Quantitative Model of Collision Causes in Japan

Haryanti RIVAI *, Kohei HIRONO ** and Masao FURUSHO ***

Abstract

Sea route around Japan has high traffic density. The ratio of ship's collision is 62.6% represented from the total kind of marine accidents since 1998-2008 (Marine Accident Inquiring Agency(MAIA),Japan). Measuring for risk minimization, such as the quantitative method, which evaluated with respect to their performance relationships between man, machine, media and management, is still very rarely used. Furthermore, the development of quantitative model in a simple and sequential way would be helpful to explain and predict phenomena in the accident to the specific problems that are used. As a result the probability relationships between causes of collision in the term maritime transport systems have been estimated.

Keywords: *marine casualty, causes of collision, maritime transport system, human element, quantitative model*

1. Introduction

1.1 Backgrounds

Sea routes around Japan have high traffic density. The collisions of ships represented 62.6% of the total kinds of maritime accidents in the period 1998-2008 (Source: by Marine Accident Inquiring Agency (MAIA),Japan)^[1]. The Japan Marine Accident Inquiry Agency (JMAIA), since October 2008 merged with the ARAIC (Air and Rail) and now known as the Japan Transport Safety Board (JTSB), is the Japanese government agency that investigates causes of accidents on ships.

According to maritime accidents statistics, the collision is one of the casualties occurring at sea. Accidents, including collisions, still occur at a high rate every year; even when competent navigators are controlling the ship. Dependence on human performance in the motion and safety of the ship is very important. Written studies^[2,3,4], of research into the maritime casualty area reveal that 96% of all collisions can be attributed to the human element.

1.2 Objectives

The objectives of this study are to analyze the

human element as an indirect contributory cause of collisions as variable X1-X29 and to analyze the relationships between elements in the maritime transport system considering the factors of man, machine, media and management. Considerable progress has been made, and some frequently occurring unsafe acts in collisions have been roughly identified; collision risk incorporating human factors has been estimated quantitatively; navigators' customary behavior in collision avoidance has been mathematically modeled.

2. Human Element in Collision Accidents

2.1 Human Element in Navigation Systems

The maritime transport system is a very complex and large-scale socio-technical environment (STE) system comprising human and man-made entities that interact with each other and operate in a physical environment.

The main elements of the system are objects of transport, infrastructures and facilities, which are linked by the information system and transport-related activities^[5]. The human element is a very important element that designs, develops, builds, operates, manages, regulates and interacts with other elements

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of this system. These elements are embedded in very complex, interdependent, and dynamic relationships. The IMO Assembly adopted resolution A.850(20)^[6], which interpreted the meaning of the term “human element” as “a complex multidimensional issue that affects maritime safety and marine environmental protection”; it “involves the entire spectrum of human activities performed by ship’s crew, shore based management, regulatory bodies, recognized organizations, shipyards, legislators and other relevant parties”. It means that the human element is a component of a system.

The navigation system is established as a maritime safety system with three subsystems: operator, ship and environment. The relationships among the three subsystems are shown in Fig. 1. Apparently, this system is structured from the point of view of the ship operator which means navigator.

Fig.1 Relationship among operator, environment and ship^[7].

2.2 Human Element in Maritime Transport Systems

The maritime system is a people system (as shown in Fig.2). The technology interactions on people include perception, decision-making, and performance; the environment interconnections on people include physical and mental performance, fatigue, risk taking; the organization interconnections on people include fatigue, knowledge and skill, and work practices. In this system people (man) includes captain, navigator, ship’s crew, pilots, dock-workers, VTS officer, operators and quarantine, customs and immigration officers. Technology (machine) is the interconnections on people include the design of the ship and the equipment of the ship that may have some kind of impact on people’s performance and

perception. Environment (media) means interconnections on people include weather environment, geographical, physical work environment and the regulatory, economic climates. Organization is (management) interconnections on people include and includes crew organization, company policies and the regulatory governance. Each of these system structures has its own characteristics. Some of them cover a wider scope, but people, ship, and environment are common components that they share.

Fig.2 Development of model interconnections between technology, people, organization and environment in Maritime Transport System^[8].

2.3 Methods of Quantitative Model

Many models such as the Swiss cheese analogy model (Reason, 1997), the Bowtie model (Hollnagel, 2008), the FSA (Formal Safety Assessment) (IMO, 2002), FTA (Fault Tree Analysis) and ETA (Event Tree Analysis) techniques, and other models have been introduced or proposed by experts in the fields with no reference to or systematic analysis of empirical data. Accident studies in many domains, including the maritime industry, are firmly rooted in qualitative methods and other summary statistics. The studies are largely confined to a few variables, such as vessel type, and business line, total loss incidents and some categories of accidents such as fire, explosion, collision, and grounding.

