Evaluation of Navigators' Performance Shaping Factors in Marine Incidents

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Abstract

This article discusses progress in the development of an incident investigation system to improve maritime safety management. The authors designed a questionnaire about marine incidents and the conditions of navigators' Performance Shaping Factors (PSF) in those incidents. The results revealed important dangerous relationships between unsafe acts and PSF, through analysis by a contingency table and stratification of the contingency table by a third factor, step by step according to cause and effect. The results showed that an unsafe delay in the recognition of danger was strongly affected by 5 factors directly, 13 factors indirectly, and some background factors. Mistakes in decision-making were affected by 5 direct factors, 19 indirect factors, and a few background factors. The frequency of these unsafe acts ranged from 11 to 40%, depending on the combinations of the factors. The particularly influential combinations of factors contributing to delays in danger recognition were 'Enthrallment' with 5 indirect factors and 'Drowsiness' with 5 indirect factors. Those of mistakes in decision-making were 'Drowsiness' with 10 in direct factors and 'Unexpected' with 5 other factors.

Introduction

The oil tanker *Exxon Valdez* grounded on Bligh Reef off Alaska in 1989 and spilled a large amount of crude oil, polluting the pristine Prince William Sound. It was one of the most highly publicized accidents in the history of marine pollution. This oil spill highlighted various safety issues in maritime traffic and led to studies by the International Maritime Organization (IMO), which governs international maritime traffic. Until now, the IMO has adopted a number of specific safety measures but has failed to come to a conclusion concerning matters of seafarers' fatigue. Its failure to reach a consensus on this issue is mainly attributable to a lack of a clear understanding of the relationship between the degree of fatigue and the occurrence of marine accidents, or of what contributes to the fatigue of a seafarer and to what degree.

In order to clarify such matters, the IMO adopted resolutions to standardize both a method to investigate marine accidents and international cooperation in such investigations, with special emphasis on human factors. These resolutions have expanded the scope of investigation to include hazardous events that might have led to casualties (IMO,1997), and they require investigation on safety management (IMO,2000). The investigation needs various point of view; Reason's defense model (Reason 1994) and Hawkins' SHEL model (Hawkins 1992). Every country is currently studying specific ways to investigate marine incidents. In the private sector, various incident investigations have already been conducted. It is difficult to use their results for public purposes, however, since they are not standardized. It is therefore necessary to develop a practicable, standardized method to investigate marine incidents and a method to analyze such data for safety measures.

Against such a background, we have developed a method to investigate human factors in marine incidents and to analyze the collected data. In order to clarify the factors that contributed to actions (performance shaping factors or PSF; Miller, 1987), we have devised an investigative method for navigators who have experienced marine incidents. This method includes a checklist to investigate not only events but also the PSF involved, i.e., the conditions of the navigators, facilities, environment, and management (Murayama,1999).

The analysis of collected data concerning collision incidents clarified problems in the recognition of a dangerous positioning of a ship relative to another ship, particularly with regard to the potential for collision. In addition, a contingency table, an extremely fundamental methodology, revealed important relationships between the events and their causal factors, which we call direct factors (Murayama, 2002).

This article reports on a method to identify the indirect factors that influence the direct factors in maritime incidents, as well as background factors that influence the indirect factors. The article provides a method to evaluate the influences that cause the events.

Concept of the methodology

Links between events and factors: Safety measures to prevent accidents are derived from investigations into the causes and contributing factors of accidents that have already occurred. For such investigations, fault-tree analysis (FTA) and event-tree analysis (ETA) are used, following the time sequence or causal sequence of events and factors. FTA and ETA are rather easy to structure when the order of operations, or the difference between normal and abnormal states, is clear, as in the case of industrial plants. But both types of trees become complex and vague when operations greatly differ and/or multiplex selections are possible, depending on external conditions.

Human action, in particular, is affected by numerous factors and the relationships among them. For example, when two ships encounter each other in marine traffic, they can select between two maneuvering actions: (1) if there is ample distance, the ship can dissolve the positional relationship before marine traffic rules bind it to a specific course; or (2) when the distance is not ample enough, the ship can avoid collision by following marine traffic rules. This selection is linked to several PSF: the sea area, traffic, the navigator's cautiousness, time pressure, etc. It is difficult to construct a tree that links these factors.

