Innovative Probabilistic Prediction of Accident Occurrence

K. Inoue
Kobe University, Graduate School of Maritime Sciences, Japan

M. Kawase
Japan Marine Science Inc., Japan

ABSTRACT: In the present paper, a safety evaluation index that determines the probability of accident occurrence of collision and stranding when the experiment is executed using a ship handling simulator is proposed, by noting Unsafe Ship Handling Situations. The number of Unsafe Ship Handling Situation was counted from the results of simulator trials, and the accident ratio was surveyed from the past records of sea casualties in the corresponding water area. The correlation between the appearance ratio of Unsafe Ship Handling Situation and the accident ratio showed reasonable coincidence with the order of 10^{-3}. When port administrator tries to assess the effectiveness of safety improvement planning of port and harbour facilities, it can be said that this kind of probabilistic prediction model of accident occurrence is indispensable from the aspect of introducing cost effectiveness analysis.

1 INTRODUCTION

A ship-handling simulator has been used as a powerful tool to assess the effectiveness of safety improvement planning of port and harbour facilities. Ship handling simulator oriented experiments are already practiced broadly and globally for verifying the adequacy of the countermeasure taken by port administrator from the safety aspect.

In the present paper, a model to evaluate accident occurrence probability is proposed by introducing “Unsafe Ship Handling Situation”. An Unsafe Ship Handling Situation can be determined, in each time section, in terms of whether or not the Time To Collision (TTC) exceeds the Short Stopping Time (SST) under the corresponding speed. Time To Collision (TTC) is calculated as the time until the ship makes contact with the obstacle or other ship on the predicted ship’s path.

According to the Heinrich’s Law, an Unsafe Situation corresponds to the detection of some several thousand hidden unsafe situations behind one obvious case of an accident. If the appearance ratio of the proposed Unsafe Ship Handling Situation and the accident ratio in the corresponding sea area coincide with the order of 10^{-3}, this means that, by deriving the number of Unsafe Ship Handling Situations from a series of ship-handling processes, the underlying accident risk in the process of ship handling may be estimated from the relation with this ratio of 10^{-3}.

To verify this relationship, calibration was attempted using ship-handling simulator. In trails, several scenarios of the existing ports in Japan in which the ship encountered other ships in a curved, narrow waterway were prepared. The number of Unsafe Ship Handling Situation was counted from the results of trials, and the accident ratio was surveyed from the past records of sea casualties in the corresponding port.

The correlation between the appearance ratio of Unsafe Ship Handling Situation and the accident ratio showed reasonable coincidence with the order of 10^{-3}. The proposed safety evaluation index is considered to be an objective index that is unbiased towards subjectivity, and to contribute to maintaining the universality of the results on a probabilistic basis.

This prediction model of accident occurrence probability by noting Unsafe Ship Handling Situation as an index is a practical model for evaluating the ship handling risk in topographically restricted and congested waterways, and in ports and harbours.

2 DEFINITION OF UNSAFE SHIP HANDLING SITUATIONS

Heinrich’s law, as can be seen in Fig. 1, explains that there are 29 accidents with slight damage and 300 near misses, furthermore, there are several thousand latent unsafe situations behind one obvious accident. When evaluating the level of safety in a ship-handling simulator oriented experiment, one method is to estimate the potential risk of accident at a ratio of 1: 300 by counting the number of near misses from experiments.

However, it is difficult for us to perform many cases of experiments using a ship-handling simulator, and it is more difficult to objectively determine near misses. In this study, latent unsafe situations behind near misses are noted. That is, by detecting physically unsafe events, the objective level of accident risk may be estimated. Such physically unsafe situations are termed Unsafe Ship Handling Situations in this paper. (Inoue, 2000)

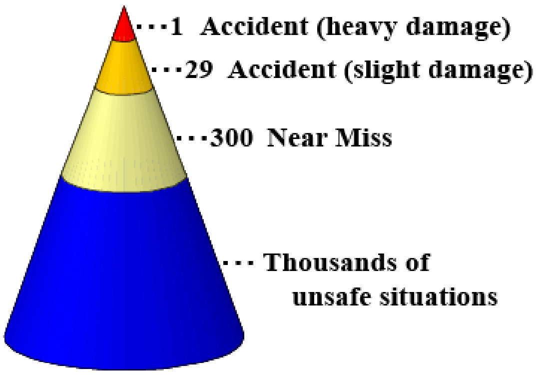

Fig.1. Heinrich's accident triangle

During the process of executing ship handling operation, ship handling is considered not to be dangerous when there is no obvious risk when maintaining the present maneuvering condition; however, such ship handling includes the possibility of an accident when there is an obvious risk in the near future by maintaining the present maneuvering condition. As stated above, an Unsafe Ship Handling Situation is defined as a condition in which the risk becomes obvious in the near future by maintaining the present condition in spite of an accident not having occurred.

