

EVALUATION OF OCCURRENCE FREQUENCIES OF MARINE ACCIDENTS IN THE FSA FRAMEWORK

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ABSTRACT

Event tree analysis has been applied to the estimation of occurrence frequency of marine accidents (ship collision accident, ship grounding accident, ship capsizing accident, ship flooding accident). Questionnaire surveys to captains and navigators were performed for the estimation of human error probabilities and occurrence probabilities of navigation conditions, and valuable data in maritime field were collected. Occurrence probabilities of events peculiar to marine accidents are estimated by utilizing maritime data and methods used in marine field. Risk control option (RCO) was evaluated by the developed event tree, and effective RCO was identified as "navigation support system".

KEY WORDS: Event tree analysis, Marine accidents, Collision accident, Grounding accident, Capsizing accident, Flooding accident, Human error, Questionnaire survey, Risk control option, FSA

INTRODUCTION

The concept of the "Design for Safety" has been advocated among International Maritime Organization (IMO) and European Countries and is growing into a substantial surge to address ship safety cost-effectively.

For the establishment of safe sea navigation, IMO has adapted many international conventions, such as SOLAS, MARPOL. In March 2002, IMO has approved Guidelines for Formal Safety Assessment (FSA) (IMO (2002)), which is a rational and systematic process based on the probabilistic approach for assessing the risks associated with shipping activity and for evaluating the costs and benefits of IMO's options for reducing these risks. FSA can be used as a tool to help in the evaluation of cost-effectiveness for a new design of safety equipment or safety system.

Member governments of IMO have already made many FSA studies and reports of FSA have been submitted to

IMO. They are discussed at IMO committee and utilized for legislative process.

The National Maritime Research Institute also has been conducting researches relating to FSA. Under such a background, the Shipbuilding Research Association of Japan organized the Research Panel No.49 to correspond to IMO's FSA and to develop methodology to apply PSA to maritime field under the supervision of Professor Hiroyuki YAMATO, the University of Tokyo.

As one activity of the Research Panel No.49, the occurrence frequencies of ship accidents (ship collision accident, ship grounding accident, ship capsizing accident, ship flooding accident) were estimated by event tree analysis (Matsuoka et al. (2004)). In this paper, the procedure to evaluate the occurrence frequencies and the main results are presented.

ANALYSIS PROCEDURES

The procedure of the present analysis is as follows;

- (1) to investigate the report of the Marine Accident Inquiry Agency, Ministry of Land, Infrastructure and Transport of Japan,
- (2) to set up scenario of ship accidents based on the actual previous accident cases,
- (3) to express the above scenario in the form of event tree,
- (4) to carry out quantitative analysis of the event tree.

Occurrence probabilities of events (headings) in the event tree were estimated by fault tree analysis, which is mainly adapted to mechanical system failures.

With regard to maneuvering error (Human factors) and navigation conditions, we have collected expert's opinion by questionnaire surveys to captains and navigators.

We considered mainly 199GT or 499GT domestic cargo vessels in generalizing accident scenarios.

ACCIDENT SCENARIOS

Collision Accident

With the investigation of the report of the Marine Accident Inquiry Agency (MAIA (1990), MAIA (1992)),

we deduced three situations which result in collision accidents, (a) two ships are on a collision course, (b) one ship suddenly changes its direction during two ships sail side by side, (c) attraction force is generated between two ships during they sail side by side.

In the present analysis, case (a): two ships are on a collision course, is taken as an initiating event, and the following scenario is identified as a generalized scenario leads to collision.

Two ships are on a collision course

- Environmental condition → Navigation condition
- Failure of observation instrument → Observation error
- Recognition error → Communication between two ships
- Planning error of avoidance → Execution error of avoidance → Failure of navigation instrument
- Collision accident

Grounding Accident

The report of the Marine Accident Inquiry Agency shows us that grounding accident, stranding accident and single collision accident are brought by similar causes. So, we analyzed all three accidents together, and identified the following seven generalized scenarios leads to these accidents. In this case, we could not consolidate accidents in one generalized scenario.