The development of statistical methods in a simple and sequential way would be helpful to explain and predict phenomena in the accident to the specific problems that are used when the database is also complete. Measures for risk minimization, such as the qualitative method, which evaluated with respect to

their performance relation between man, machine, media and management is still very rarely used. Concept based on 4M (Man, Machine, Media and Management) factors.

Whereas incident or accident can be prevented when we can maintain the relationship of each element in maritime transport systems.

3. Construction Estimating Causes of Collision Frequency

The focus of this paper is to construct a classification framework for identifying and characterizing human elements involved in collisions at sea. For this purpose, various human element classifications used in different accident reports and databases will be reviewed. Within the MAIA (Marine Transport Inquiry Agency), Japan the data reports are classified under two kinds: accidents, and causes of accidents, at sea.

For these kinds of accidents, the item “collision” under accidents at sea, has the highest percentage of all. The report shows causes of accidents which are most influenced by the human element.

3.1 The Total Number Causes of Collision

The essential attributes and relationships of the variables in the MAIA, Japan database were thoroughly studied. The database contains 29 variables representing the maritime systems and risk elements in complex relationships (see in Table 1).

The total number of variables are taken into consideration and from these data will be designed the new model equation. As the variable ‘event description’ was in text format it was excluded, as in that form, neither summary nor inferential statistics were applicable to it. However, the detailed information on marine accidents that it contained provided valuable insights for conceptual and relation analysis.

In view of the data provided by the report of MAIA, Japan the author has tried to make a simple equation that can ultimately be used to deduce the total number of each variable on the causes of the accident collision in the maritime transport systems.

This equation is

$$\text{Total number of each causes}(X_i) = \sum_j^n F(\text{Event}) \quad (1)$$

Table 1 Causes of collision with Variable X1-X29.

Related human element	Variable	Related human element	Variable
Improper management	X1	Improper ship's speed	X16
Poor repair condition	X2	Not obeying COLREG	X17
Poor preparation for sea	X3	Main engine failure	X18
Improper hydrographic survey	X4	Auxiliary engine failure	X19
Poor selection and keeping	X5	Poor management of lubricant oil	X20
Improper ship handling	X6	Poor management of electrical equipment	X21
Unconfirmed ship's position	X7	Improper handling and other task	X22
Improper look-out	X8	Improper fishing work	X23
Snooze	X9	Poor management of cargo loading	X24
Insufficient maintenance of steering systems and nautical instruments	X10	Inadequate supervision	X25
Poor attention of the meteorology and oceanography	X11	Taking over the watch	X26
Improper anchoring and mooring	X12	Poor management on fire	X27
Inadequate preparation for rough sea	X13	Force majeure	X28
No indication of navigation lights and shapes	X14	Others	X29
Signalling failure	X15		

(Remarks: Bold fonts means remarkable and higher number of causes)

Whereas the total number of each variable on the causes of the accident collision (X_i) which counted of F : frequency each event, where the event is sum of product during n years; j : start and n : end of events

have occurred; by using the equation 1, it can be shown in Table 2 the frequency of collision causing an accident that occurred over an eleven-year period.

Table 2 Total number of causes of collision in period 1998-2008 variable X1-X29.

Causes of collision Related human element Variable	Frequency in each year											Total of number causes
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
X1	5	8	3	2	5	4	4	8	1	14	12	66
X2	1	0	0	0	0	1	3	1	1	5	3	15
X3	0	0	0	0	0	1	5	3	0	0	0	9
X4	1	4	5	3	4	5	3	1	6	3	4	39
X5	3	2	6	6	11	4	7	5	8	5	10	67
X6	21	24	22	15	21	21	11	14	18	21	11	199
X7	13	10	17	17	8	9	11	9	16	9	8	127
X8	441	415	444	457	504	502	417	398	360	358	389	4685
X9	28	31	34	36	38	40	26	36	32	30	39	370
X10	2	1	2	0	0	2	0	1	1	0	5	14
X11	5	9	7	6	10	4	0	8	2	6	5	62
X12	2	3	2	3	1	3	3	1	2	6	2	28
X13	0	0	0	2	0	0	1	0	2	3	1	9
X14	21	30	16	31	21	18	15	13	8	6	10	189
X15	90	89	100	72	83	86	79	99	66	68	63	895
X16	62	47	56	54	5	23	27	42	21	9	5	351
X17	178	194	178	148	164	180	142	150	119	115	115	1683
X18	1	1	1	2	1	1	0	2	0	0	1	10
X19	3	2	5	1	3	2	1	2	1	2	0	22
X20	0	0	0	0	0	0	0	1	1	0	3	5
X21	0	1	0	0	0	0	0	1	2	2	0	6
X22	0	0	2	1	0	0	0	1	1	1	1	7
X23	0	0	0	0	0	0	0	0	0	0	0	0
X24	0	0	0	0	0	0	0	0	0	1	1	2
X25	70	76	68	38	53	45	44	51	43	38	45	571
X26	37	38	26	28	20	17	20	25	18	20	14	263
X27	0	0	0	0	0	0	0	0	0	0	0	0
X28	1	0	0	0	0	0	0	0	0	0	0	1
X29	1	0	1	0	0	1	0	3	4	5	6	21

