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Causative Chain Difference for each Type of Accidents in Japanese Maritime Traffic Systems (MTS)

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ABSTRACT: Causative chain (CC) is a failure chain that cause accident as an outcome product of the second step of MOP model, namely line relation analysis (LRA). This CC is a connection of several causative factors (CF), an outcome product of first step of MOP model, namely corner analysis (CA). MOP Model is an abbreviation from 4M Overturned Pyramid, created by authors by combining 2 accident analysis models. There are two steps in this model, namely CA and LRA. Utilizing this model can know what is CF that happen dominantly to the accidents and what is a danger CC that characterize accidents in a certain place and certain period. By knowing the characteristics, the preventive action can be decided to decrease the number of accident in the next period. The aim of this paper is providing the development of MOP Model that has been upgraded and understanding the characteristics of each type accident. The data that is analyzed in this paper is Japanese accidents from 2008 until 2013, which is available on Japan Transportation Safety Board (JTSB)'s website. The analysis shows that every type of accidents has a unique characteristic, shown by their CFs and CCs. However, Man Factor is still playing role to the system dominantly.

1 INTRODUCTION

Japan Transportation Safety Board (JTSB) did investigation for all accidents in maritime, land, train and air. All the reports are open source in its website thus all stakeholders can utilize the reports to get some lesson learnings. In maritime field, there were 3090 accidents in 2008 to 2013 (JTSB 2016).

There were many papers that has been published in order to analyze the accidents. Mutmainnah & Furusho (2015) propose an easier method for maritime accident, namely 4M Overturned Pyramid (MOP) model, to find the causative factors that lead accidents as well as the causative chain (Mutmainnah et al. in prep.). Authors has tried MOP model to analyze several maritime accidents, such as collision in Japan, United Kingdom (UK) and Indonesia (Mutmainnah & Furusho 2015, 2016a, b). Besides, this method has also been used to a more specific subject, such as finding the most common improper look-out (Mutmainnah & Furusho 2016b) and the most common causative factors for each time occurrence, namely day, night and twilight (Mutmainnah et al. 2017).

There are so many types of accidents, such as collision, accidental work, fire, sink, and so on. Each type of accident has different causative factors that create different characteristic. The aim of this paper is to see the differences of causative chains of accident in collision and accidental work. From 50 accidents occurred in Japan that are published on JTSB website in English, 20 cases are collision, 20 cases are accidental work including fatality and injury, while 10 others are capsize, foundering, and so on, which

counted only one, two, or maximum 5 cases. Because of that difference number of accident case in each type, authors decide to compare collision and accidental work. Thus in total, there are 40 cases that are analyzed in this paper from 2008–2013.

Same like previous papers, in this paper we utilized a MOP model to analyze Maritime Traffic System (MTS), include past accidents, and determine their causative factors and causative chains to generate the characteristics. The MOP model is based on the combination of the Septigon model (society and culture, physical environment, practice, technology, individual, group, and organizational environment network) created by Grech et al. (2008) and the IM model proposed by Furusho (2000, 2013). The IM model consists of 4M factors (man, machine, media, and management) that are connected by the individual element (I) as the core of the system. The MOP model is drawn as a three-dimensional relationship that appears as a three-sided inverted pyramid, where each corner of the pyramid represent one 4M factor. Each corner (factor) is connected to and affects the other factors. The man factor should always be at the bottom of the inverted pyramid because it is the intrinsic factor that significantly affects all other factors. Because the model is drawn three-dimensionally as a three-sided inverted pyramid, it has four corners representing the 4M factors, and six edges representing interaction between the two factors that are connected by the edges. The edges, which are called line relations, show that the system is the result of interactions among the 4M Factors. Thus, to obtain a safe system, all corners and edges should be reliable and balanced.

These investigation reports were analyzed in two steps, as will be explained in the section 2. There are three accident development stages: the beginning of the accident, the accident itself, and the evacuation process; these stages are labeled as Stage 1, Stage 2, and Stage 3, respectively (Nurwahyudi 2014). When characterizing the accidents in the reports, failure events at every stage of accident development are described. Several failures that occur are categorized into these stages. If we know the failures that occur at every stage until the evacuation process, we can predict the loss caused by the accident and also develop countermeasures.

2 JAPANESE MTS ACCIDENTS

JTSB posted 50 accidents in English that happen in 2008-2013. Figure 1 shows the number of each accident type. As explained in Section 1, a total number of 40 cases are analyzed in this study that contains of 20 cases of collisions and 20 cases of accidental work. We can see from figure 1 that the number of collision and accidental work are slightly different with other accident types. Figure 2 shows the number of each accident type in each year.