- (1) Mooring → Start of drifting → Grounding
- (2) In navigation → Encounter with other ship(or with fish netting) → Course change → Identification of the position/Recognition of danger → Failure → Grounding
 - Failure to return original course → Grounding
- (3) In navigation → Go off course → Grounding
- (4) In navigation → Failure of position identification
 - Keep unidentified → Pass the course change position → Grounding
- (5) In navigation → False recognition of position
 - Keep false recognition → Pass the course change position → Grounding
- (6) In navigation → Drowse
 - Pass the course change position → Unawake → Grounding
 - Awake → False recognition of position → Keep false recognition → Pass the course change position → Grounding
- (7) In navigation → Dangerous water area
 - Careless judgment → Grounding

Capsizing and Flooding Accidents

For capsizing and flooding accidents, we have to consider the adequacy of beforehand preparation. We have to also consider multiple scenarios for covering many kinds of "capsizing and flooding" accidents. Scenario 1) is complicated, and is divided into two parts. The first part is preparation before start. In the second half part, intrusion of seawater is considered.

- 1) Design & Manufacturing → Affirm Stability by calculation → Affirm Stability by test → Weather condition, Swell → Acquire weather information

- Judge the weather → a) Mooring, b) Sailing
- a) Mooring → Preparation for mooring → Stay of crew Patrol → Hatch condition → Condition of door way of living space → Seacock → Sea suction valve
- Check → Inflow of Sea water → Flooding/Capsizing
- b) Sailing → Preparation and check → Loading operation → Excess loading → Judge the loading condition → Big wave/Swell → Shipping water
- Flooded sea water → Failure of drainage pump
- Main engine stops → Hatch condition
- Collapse of cargo → Crane turning
- Stability condition → Flooding/Capsizing
- 2) Bad constriction of valve → Loose by vibration → Fall away → Inflow of Sea water → Sinking
- 3) Mooring → Drift motion → Misjudge → Heeling → Sea water through drain hole → Sinking
- 4) Discharge of bilge → Another duty → Presume sea suction valve is closed → Not confirm the valve state → Failure of check valve → Inflow of Sea water → No watcher → Sinking
- 5) Opening → Rain water → Plugged drain hole → Strong wind → Heeling → Sea water in pour → Sinking
- 6) Collapse of cargo during loading → Heeling → Sea water in pour → Sinking

EVENT TREE CONSTRUCTION

Based on the accident scenarios, event trees are developed. Event trees are constructed as possible as simple and general. The time length, in which the trees cover, is one voyage, which means a sailing between a port to next port.

As an example of constructed event tree, figure 1 shows the event tree for the first part of scenario (1) in "capsizing and flooding accidents".

QUANTIFICATION OF EVENT TREE

To estimate branch probability at each heading of ET, it is necessary to quantify failure probabilities of navigation instrument, occurrence frequencies of navigation conditions, and human error probabilities under specific conditions.

We have used fault tree analysis for the estimation of the occurrence probabilities of instrument failures or some activities. Failure probabilities of mechanical components are deduced from failure data in maritime field, called "SRIC" (Kiriya (2000)), collected by Ministry of Land, Infrastructure and Transport of Japan. The SRIC data base system collects failure data of all kinds of components and equipment on 265 ships, from 1982 to 1999. Its data number is more than 110,000. Human error rates are estimated by THERP (Swain and Guttman (1983)) in the present analysis.

We have also used expert's opinion for the estimation of human error probabilities (error during maneuvering) and occurrence probabilities of some specific navigation conditions. We have made questionnaire surveys to captains and navigators. Question items are set relating to the headings in the event trees, and question sheets are