However, bad PSF conditions do not always result in unsafe acts or incidents, because ordinary working conditions vary. Likewise, although there are various unsafe actions and conditions in PSF, a factor is not necessarily related to an unsafe action, or an unsafe action to an incident. Consequently, we need to evaluate the influence of PSF on unsafe actions and incidents by comparing the frequencies of unsafe actions in every type of incident and under each PSF condition.

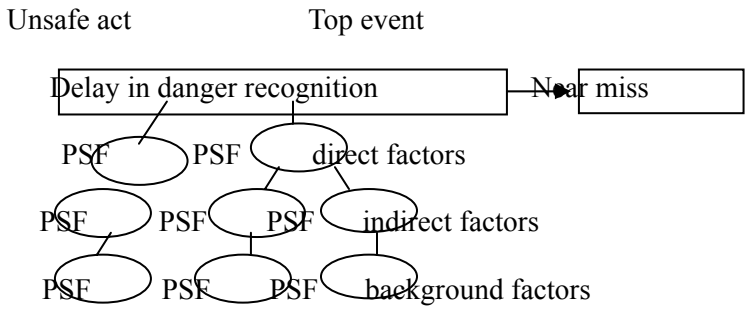

Figure 1 - Links between events and PSF

Relating factors to problems: To estimate the influences that PSF and PSF conditions have on human actions, psychologists and sociologists often rely on a coefficient of correlation matrix or a score of a principal component analysis.

These indexes mainly emphasize deviations and the numbers of subjects. They disregard small numbers of cases as special unsafe acts and discount PSF as important components of an accident. Furthermore, the value of a principal component analysis changes every time a different combination of PSF is studied.

The simplest approach is the use of a contingency table, which reveals…categories, combined with a specific method to show a one-to-one correlation between an event and a factor or between factors. The odds ratio of a contingency table based on the number of cases is not much affected by the total number of cases. For these reasons, it is easy for a businessperson to use the table and to understand the results. This approach is effective for revealing relations when the number of cases is small. In addition, a contingency table created by combining other factors allows us to examine correlations with multiple factors.

Procedure of the method

Target of analysis: The first step in the analysis is to categorize the problem into an incident type, based on the frequency distribution of similar incidents. We also clarify the PSF involved in the incident; we identify these direct factors by a contingency table between the problem and the PSF.

Factors involved in the target: Next we clarify what we call indirect factors, which are the PSF that contribute to direct factors. For this, we use a contingency table between the direct factors and the PSF. Then, in turn, we clarify the background factors, which are PSF contributing to the indirect factors. For this we use a contingency table between the indirect factors and the PSF. These relations are selected based on an odds ratio of over 1.3 and are confirmed by Yule's coefficient of association.

Effects of third factors: Some relations may be strongly affected by other factors (third factors). For this reason, when we evaluate one-to-one relations between a problem and the factors, it is also necessary to consider the impact of third factors on those relations. The contribution of third factors to a problem can be evaluated by stratifying a contingency table by the third factor between the problem as a dependent value and the factor as an independent value. When we consider the occurrence of a problem, two contingency tables between dependent values and independent values are described as the two lines in the Figure 2.

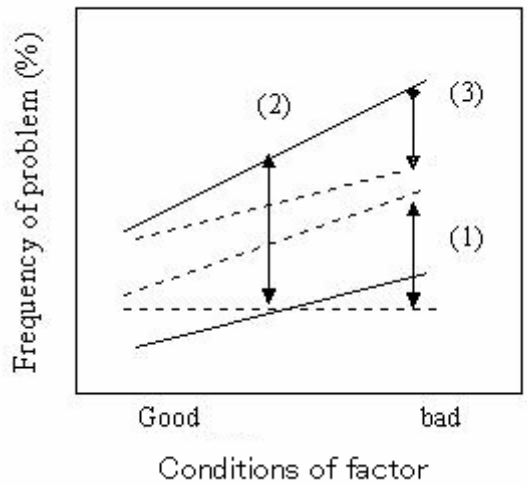

Figure 2 - Evaluation indexes of third-factor effects

When the effect of the independent value is large, the inclination of the two lines is large. In order to neglect the influence of third factors in the relation, we consider that the inclination of the middle line between the two lines is the basic component representing the direct effect ((1) in the figure).

