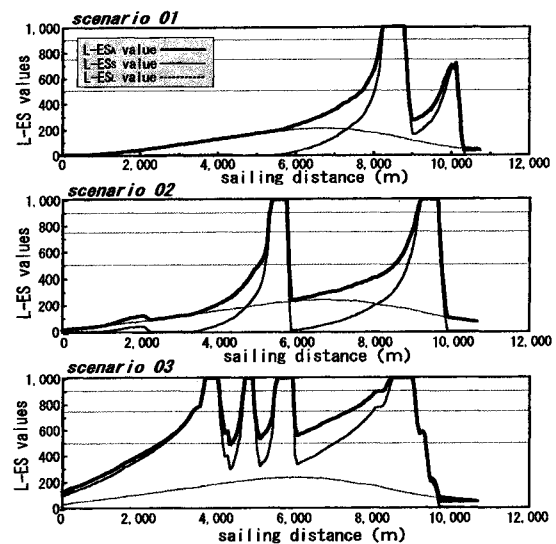


Fig. 4 Results of $L-ES$ values

4.2 Display of recommended course

The navigation supporting system based on $L-ES$ value displays the assessment of environmental stress imposed on a mariner due to restrictions to avoid collision and/or stranding at a navigable water area.

In Fig.5 a snap shot screen presented from proposed navigation supporting system. In the screen of the system the left upper corner shows the percentage of rank of ES value, the left bottom corner shows the surrounding situations included traffic and land in the radar screen, the right bottom corner shows the time-scale ES value, right-middle shows the distribution of ES_L & ES_S , and right upper corner shows the distribution of ES_A . Grey color represent most safe situation and on contrary red color represents most dangerous environment situation. In Fig.5 risk level unacceptable due to topographical condition. $L-ES_L$ value is less than 750 and $L-ES_S$ value is less

than 500 but aggregation of both value $L-ES_A$ is over than 750 which makes unacceptable traffic condition. Aggregate Stress Value draws navigator's attention, residual time to collide screen gives reason of danger and left bottom corner screen recommends the required action to mitigate imminent danger.

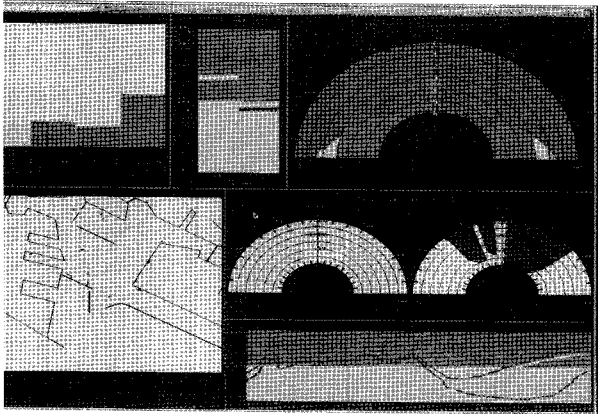


Fig. 5 Display of navigation supporting system

5. Conclusion

In a navigation system, which consist by ship-human-environment relationship, the human factor plays a significant role in triggering of a accidents. However, the environmental conditions which determine the level of ship-handling difficulty are also important factors and may affect the possibility of an accident occurrence.

The risk of an accident thus strongly related to the skill of navigator, the environmental conditions which force ship-handling difficulty on navigator during execution of ship operation and the maneuvering performance of the ship.

The real-time navigation supporting system has been developed to offer the collision avoidance course in the difficult waterways such as narrow channels, ports and any other restricted areas. Results of the assessment displayed quantitatively with graphics.

In this paper a basic concept about the navigation supporting system is proposed. Afterwards, an algorism attempt will be made to apply ES model on radar image.

This visual-aid navigation supporting system is expected to contribute to further wide range of applications in the safety, traffic control and training fields.

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