(Remarks: Bold fonts means remarkable and higher number of causes)

3.2 The Relationships 4M Factors in the Causes of Collision

In mathematics, an element, or member, of a set is any one of the distinct objects that make up that set^[9]. The relation "is an element of", also called set membership, is denoted by the signature $\in$. Writing is

$X \in A$ (2)
means that "X is an element of A". Equivalent expressions are "X is a member of A".

In this paper, the elements covered are four categories relating to the maritime transport system

for the safety known as Man, Machine, Media, and Management. From equation (1) and (2) could be explained in relation to the maritime transport system as

$$X_i \in \{\text{Man or Machine or Media or Management}\} \quad (3)$$

The number of elements in a particular set is a property known as cardinality; informally this is the size of a set. In the above the cardinality of the set for every elements man, machine, media and management are determined from the total number each causes

(Eq.1) and perspective of the causes of induction 4M factors^[8,10].

Table 3 shows the next stage has been done by reconstructing the relationships from the total number of collision in the maritime transport systems, more detailed explanation in section 4.

In condition:

Nine (X8,X9,X14,X15,X16,X17,X18,X25,X26) are variable causes of collision which are independent and higher number of causes.

Four (Man, Machine, Media, Management) are variables in maritime transport system wherein dependency is determined.

Table 3 The relationships 4M Factors with causes of collision in extreme cases

Variable causes of collision	Total number of causes	4M Factors of maritime transport system			
		Man	Machine	Media	Management
X8	4685	●		●	
X9	370	●		●	●
X14	189	●		●	●
X15	895	●	●		
X16	351	●	●	●	
X17	1683	●		●	●
X18	10	●	●		●
X25	571	●			●
X26	263	●			●

(Remarks: Bold fonts means remarkable and higher number of causes)

() Not have relationships between causes of collision and one of 4M Factors)

(● Yes have relationships between causes of collisions and one of 4M Factors)

4. Analysis of Related Causes of Collision in Maritime Transport System

In analyzing the relationships of causes of collision in maritime transport systems (see in Table 3), perspective of the causes of induction 4M factors^[8,11,12] arguments and simple equations (1),(2) have been used. Sources^[11,12,13,14,15,16] are from both printed theories and from opinions of experts, as well as from real accident reports.

Several explanations below are based on the greatest values of the total number that have been obtained in the calculation of Table 3, and are as follows;

Improper look-out (X8). The international COLREGs define, under Rule 5, the criteria for keeping a proper look-out. Look-out is an important element of safe watch keeping, especially when the visibility is restricted and includes look-out by hearing, radar, VHF, AIS as well as by sight. There is no excuse for an improper look-out but there are frequently reasons: lack of support, low discipline, disinterest, carelessness, laziness to name but a few.

Snooze and fatigue (X9) could be due to how the motion of the ocean can affect one's balance, coordination, response time, eyesight, hearing, reflexes, judgment and the ability to enjoy daily work. The combination of wind and waves can cause sea sickness, which will affect motor skills and one's ability to think clearly. However, the main reasons are overwork, under-manning and non-adherence to the STCW Hours of Rest requirements. Operating a boat while fatigued is always a bad idea.

No indication of navigation lights and shapes (X14) because a ship cannot suspend piloting operations when darkness falls and daytime navigational aids can no longer be seen. For purposes of identification, lights have individual characteristics regarding color, intensity, and system of operation. For this reason, aids to navigation are lighted whenever it is necessary. However, its application involves the exercise of special skills and fine techniques, which can be perfected only by experience and careful practice.

Signaling failures (X15). It refers to lack of proper

interpretation about maneuver by the relevant signals on the ship's whistle. It further means any sound signaling appliance capable of producing the prescribed blasts and which comply with the specifications.

Improper ship's speed (X16). One of the factors affecting ship speed is correct operation of controllable pitch propellers. It is possible to operate under different conditions of displacement of ship resistance at the same engine RPM (Revolutions per Minute) and power by varying the pitch of the propeller. Operation of engines fitted with controllable pitch propellers should be in accordance with the applicable NAVSEA Technical Manual and Engineering Operating Sequencing System (EOSS) if applicable.