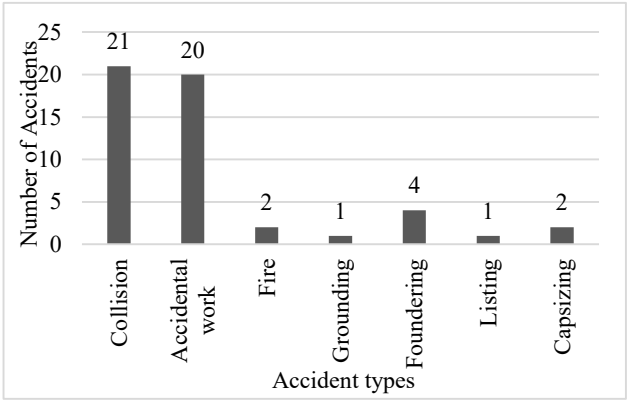

Figure 1. Number of accident in each type from 2008–2012 (JTSB 2016)

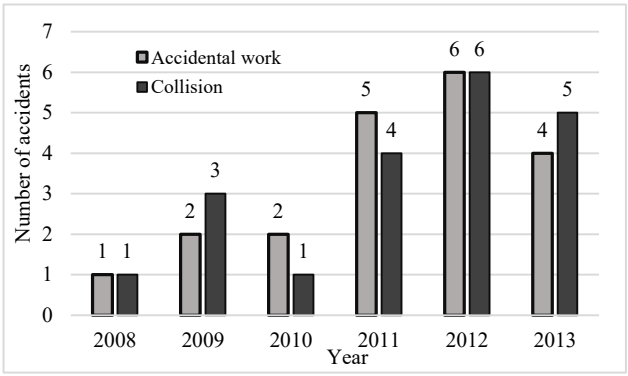

Figure 2. Number of collision and accidental work cases in Japan in each year from 2008–2012 (JTSB 2016)

3 MOP MODEL

MOP model was developed in the maritime domain by the authors which is a combination of the epidemiological, Septigon, and IM models. The Septigon model is a concept that categorizes the MTS into seven domains: society and culture, physical environment, practice, technology, individual, group, and organizational environment network (Grech et al. 2008). All domains are connected to and affected by each other in a system. Any error in one domain can affect the system. In 2000, Furusho proposed a simpler system called the IM model. This model consists of 4M factors (man, machine, media, and management) that are connected by the individual element (I) as the core of the system (Furusho 2000, 2004). MTS is better explained by the epidemiological model that consists of latent conditions, barriers, and active conditions, as shown in Figure 3.

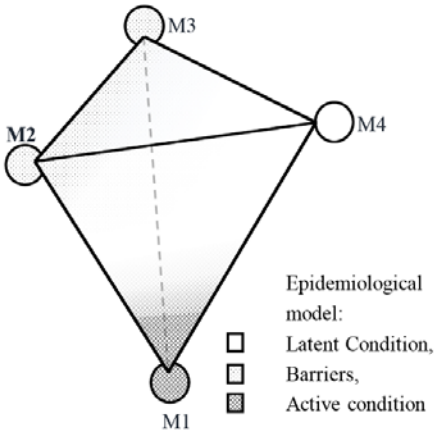

Figure 3. MOP model

The MOP model is drawn three-dimensionally as a three-sided inverted pyramid that has four corners, representing the 4M factors, and six edges, representing an interaction between two 4M factors that are connected by the edges, as shown in Figure 3.

The edges, called line relations, show that the system is a result of interactions among the 4M factors. Failures that are classified into the corner of the MOP model do not occur only because of that particular corner. Often, the failure is caused by other corners. When there are failures that are caused by several corners, it implies that the line relations connecting those corners are also contributing to the instability of the system. For example, consider a failure in communication. Communication cannot be classified into one corner because communication is related to all four corners. The failure in communication among seafarers is classified as man factor (M1) because this type of communication depends on the person. Often, several seafarers do not share information with other seafarers. However, communication failure among ships and port administrations does not belong to the man factor. It can belong to either the management or the machine factor that is affected by the media factor. The classification of failure depends on the condition of the accidents. When a line relation contributes to the accident, a preventive action for the line relation has to be determined. Thus, for a safe system, all corners and edges should be reliable and balanced.