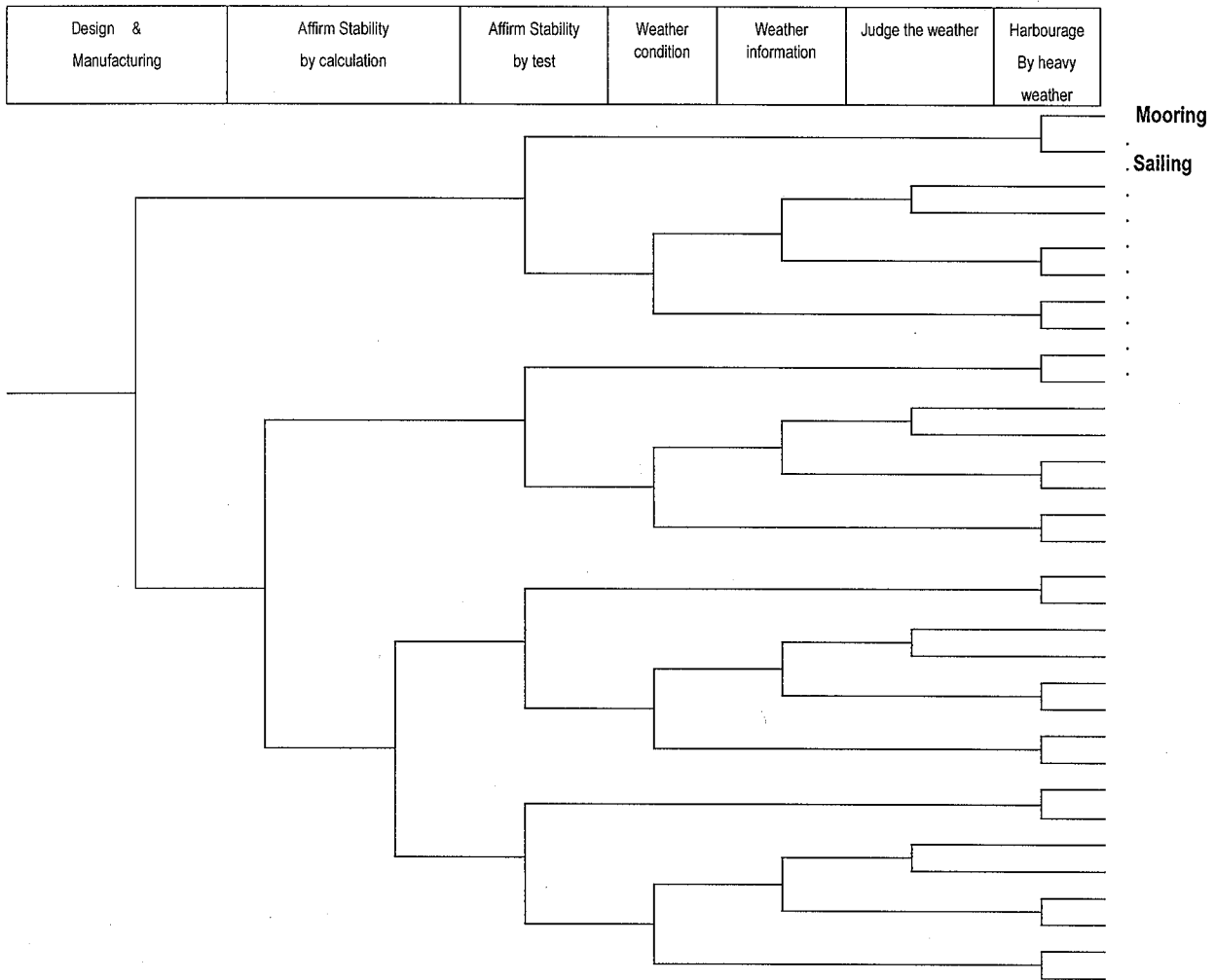


Figure 1 Event tree for the first part of scenario (1) in “capsizing and flooding” accidents.