3 METHOD OF DETECTING UNSAFE SHIP HANDLING SITUATION

The concept of Potential Area of Water (PAW) is introduced as a means of determining whether or not there is a latent Unsafe Ship Handling Situation during execution of ship handling. (Inoue, 1990)

PAW can be estimated by predicting ship's vector and ship's track in the future. Predicted tracks are obtained by the following procedures:

(1) With time constant, quantitative conditions of all operational means acting on the ship such as rudder angle, main engine revolutions, tugs, thrusters, mooring lines, and holding power of anchors and anchor chain, and quantitative conditions of ship movement such as ship's heading, velocity, yaw rate and acceleration component are extracted. These quantitative conditions, along with quantitative conditions of external force become input conditions for calculations of predicted tracks.

(2) With time constant, ship movement is estimated by substituting value (1) above into the equation of motion under the condition that quantitative conditions of operation, ship movement and external forces are fixed, and predicted tracks are obtained.

As illustrated in Fig.2, Unsafe Ship Handling Situations are detected by inspecting whether or not the PAW obtained at each time segment overrides obstacles such as a wharf and quay wall, buoy and breakwater or another ship under way. (Inoue, 1998)

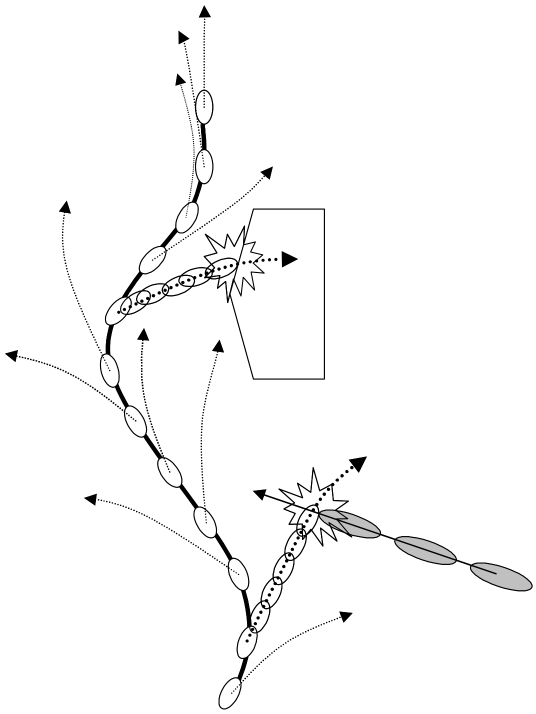

Fig. 2. Illustration of unsafe situation

Concretely, as shown in flowchart of Fig.3, an Unsafe Ship Handling Situation is detected by the following procedure:

(1) A series of ship handling maneuvers is divided into time segments.

(2) In each time segment, the PAW is estimated.

(3) The Time To Collision (TTC) is calculated. TTC is the time until own ship collides with another ship and or strands on the predicted tracks.

(4) An Unsafe Ship Handling Situation is detected if the TTC value exceeds the judgment criteria of the Unsafe Ship Handling Situation.

4 JUDGMENT CRITERIA FOR UNSAFE SHIP HANDLING SITUATION

An Unsafe Ship Handling Situation is determined in each time segment if Short Stopping Time (Time to stop with crash astern engine, SST) corresponding to