Because the MTS consists of latent conditions, barriers, and active conditions, any accident that occurs in the MTS should be traced for each of these factors separately. Each factor (corner) of the MOP model represents the epidemiological model as shown in Figure 3. In Figure 3, the individual from M1 (man factor) receives some information from M3 (media factor: environment) and from M2 (machine factor: crew complement) factors; then, this information is used for decision making. Hazard perceptions are also influenced by M4 (management factor). The detail explanation how MOP model is created is written in Mutmainnah & Furusho (2014) and then it has been developed more in Mutmainnah et al. (2016).

There are 2 steps in analyzing accident reports by MOP Model, namely Corner Analysis (CA) and Line Relation Analysis (LRA). Section 4 will explain more about this steps as well as the result in this study.

Table 1 lists the definition and examples of the corners in the MOP model. By understanding the definition, it is easier to determine the causes of the accidents using the epidemiological model, and then, prevention actions can be considered. Besides, the characteristics of several accidents can be explored by analyzing several accident reports and by finding the tendency, as carried out in this paper.

Table 1. Definition and examples of each corner of the MOP Model

4M Factors	Definition (Example)
Man (M1)	All elements that affect people doing their tasks (Knowledge, skills, abilities, memory, motivation, alertness, experience, etc.)
Machine (M2)	All elements, including technology, which help people to complete their tasks (Equipment, information display, environmental design, crew complements, construction, etc.)
Media (M3)	All environments that affect the system and/or people (Climatic/weather condition (temperature, noise, sea state, vibration, wave, tide, wind, etc.), economic condition, social politics, culture, etc.)
Management (M4)	All elements that can control the system and/or people (Training scheme, communication among companies/institution, work schedule, supervising/ monitoring, regulatory activities, procedures, rules, maintenance, etc.)

4 RESULT ANALYSIS USING THE MOP MODEL

The investigation reports explain all facts and causes of the accidents. We re-analyzed those reports using the MOP model. The analyses were carried out in two steps: corner analysis, which is listing causative factors for each corner of the MOP model; and line relation analysis, where the relationship among causative factor in the corner is explored.

The CF list of collision has been written in previous paper. Thus, in this paper we only show the result analysis of accidental work. But in the next section, we will review again the result analysis of collision the compare them with the result of accidental work.

4.1 *Corner Analysis (CA)*

In this step, we traced and listed all failures that caused accidents and divided them based on the definition of each corner of the MOP model. Then, we counted the number of failures after all reports were analyzed. The failures that has been listed are named as causative factors (CFs). Tables 2–5 list the causes and the number of failures for CF for each corner of the MOP model.

CFs that are listed in table 2-5 above belong to accidental work because the CFs' collision has been shown in Mutmainnah et al. (2016).

There are several categorizations in each corner to make it easier to be understand. For example, in M1, the failures can be divided into careless workmanship, doing personal decision, disobeying procedure manual, carrying out irregular procedure, incapability of seafarers/workers, and human element problem. Careless workmanship means that the failures that has been done are with no intention of being fail meanwhile disobeying procedure manual means the workers know that what would they do are not based on the procedure manual but they keep doing (they made a deal with other workers/some workers know but not all crew members and workers agree). Disobeying procedure manual without any deal with other workers is classified into 'doing personal decision' which means he did not confirm to another worker that he will do something which is written in the manual. However, carrying out irregular procedure means that all the workers include seafarers agree to do some procedures that is different with their procedure manual.

In M2, the classification becomes ship equipment, ship construction, port facility failure/damage and falling items. This classification is made because there are many failures in M2 which is not like what happen in collision cases.

Table 2. Number of failures for each CF categorized as M1

Code	Causative Factors	Number of failures
CARELESS WORKMANSHIP		
M11-01	In communication among the seamen	8
M11-02	Misunderstanding condition (Wrong Judgement)	9
M11-03	In deciding speed	1
M11-04	a person fell down	4
M11-05	In using proper tools	3
DOING PERSONAL DECISION		7
DISOBEYING PROCEDURE MANUAL		
M13-01	Start cleaning without asking master's permission	1
M13-02	Enter enclose tank without asking master's permission	2
M13-03	Not measure gas concentration	5
M13-04	Working alone in dark	1
M13-05	Lubricating without stopping	1
CARRYING OUT IRREGULAR PROCEDURE		
M14-01	In mooring operation	2
M14-02	In cleaning tank process	1
M14-03	In loading/unloading process	3
INCAPABILITY OF SEAFARERS/WORKERS		
M15-01	In operation process	6
M15-02	Speaking in English	1
M15-03	In understanding hazards	6
M15-04	In wearing correct mask	1
M15-05	In monitoring/identifying any accident risk	9
M15-06	In utilizing gas detector	2
M15-07	In understanding weather condition (secondary undulation)	1
M15-08	In understanding creation of toxic by chemical reaction	1
HUMAN ELEMENT PROBLEM		
M16-01	Alcohol effect	1
M16-02	Felt impatient	2
M16-03	Could not smell the odor gas	1