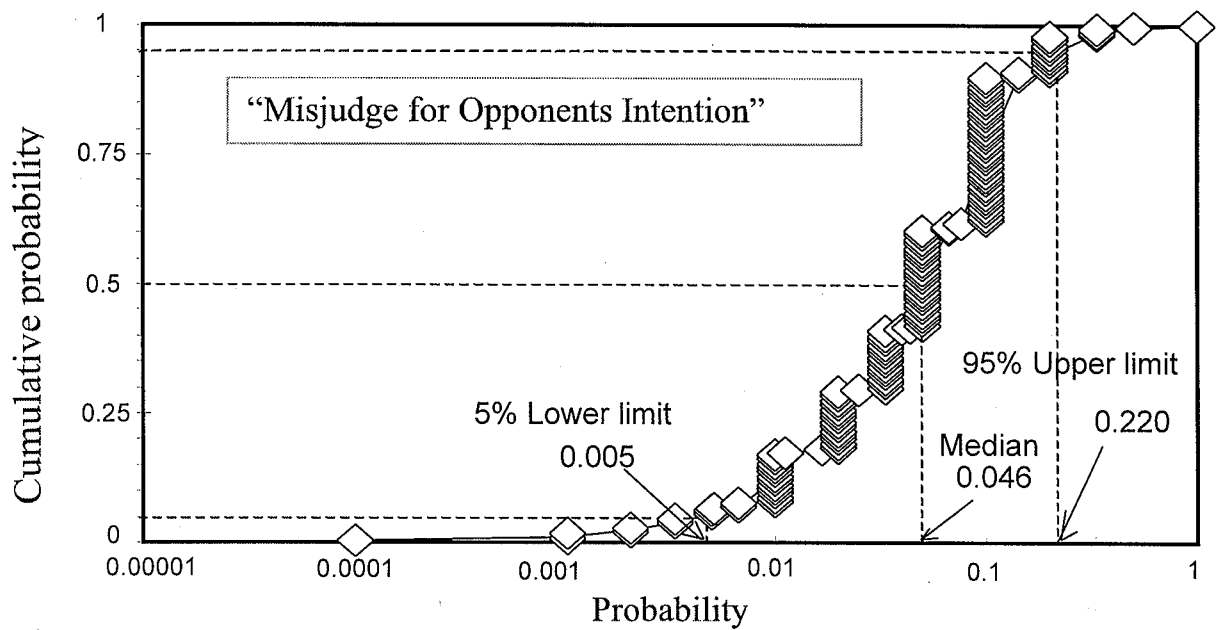


Figure 2 An example of the data obtained by questionnaire surveys.

delivered to district transport bureau in all over Japan. We have made these questionnaire surveys for three times, and received nearly 1000 answers. All the answers are converted into probability values and lined up from small to large as shown in figure 2. From the data, 5% lower limit, median and 95% upper limit are deduced. We have used median value as the estimated human error probability or occurrence probability of navigation condition. We have collected data for 36 items of human error and navigation condition.

The event trees contain events peculiar to marine accidents. For the estimation of the occurrence probabilities of these events, we have utilized maritime data and methods used in this field. The following sub sections explain some of them, as examples.

Probability of Shipping Water and Big Wave

Probability to encounter shipping water is calculated by a prediction method utilizing a joint frequency table for the significant wave height and the mean wave period. The statistical wave data at two regions near Japan are used for the analysis (indicated by arrow in figure 3). The results are 3.4times/voyage (weather condition of significant wave height is less than 3.75m) and 120times/voyage (weather condition of significant wave height is more than 3.75m).

Probability to encounter big wave is calculated in the similar way with the assumption that height of big wave is 1.5 times of freeboard. The results are 0.01 times/voyage (>3.75m) and 3 times/voyage (3.75m>).

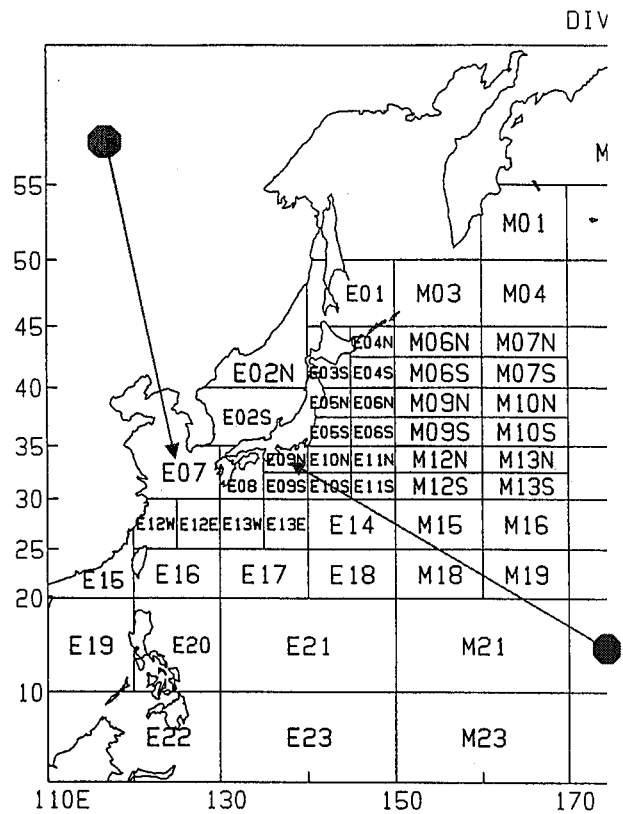


Figure 3 Regions used for wave height analysis.