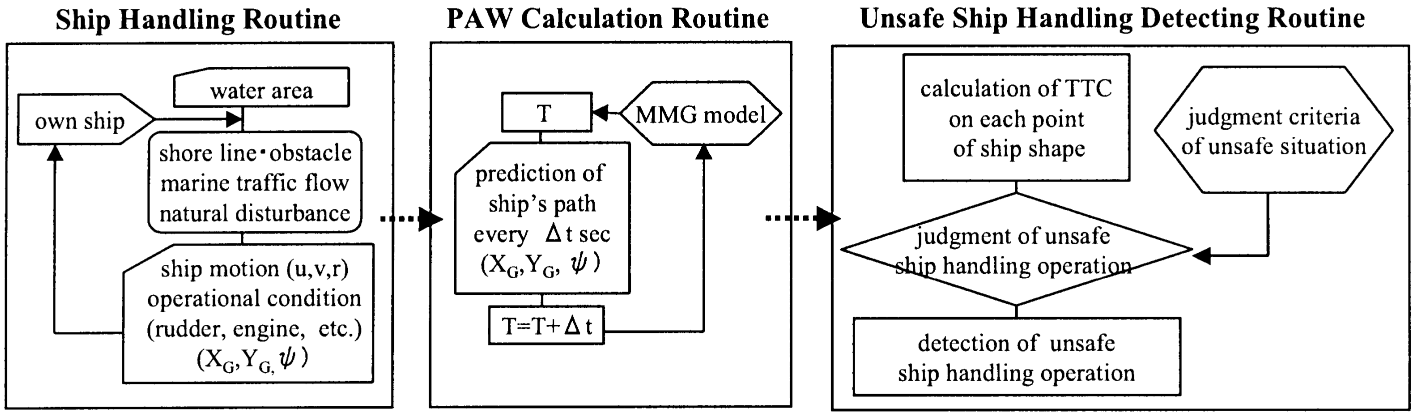

Fig. 3. Flowchart of detection procedure

the ship's velocity at the time exceeds the TTC value. The purpose is to determine potential risks physically, that is, for a certain TTC, if TTC ≤ SST, it is determined that the ship is in an Unsafe Ship Handling Situation (hereinafter called SST criterion).

On the other hand, when berthing or un-berthing, ship speed is decreasing sufficiently, and the main component of ship motion is no longer ahead (u), but drift (v), turn (r), and occasionally astern (-u) are taking place. Under such conditions of ship motion in the vicinity of a berth, it is not reasonable to follow an SST criterion that controls only ahead motion. In general, the motion of drift (v), turn (r), and occasionally astern (-u) or their coupled motion, are eliminated by main engine, thrusters and tugs, but the same methods cannot be applied to them all. When simulating the time required to eliminate typical ship motions in the vicinity of a berth using a tug or a thruster, it was found, for any type of ship, that the above time to eliminate ship motions coincides with the time required to eliminate a headway of 2 knots with full astern engine. Therefore, in the speed range of 2 knots or less, it is concluded that Unsafe Ship Handling Situations are to be determined by SST criteria based on the time required to eliminate a headway of 2 knots with full astern engine. Fig.4 illustrates the judgment criteria of Unsafe Ship Handling Situations.

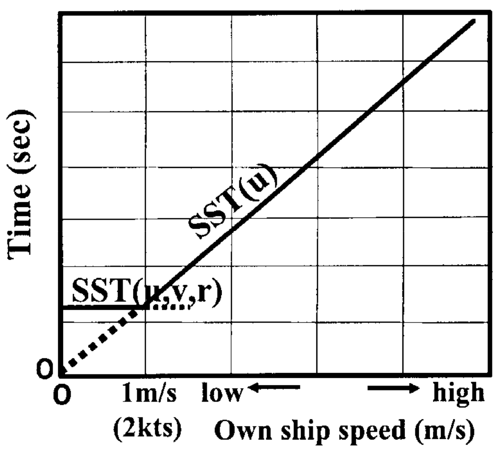

Fig. 4. Schematic diagram of judgment criteria

5 EXAMPLE OF UNSAFE SHIP HANDLING SITUATION DETECTED

Fig.5 shows the calculation results of TTC over time with the speed-reduction sequence while proceeding to a wharf. The following elements are shown on the figure: time series on the abscissa, TTC on the left ordinate and ship velocity on the right ordinate.

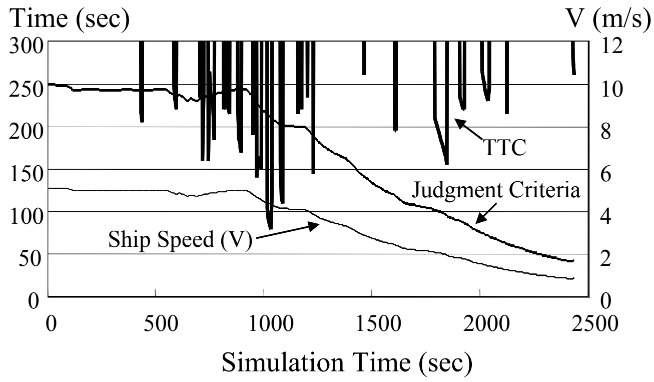

Fig. 5. Calculation results of TTC

To determine Unsafe Ship Handling Situations, an SST criterion is also shown in this figure. If the TTC value plotted falls under the line showing judgment criteria, the ship is determined to be in an Unsafe Ship Handling Situation. The passing of the ship through a breakwater entrance corresponds to 1,000 seconds on the abscissa, where an Unsafe Ship Handling Situation is perceived. After entering port, the Unsafe Ship Handling Situation is decreased due to sufficient speed-reduction.

