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4M Overturned Pyramid (MOP) Model Utilization: Case Studies on Collision in Indonesian and Japanese Maritime Traffic Systems (MTS)

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ABSTRACT: 4M Overturned Pyramid (MOP) model is a new model, proposed by authors, to characterized MTS which is adopting epidemiological model that determines causes of accidents, including not only active failures but also latent failures and barriers. This model is still being developed. One of utilization of MOP model is characterizing accidents in MTS, i.e. collision in Indonesia and Japan that is written in this paper. The aim of this paper is to show the characteristics of ship collision accidents that occur both in Indonesian and Japanese maritime traffic systems. There were 22 collision cases in 2008–2012 (8 cases in Indonesia and 14 cases in Japan). The characteristics presented in this paper show failure events at every stage of the three accident development stages (the beginning of an accident, the accident itself, and the evacuation process).

1 INTRODUCTION

MOP Model was discovered in 2013 by authors which is a development of man, machine, media and management (4M) factors concept, originated by IM Model and Septigon model. Authors tries to develop the concept to be applicable in more general aspect in characterizing maritime traffic system (MTS), especially accident at sea because many errors can lead to incidents and/or accidents in operating ships. Because the characteristics of each type of maritime accident are different, it is necessary to analyze each type of accident separately. In this study, authors decided to re-analyzed accident in Indonesia and Japan because in the Asian region, Indonesia and Japan are the largest archipelagoes. Thus, it is important to maintain transportations at sea, which act as their lifelines and support their productivities. Authors consider the ship collision accident because it involves problems associated with more than one ship. Often, ship collision results in explosion, sinking, grounding, etc. Therefore, in an effort to reduce the number of accidents caused by collisions, one of the steps could be to analyze previous collision accidents to identify their characteristics.

In Japan, the Japan Transportation Safety Board (JTSB) investigates major accidents in the Japan area, and in Indonesia, the National Transportation Safety Committee (NTSC) performs the same function as JTSB. All investigation reports can be viewed on their respective webpages.

The aim of this paper is to clarify the characteristics of ship collision accidents that occur both in Indonesian and Japanese maritime traffic systems (MTS). By understanding the characteristics of ship collision accidents, necessary countermeasures can be proposed.

In total, there are 22 collision cases that are analyzed in this paper; 14 from Japan and 8 from Indonesia, from 2008–2012. The analyzed cases are the investigation reports from each government. Note that, not all reports on the JTSB or NTSC website are translated in English. Therefore, only the English versions of the investigation reports were considered in this study for analyses. Thus, for Japan, there are 14 such cases from 2008–2012 and these cases involve 27 ships. In Indonesia, there are 8 collision reports that involve 16 ships from 2008–2012.

These investigation reports were analyzed by MOP model in two steps, as will be explained in the section 3 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.

The characteristics of the Indonesian and Japanese ship collision accidents can be determined using the proposed MOP model. This paper shows several analyses on the characteristics of these ship collision accidents. In several terms, ship collision accidents in Indonesia and Japan have the same characteristics, for example, the time of accidents (night) and improper lookout. Both Indonesia and Japan has a high ratio in these causative factors. However, each country also has unique characteristics that are not evident in the other country. The details of the accident characteristics are provided in Section 2.

2 MTS ACCIDENTS IN JAPAN AND INDONESIA

As explained in Section 1, a total of 22 cases are analyzed in this study. Figure 1 show the number of collision accidents that have occurred for each year from 2008 until 2012.

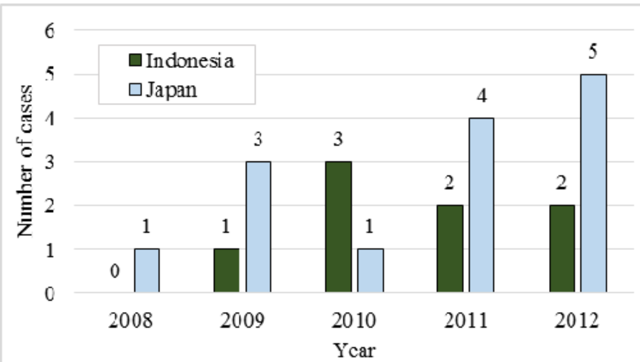

Figure 1. Number of collision cases in Indonesia and Japan from 2008–2012 (NTSC 2014, JTSB 2014)

The accident reports available for Indonesia are from 2007 to 2013. However, there were no reports of collisions in 2008. On JTSB's website, the English versions of the reports are available for accidents from 2008–2013. The analysis in this paper was carried out for the collisions in 2008–2012 because the collisions in 2013 are yet to be reported.