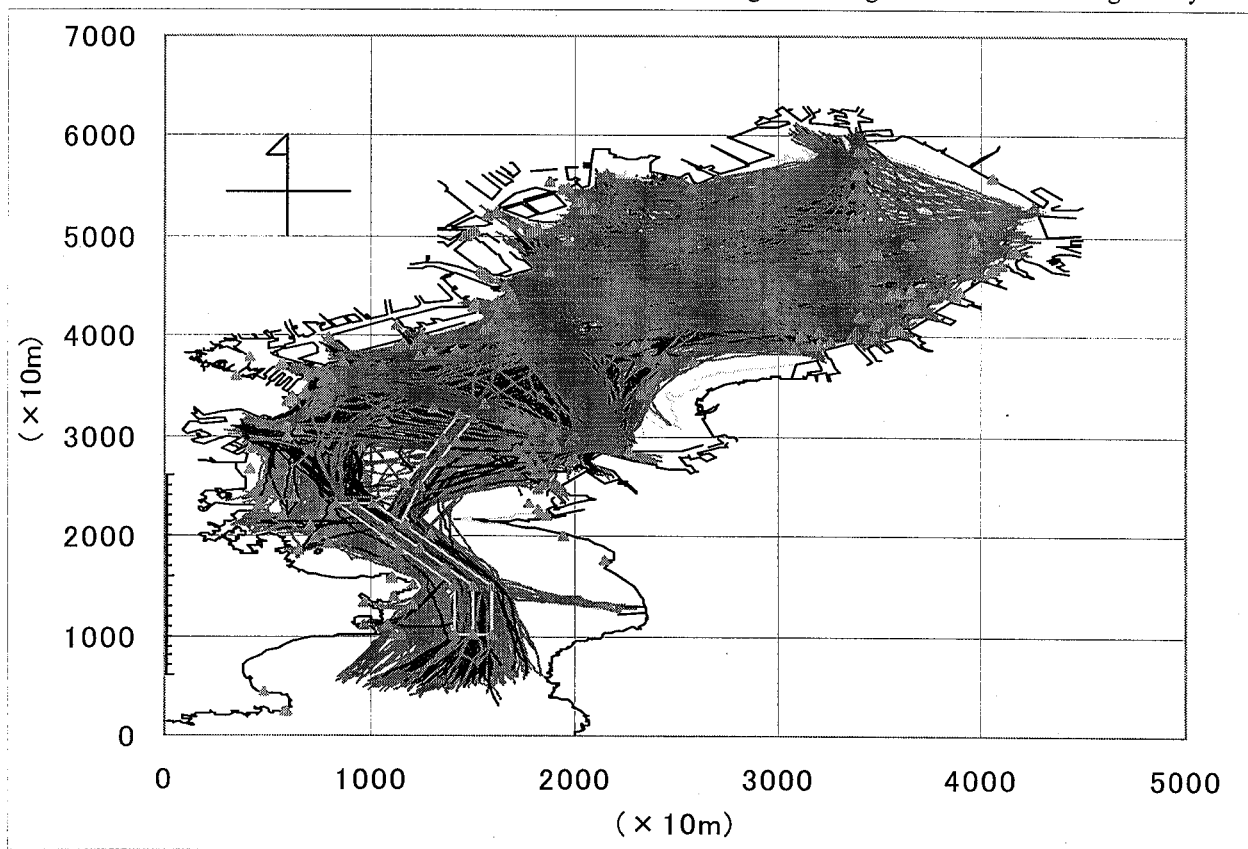


Figure 4 Records of ship routes in Tokyo bay.