In Fig.6, the occurrence ratio of Unsafe Ship Handling Situation detected during experiments on a ship-handling simulator in major ports in Japan are compared with the accident ratio of collision and stranding occurred in the corresponding ports. A characteristic read from the figures above is that the occurrence ratio of the proposed Unsafe Ship Handling Situation and the accident ratio in the corresponding ports approximately coincide with an order of 10^{-3} in any case. That is, according to the

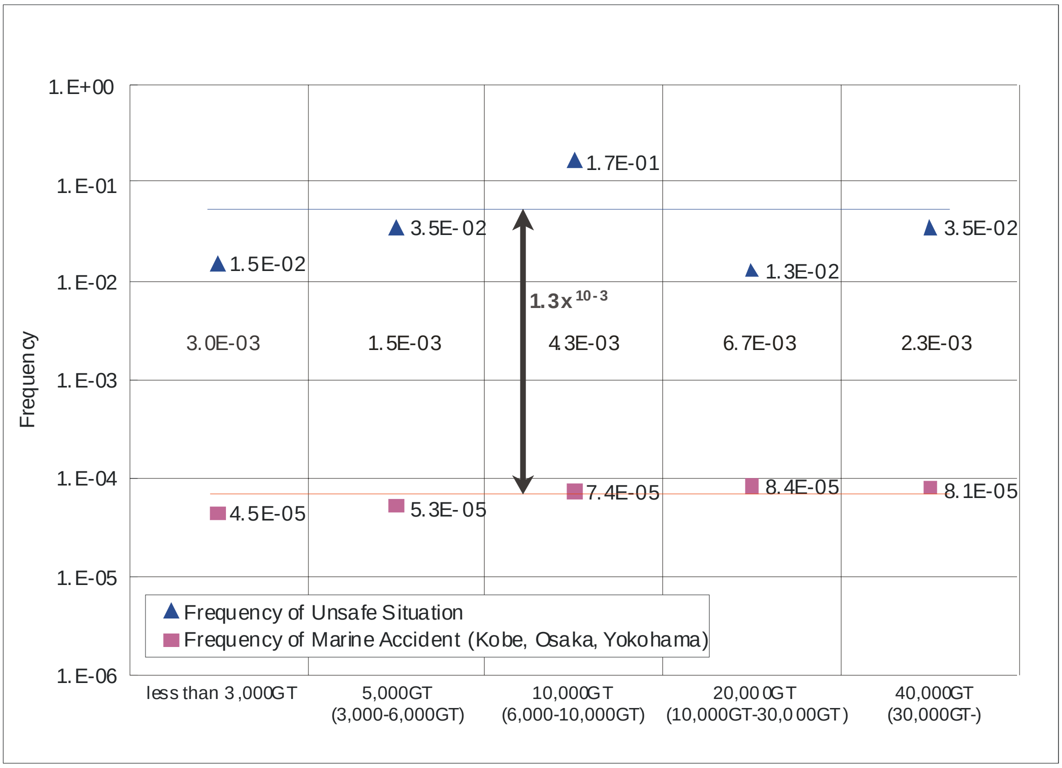

Fig. 6. Comparison of occurrence ratio of unsafe situation and marine accident

Heinrich's law, the Unsafe Ship Handling Situation corresponds to the detection of some several thousand latent unsafe situations (order of 10^{-3}) behind one obvious case of an accident. This means, by deriving the number of Unsafe Ship Handling Situations from a series of ship handling maneuvers, it may be possible that the underlying accident risk in the process of ship handling is estimated from the relation with the ratio of 10^{-3}.

6 CONCLUSION

If there is a little time until collision or stranding to recover, an error by the mariner or misjudgement will lead to an actual collision and stranding, so we proposed an evaluation model that extracts an Unsafe Ship Handling Situation under a certain judgment criterion from the events inherent in a series of ship handling maneuvers.
This safety evaluation index is considered to be an unbiased yardstick that objectively determines the quantitative risks of collision and stranding, and to be practical for maintaining the universality of the results on a reasonable probabilistic basis.

When port administrator tries to assess the effectiveness of safety improvement planning of port and harbour facilities, it can be said that this kind of prediction model is indispensable. Furthermore, to deepen mutual understanding and to create consensus-building among the parties concerned in different situations such as the port administrator and ship handler, scientifically based explanations are indispensable for problems of maritime safety. From this point of view, it is expected that the new yardstick developed in this study will contribute to the utilization of ship-handling simulators for safety evaluations.

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