Table 3. Number of failures for each CF categorized as M2

Code	Causative Factors	Number of failures
SHIP EQUIPMENT FAILURE/DAMAGE		
	Mooring line problems:	
M21-01	-Insufficient line length	1
M21-02	-Mooring line was broken	3
M21-03	-Line was bounced	1
M21-04	-Pendant wire diameter was small	1
M21-05	-Heaving line was old	1
M21-06	Exhaust fan was not working	2
M21-07	Gas detector was not there	1
	Hook assembly problem:	
M21-08	-Existence of twisted shackle	1
M21-09	-Shear fracture in shackle split	1
M21-10	-There were rusted bolts	1
SHIP CONSTRUCTION FAILURE/DAMAGE		
M22-01	No fall protection fence	2
	Some construction parts were not secured well:	
M22-02	-Deck support was not stated	1
M22-03	-Tween deck hatch cover fixing pins were not inserted	1
	Some construction parts were fracture/rupture:	
M22-04	-Weld line was ruptured	1
M22-05	-doubling plate weld brittle	1
M22-06	-There were fatigue& ductile fracture bolts	1
M22-08	Support deck panel overlapped	1
M22-09	Lack of dunnage and small	1
PORT FACILITY FAILURE/DAMAGE		
M23-01	Existence of small crack	1
M23-02	Fracture of main sheave	1
M23-03	Wire was broken	1
M23-04	Existence of abnormal noise	1
FALLING PARTS		
M24-01	Rescue boat fell	1
M24-02	Cargo fell	2
M24-03	Crane collapse	1
M24-04	Deck panel fell	1

Table 4. Number of failures for each CF categorized as M3

Code	Causative Factors	Number of failures
M31-01	Strong wind	1
M32-01	High wave	1
M33-01	Secondary undulation	1
M34-01	Existence of odorous gas	4

Table 5. Number of failures for each CF categorized as M4

Code	Causative Factors	Number of failures
POOR COMMUNICATION		
M41-01	Among companies	2
MANAGEMENT FROM ONSHORE		
M42-01	Could not identifying/monitoring/ communicating any risk accident	4
M42-02	There was changing route	1
M42-03	Company did not establish some procedures	5
M42-04	Company had given incorrect explanation	3

If we see from the tables, there is no classification in M3 because it has only 4 CFs that is still easy to be understood. In other side, M4 has 2 classification which are poor communication and management from onshore.

Generally speaking, the number of CF in accidental work is higher than in collision in M2, M3, and M4. Even total failures that happen is not so much different.

4.2 *Line Relation Analysis*

Causative factors written in Tables 2–5 are not pure belongs to one corner. In this step, of all the causative chains listed, the relationship among the corners of the MOP model is explored. The chains that is performed by several CFs is called as causative chains (CCs). By performing line relation analysis, we can understand which line relation is the most vulnerable to failure.

Table 6. Number of Causative Chain

No.	Causative Chain (CC)
1.	M16-02> M14-03> M11-05> M11-04
2.	M14-03> M11-04
3.	M22-08> M15-01> M11-05> M15-05> M11-04
4.	M22-01> M11-04
5.	M23-01> M23-02> M23-03> M24-02> M11-04
6.	M22-06> M24-03> M11-04
7.	M21-10> M24-03> M11-04
8.	M14-01> M15-01
9.	M21-04> M14-01> M15-01> M15-03
10.	M14-03> M15-01> M15-04
11.	M42-03> M42-01> M15-01> M15-04
12.	M42-03> M34-01
13.	M42-03> M11-02
14.	M41-01> M42-01> M11-02> M22-05> M22-09
15.	M42-04> M11-02> M22-05> M22-09
16.	M15-02> M11-02> M12-01
17.	M11-01> M11-02
18.	M11-01> M11-02
19.	M11-02> M13-03
20.	M11-02> M11-01> M15-04
21.	M22-01> M24-02> M11-02> M15-05
22.	M11-01> M15-05
23.	M42-04> M42-01> M15-08> M15-05> M11-01> M15-03> M12-01
24.	M15-03> M15-05
25.	M15-08> M12-01> M15-05> M15-03
26.	M15-01> M15-05> M12-01
27.	M16-01> M16-03> M12-01
28.	M42-04> M15-06> M13-03> M21-07
29.	M22-04> M22-07> M24-04
30.	M22-02> M22-07> M24-04
31.	M21-05> M21-02
32.	M32-01> M21-02
33.	M33-01> M21-02
34.	M11-03> M21-03
35.	M21-01> M21-03
36.	M15-04> M13-03
37.	M21-09> M24-01
38.	M42-02> M41-02
39.	M15-08> M34-01