When the two lines diverge to the upper and lower sides, it means that a third factor has a large influence on both lines. We consider that the gap in the frequency of the dependent value between the of the lines is a weighting component representing a separation effect ((2) in the figure).

When the line segments cross each other, it means there that a third factor is causing a large difference between the groups. We consider that the difference between the inclinations of the lines is a cross component representing the interaction effect ((3) in the figure).

We disregard any relations that have differences of less than 5 percent in the frequencies of problems of dependent values between the divided groups.

The relations between incident events and PSF conditions become complex and redundant according to progress analyses into the factors.

Order of cause and effect: We coded factors into two types in order to reduce the need to analyze relations. One type of code is that of the causes and effects of the events and of the PSF. These include: (1) matters concerning an unsafe act that occurred during an incident (2) matters directly related to those acts (direct factors), (3) matters related to those direct factors (indirect factors), and (4) matters in the background (background factors). This code is used to create a set of factor chains showing causal relations, as in a fault tree.

The other types of codes are of the fields of safety measures to concentrate on the practical use of the results. This code are for PSF and for SHEL that are categories of safety management.

Collecting data

The data of this report were in the form of answers to our questionnaire about situations surrounding marine incidents and the PSF conditions of navigators who have experienced a dangerous situation. The questions were 100 items: 55 main items included an additional 45 sub-items for PSF in seven sections. The answers were in the forms of numerical values and adjectival scales. For example, the value of the recognition time of danger was "the time from the moment when danger was first recognized until the most dangerous distance to the obstacle was reached"; relations to an obstacle ship were "crossing from the right", "crossing from the left", "overtaking", or "facing"; and the fatigue scale ranged from "normal" to "fairly poor", "poor", and "very poor".

The subjects of these investigations were the bridge navigators of 2,351 coastal ships belonging to 167 companies involved in domestic maritime transport. The questionnaires were mailed to the captains and distributed to the subjects through the safety managers. After filling out and sealing the questionnaires anonymously, the subjects submitted them to the captains, who forwarded them to the respective safety managers. The sealed questionnaires were then returned to the researchers. We got 2615 responses about incidents from 2831 respondents on 1274 ships (45% of subject ships).

Results

Two specific problems emerged from the frequency analysis. One was that by the time two ships become aware of each other, the recognition of the danger of collision comes too late, in many cases, for the appropriate action to be carried out. The other was that the ship's decision-making in relation to the other ship's movement was unsuitable.

It is possible to grasp the delay in recognizing a danger from answers to questions contained in the checklist, specifically those concerning the time that elapses from the recognition of a danger to the occurrence of a most dangerous situation (danger recognition time). Close to half of the respondents answered 'less than 1 minute'. This is not enough time for a general merchant ship engaged in domestic trade to change her course by 90 degrees. This is regarded as a delay in recognizing a danger.

Mistakes in decision-making can be identified from answers to questions concerning the position of a navigator's own ship in relation to that of another ship. A dangerous situation, in which another ship crosses the navigator's course from the right, is a situation in which the navigator, in guiding a give-way ship, has failed, and it is regarded as a mistake in decision-making on that navigator's part. Conversely, if a dangerous situation has occurred and the navigator's ship is a stand-on ship, the other ship has made a decision-making mistake. The frequency with which a navigator's own ship acted as a give-way ship was 30 percent.

In order to study measures to prevent collision by these problems, we clarify whether or not factors contributed to or facilitated the occurrence of such unsafe acts, and if so to what degree.

Delay in recognizing danger: Problems in recognizing danger; either under 1 minute or over 1 minute from initial recognition until the most dangerous moment passes, was related to 21 direct factors**.** These 21 direct factors were related to 353 indirect factors; the number of the factors was redundant total of them. These 353 indirect factors were related to 4991 background factors. Excluding the relations of the factors that were inversions of cause, the total number of combinations was 1008 cases. We evaluate effect of indirect factors; a separation effect and a cross

component between groups of indirect factors, and selected 170 combinations for PSF of live-ware as SHEL model. The difference in frequency described in this table is the difference in the occurrence of the incident by delay in recognizing danger, the difference between maximum frequency and minimum frequency of the unsafe act that have occurred, and combining direct factors and indirect factors.