Not obeying COLREG (X17) can be put down to misinterpretation, even though the rules are quite clear. Ignorance on how to apply them in sea conditions, and plain, deliberate non-adherence when the situation may not be obviously understood, ensures that accidents, close-quarters situations and collisions do occur.

Generally item **“main engine failure (X18)”** because lack of overhauling a cylinder, means lack of a routine periodical maintenance task on a marine diesel engine to ensure that the components of that cylinder have not worn excessively and are fit to continue service. Management of preventative maintenance and inspection work is required to ensure that equipment is capable of operating as designed and to reduce the likelihood of failures in service.

Equipment manufacturers recommend service intervals and procedures for their equipment. If these are not observed, equipment can fail without warning.

Inadequate supervision of work on board (X25), where much equipment and systems are highly specialized, can lead to costly malfunctions. The vessel is only one element of a large project and a disciplined project management approach is required to ensure smooth dovetailing with the overall economics and design plan. Time or cost over runs can eliminate projected margins, making it critical that projects are completed on time with no compromise on cost or quality. Close supervision by qualified experts is therefore of critical importance, right from a vessel's inception on the drawing board, through its sea trials to final delivery.

Inadequate reporting and taking over the navigation, engineering or cargo watch (X26) is due to inadequate shipboard arrangements and managerial planning. The possibility of the officer of the watch being affected by fatigue caused by an excessive workload due to a watch system, which is possibly inadmissible for a vessel of this size and area of operation, as well as the course of the voyage, is excluded from plans.

Figure 3 describes the “relationships causes” of collision in the maritime transport systems. To complete this analysis graphically, the relationships between the causes of collision in the maritime transport system (man, machine, media and management) were reached by inserting the resultant values from the equation (1), (2) in the table 3.

Fig. 3 The relationships causes of collision in the maritime transport system

5. Results

Fig. 3 illustrates the highest influences of the relationships as causes of collision in the maritime transport system. All together the following results can be drawn:

- (1) Relationships between man and media influenced by variable X8 (improper look-out), and X9 (snooze).
- (2) Relationships between media and management influenced by variable X16 (improper ship's speed), X17 (not obeying COLREG) and X18 (main engine failure).
- (3) Relationships between man and machine influenced by variable X14 (no indication of navigation light and shapes) and X15 (signaling failure).
- (4) Relationships management influenced by variable X25 (inadequate supervision), and X26 (inadequate report).

6. Considerations

From the results that have been obtained, this paper argues that:

- (1) Complicated Environment. The most significant relationship caused by collision accident on board, is the difficulty of fixing her position based on the complicated geographical and weather characteristics in Japan.
- (2) Good Navigator. The good navigator should keep his/her ability for utilizing and controlling navigation equipment for the purpose of preventing incidents and accidents.
- (3) Effective nautical equipment. The Automatic Identification System (AIS) is a great tool which can detect a larger number of targets, without considering shadow effect which can prevent a proper look-out. AIS also provides more voyage information for the VTS centers.
- (4) Management arrangement.
Conducting the investigation of any accident takes a long time and consideration of conducting reports in real time will be effective.
- (5) Attention and situation awareness.
The watch rotation and fatigue of the officers on board should be understood. Measures to call other officers when required should be in place so that exhausted officers do not have to take the

watch and many accidents can be prevented.

7. Conclusions

In this matter, we strongly believe that:

- (1) Reasonable to apply.
Using this qualitative model, we could find relationship causes of collision in the term maritime transport system.
- (2) Flexible data.
Using one variable as independent we could find relationships to other data. Probabilistic arguments and logic have been used. Sources are from both printed theories and from opinions of experts, as well as from real accident reports.
- (3) Alternative qualitative model.
Use of this model can be included as a second opinion in the decision-making for management improvement.
- (4) Simulate qualitative model.
Using this model for the relations between man, machine, media and management in the maritime transport system for further research.

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Questions and Answers

Mr. El-Hocine TASSEDA (Tokyo University of Marine Science and Technology):

1. Is it order of 4M model relevant or not?
2. What does mean of "media" of the context of this paper?

Haryanti RIVAI:

1. The concept 4M (Man, Media, Machine, and Management) is not relevant based on the order. This method utilizes the concept of the method accident investigation used by the National Transportation Safety Board (NTSB) and rather than constituting mere guidelines on procedures.
2. Media is not newspaper or magazine. Media means environment. All aspect from environment interconnections on people includes weather environment, geographical, physical work environment and the regulatory, economic climates.