Same with list of CFs above, the CCs listed above only belong to accidental works. Different with collision, the accidental work do not have core CC because we can not find CC that happen in several times. Perhaps there are some confusion reading table 6. The first CF code that is written in table 6 means that that CF causing the next CF writer after '>'. In example, CC number 1 is M16-02>M14-03>M11-05>M11-04. This means that M16-02 (Felt impatient) cause M14-03 (carrying out irregular procedure in loading/unloading process) and so on. The CC list are not ordered based on how they happen but only to be easier to get some characteristic.

5 DISCUSSION

Different accident type has different characteristic. This paper shows the difference characteristic of collision and accidental work. There are other accident happen in Japan but the number of available investigation reports in English are not many. Thus, we only pick 2 accidents that has bigger number. The MOP model analysis of collision has been written in Mutmainnah (2016) in detail. Thus, only result of accidental work is shown in this paper in detail and several comparisons of collision and accidental work will be discussed here.

Out of CFs that happen in collision and accidental work, there are several differentiations. While in accidental work, CFs in M1 are classified into 6 parts as written in table 2, CFs that happen in collision are classified 3 parts, namely careless workmanship, incapability of seafarers, and human element problem. CF that is the most happen in both accidents is failure in identifying/ monitoring accident risk.

CFs that are listed in M2 are very different between what happen in collision and accidental work. There are only 4 CF that happen in collision which are only classified into equipment failures. However, there are 17 CFs that happen in accidental work that are classified into 4 parts. This differentiation means that there are view contributions of M2 to collision, not like in accidental work.

There is also one thing different in M3. In accidental work accident, not only natural condition that contribute to accidents but also there is existence of odorous gas or toxic gas. Meanwhile in collision, only natural condition that contribute to accidents. However, there are no special different in M4 between collision and accidental work accident.

The special CF that only happen in collision are careless workmanship in maintaining proper lookout (M1), erratic/ineffective action in avoiding accident (M1), and poor management of personal on board (M4). Besides, the special CF that only happen in accidental work are those in M2, existence of odorous gas (M3), and all CF that is related to tank cleaning procedure. The other difference thing is the get involved ships. In collision, most of the get involved ships are fishing vessel while in accidental work are general cargo.

Accidental work accident can be divided into 4 categories, namely at mooring operation (4 cases), loading/unloading cargo (10 cases), tank cleaning work (4 cases) and other (2 cases).

After doing LRA, we can know several chains that consisted of several CF. There is CF that happen only at the end of the chain, namely M11-04 (a person fell down). However, the causing CF are different. There are CF that often happen in the middle of CC, namely M15-01 (incapability of seafarer/worker in operation process), M11-02 (misunderstanding condition/ wrong judgement), and M15-05 (incapability of worker in monitoring/identifying any accident risk). Mostly M15-01 are happen because of there were irregular procedure has been carried out.

The LRA result of accidental work accident shows different style with what happen in collision. In collision, there are core causative chain, head of CC that causing the core CC and tail of CC that are caused by the core CC.

6 CONCLUSION

There are several conclusion that can be seen from analyzing collision and accidental work. Here are the conclusion:

- The characteristic of collision and accidental work are quite different.
- As written in discussion, the result of re-analyzing collision and accidental work with MOP model shows that the characteristic of those accident is different. There were more CFs in M2 that happen in accidental work compare to collision.
- The special CF that happen in accidental work are failures related to tank cleaning that generate toxic. While in collision, the special CF is improper look-out
- Both collision and accidental work are dominated by failure in M1.

This paper provide an alternative method to re-analyze accident investigation reports to understand what are the most critical point that can be chosen in order to reduce the number of accident by knowing the characteristic of accidents.

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