Table 1 lists 5 direct factors for PSF in the combinations relating to other factors. The enthrallment relates to 5 indirect factors and many background factors. The other differences of the combinations are from 11 percent to 40 percent. relations between differences of the relations between the combinations were from 16 percent to 33 percent. The background factors expand the differences.

Table 1- Difference of frequency of unsafe act as delay in danger recognition
(unit: %)

Direct factor	Indirect factor	Frequency of delay of danger recognition		
		Min.	Max.	Difference
Enthrallment	Overcrowded schedule	44	64	20
	After strain	45	72	27
	Straying mind	43	69	26
	Anxiety for private life	39	79	40
	Anxiety for work	44	70	26
Unexpected	Anxiety for private life	39	57	18
Fatigue	Bad physical condition	39	50	11
	Anxiety for private life	36	56	20
Drowsiness	Overcrowded schedule	41	57	15
	Bad physical condition	38	56	18
	Straying mind	39	63	24
	Age	32	58	26
After strain	Ability of work	43	61	18

Decision-making: Seven factors were related to problems in decision making while under duty to avoid another ship or to maintain the course of one's own ship. This unsafe act related to 30 direct factors, and the factors were related to 642 indirect factors; total number, and related to 8816 background factors. There were 1055 combinations of the factors selected according to order as cause and event. Combinations of factors of PSF for live-ware were 74 cases. Selected combinations by considering causes of factors for unsafe act are in the table 2. These combinations related to many background factors, which expand the differences.

Value of the tables: Much difference of frequency of every combination in above the tables means indexes of efficiency of safety measures. If we change worse conditions of the factors of the combinations, we can expect to reduce occurrence of unsafe acts by the difference. However there are many complicated factors, and false relations as cause and effect, we have to examine relations that are revealed by this analyses.

Table 2 - Difference of frequency of the unsafe act as mistake of decision-making.
(unit: %)

Direct factor	Indirect factor	Frequency of miss of decision-making		
		Min.	Max.	Difference
Unexpected	Maneuvering style	37	53	16
	Attitude to obstacle	33	58	25
	Many fishing boats	32	65	32
	Rare meeting ships	40	73	33
	Age	37	65	29
Drowsiness	Age	37	64	27
	Job ranking	37	65	28
	Communication of crew	39	62	23
	Ability of crew	40	64	24
	Job ranking	30	62	32
	Type of obstacle	35	53	18
	Methodical	38	58	20
	Carefulness	41	67	26
	Team work	40	62	21
	Maneuvering style	38	63	25
Straying mind	Type of ship	30	61	31
	Size of ship	36	75	39
Anxiety for work	Number of deck crew	36	52	16
Time pressure	Type of labor contract	39	54	15

Conclusions

The method for analyzing navigators' performance shaping factors in marine incidents of collision and grounding is to first identify correlated factors according to items on the incident questionnaire, by employing a contingency table and calculating the odds ratios. The second step of the analysis is to delete certain combinations of factors based on the order of the factors in cause and effect. The third step is to neglect the relations affected by third factors or those affected by third factors that do no affect the problem. Finally, we use the obtained combinations of factors to compare the frequencies of incidents involving combinations of factors selected in the field of safety measures.

In collision incidents, unsafe act as delay in danger recognition was related to 5 factors; navigators' enthrallment, unexpected for ship motion, fatigue, drowsiness and past strain. These direct relations are indirectly affected by 13 other PSF and many background factors. Maximum difference of the frequencies of the unsafe act was 40 percent. In the case of a mistake in decision-making, this unsafe act was directly related to PSF; unexpected for other ship's action, Drowsiness, Straying mind, Anxiety for work and time pressure. These relations affected by other PSF, and maximum difference of frequency of the unsafe act was 39 percent.

This method reveals a tree that simply arranges combinations of many dangerous events and their influencing factors, and the contingency tables show differences in the frequency of problems

among combinations of related factors. A businessperson would be motivated by this analysis, since it reveals the apparent structure of unsafe factors and the effects of those factors on dangerous events.

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