Probability to Encounter Shallow Waters

We have collected water depth data of Tokyo bay (figure 5) and records of all the ship routes during two days in Tokyo bay (figure 4). Then, it is examined whether ship will ground on seabed or collide with coast if ship takes the straight course from any point on the ship routes.

Geometrical relations between ship route and shallow waters are shown in figure 6 as one model example. The

grounding probabilities are calculated by the angles cover the shallow waters and distribution of ship direction.

The grounding probabilities are 0.012 and 0.045 for 3 minutes and 10 minutes continuous straight ship movement, respectively. And the collision probabilities with coast are 0.024 and 0.178 for 3 and 10 minutes continuous straight ship movement

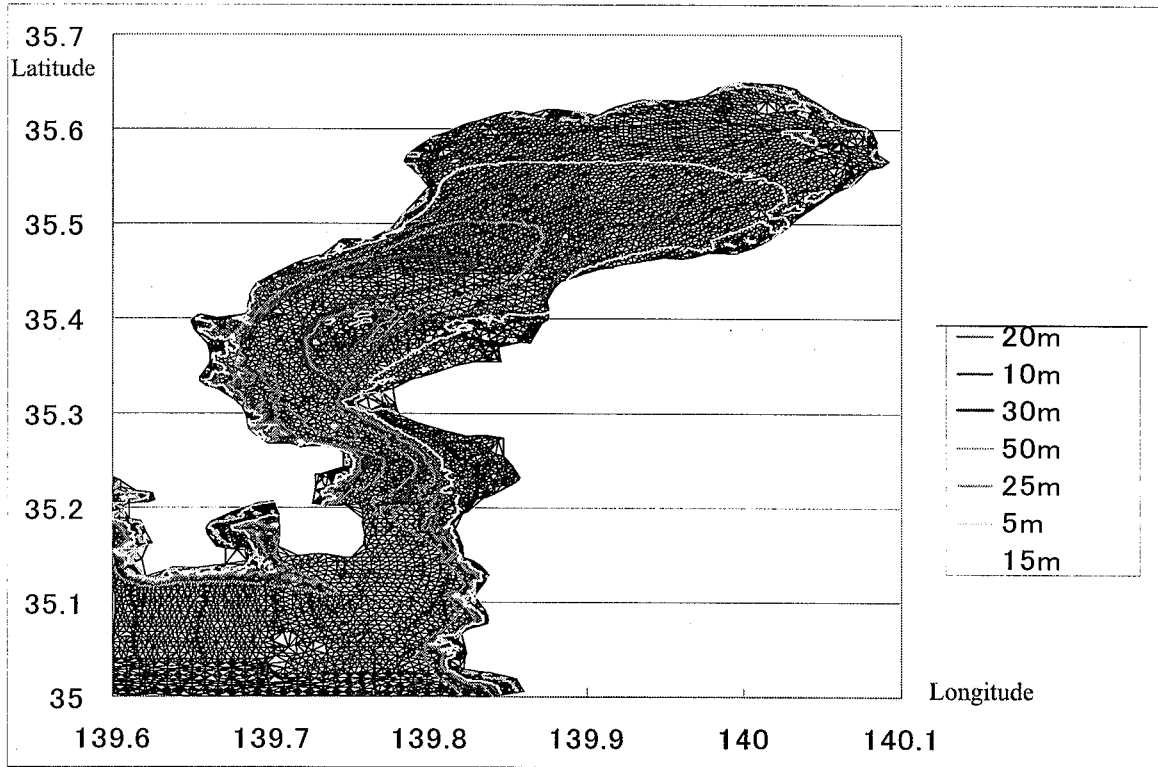


Figure 5 Water depth data of Tokyo bay.

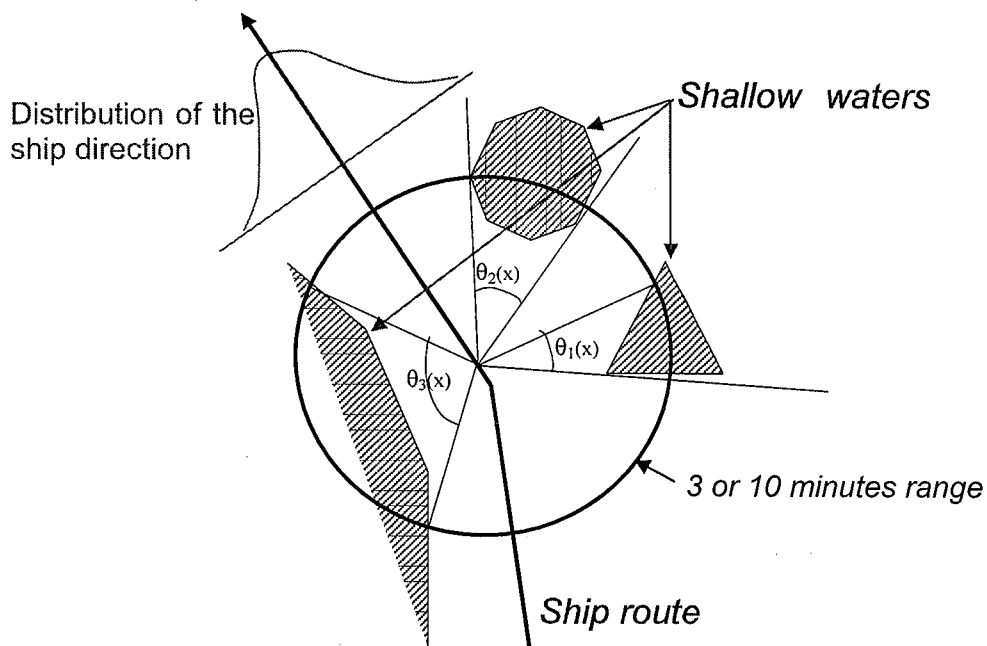


Figure 6 Relations between ship route and shallow waters

Water depth data are also obtained for the Osaka bay, Seto inland sea, Kanmon channel. Records of ship route at Akashi strait are collected and same estimation has been made for the grounding probability at Akashi strait.

RESULT OF EVENT TREE ANALYSIS

The event trees were quantitatively analyzed based on the data established in the previous sections. Numerical calculation was performed by using an event tree analysis tool "MSET(Marine Safety evaluation by Event Tree analysis)", which has been developed at the National Maritime Research Institute.

Analysis results showed us that the collision frequency is 1.31×10^{-3} /voyage, grounding frequency is 1.96×10^{-4} /voyage and capsizing/flooding frequency is 1.64×10^{-5} /voyage. These values are compared with the statistical accident data collected by Japan Coast Guard (JCG). Actual statistical data are almost the same order to the estimated values by event tree analyses.

RISK CONTROL OPTION

For the increase of safe sea navigation, many kinds of navigation support systems are considered. The event trees developed in this study can be used for quantitative assessment how the new support systems are effective for the improvement of safe sea navigation.

Combination of means of controlling a element of risk (Risk Control Measure) is called Risk Control Option (RCO) in FSA. Many RCO candidates have been quantitatively evaluated by the event tree.

It has been identified that most effective RCO for collision accident is navigation support system which is composed of man-watching-system, automatic identification system (AIS), electric chart display (ECDIS), automatic bearing system, and GPS.

CONCLUSIONS

The occurrence frequencies of marine accidents were estimated by event tree analysis in the FSA framework.

For the estimation of human error probability and occurrence probabilities of some specific navigation conditions, we have made questionnaire surveys to captains and navigators, and valuable data in maritime field were collected.

It is also discussed the methods to estimate occurrence probabilities of events peculiar to marine accidents.

Risk control options (RCOs) have been evaluated by the developed event trees, and effective RCO for collision accident has been identified as "navigation support system".

Further researches are planned to establish more consistent framework to probabilistically assess the safety of ship navigation (FSA).

FSA results represent a Risk-based optimization study in the development of the Rules. The full benefit of FSA will appear in case where a large number of RCOs are compared and ranked. The cost effective RCOs should be recommended for the installation of a new safety equipment

or system. FSA is highly technical and complex, and requires much effort. But it does offer a means of escaping from the dilemma of the past in which action was too often put off until something went wrong - with the result that the actions were taken often owed more to public opinion and political considerations than to engineering standard.

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