3 MOP MODEL

The proposed MOP model was developed in the maritime domain. As stated previously, MTS is better explained by the epidemiological model that consists of latent conditions, barriers, and active conditions. The proposed MOP model 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 as defined in table 1 (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.

Table 1. The Septigon Model Term Definitions

Term	Definition
Society and culture.	It refers to the sociopolitical and economic in which the organization operates.
Physical Environment	It refers to the surrounding environment, such as weather, visibility conditions, obstructions to vision, physical workspace environment (air quality, temperature, lighting conditions, noise, smoke, vibration, ship motion, etc.)
Practice. related	It refers to such aspects as informal rules and custom. However, these are not to written procedures or instructions.
Technology.	It refers to equipment, vehicles, tools, manuals, and signs, and also deals with human machine interaction issues.
Individual.	It refers to the human component, and incorporates such aspects as individual physical or sensory limitations, human physiology, psychological limitation, individual workload management and experience, skill, and knowledge.
Group.	It refers to the relational and communication aspects, such as communication, interactions, team skills, crew/team resource management training, supervision, and regulatory activities. Group also deals with leadership, and teamwork.
Organizational environment.	It refers to the company and management as well as the procedures, policies, norms, and formal rules.

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 in ship navigation (Furusho 2000, 2004).

The proposed 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 2.

Table 2 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 2. 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.)

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.

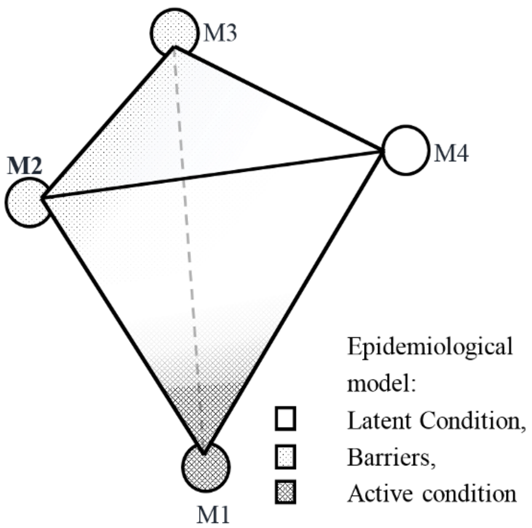

Figure 2. MOP model

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 1. In Figure 1, 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).

4 ANALYSIS ON THE MTS ACCIDENTS 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 between each causative factor in the corner is explored.

4.1 *Corner Analysis*

Corner analysis (CA) is listing all causative factors (CF) then categorize them into each corner based on the definition for each corner. The CF is all failures that causing accidents. After categorizing the CF, we counted the number of failures after all reports were analyzed. Tables 3–6 list the causes and the number of failures for each causative factor for each corner of the MOP model.

From Tables 3–6, the most common failures for each corner of the MOP model can be identified. They are "improper lookout," "cannot place the object on radar," and "insufficient light" for man, machine, and media factors, respectively. For the management factor, there are four failures that have the same total number, they are "seaman has an expired certificate/no certificate," "poor management of personnel on board in rotating personnel," "poor communication about traffic route from the company (onshore)," and "poor communication in monitoring and supervising from onshore."

Table 3. Number of failures for each causative factor of the MTS accidents in Japan and Indonesia categorized as M1

Code	Causative Factors	Japan	Indonesia	Total
SLIPSHOD WORKMANSHIP				
M1-01	Inconsistency in the navigation course	3	1	4
M1-02	Wrong course decision	0	3	3
M1-03	Wrong speed decision	3	3	6
M1-04	Lack of communication among the seamen	4	3	7
M1-05	Improper Lookout	7	4	11
M1-06	Misunderstanding conditions (wrong judgment)	5	0	5
M1-07	Lighting inappropriate (navigational light)	1	0	1
INCAPABILITY OF SEAFARER				
M1-08	In utilizing AIS*	6	1	7
M1-09	In utilizing Radar	1	1	2
M1-10	In communicating by VHF	2	0	2
M1-11	In communicating with other vessel	0	4	4
M1-12	In understanding how to avoid collision	0	4	4
M1-13	In conducting abandoned ship	0	1	1

* AIS means Automatic Identification System

Table 4. Number of failures for each causative factor of the MTS accidents in Japan and Indonesia categorized as M2

Code	Causative Factors	Japan	Indonesia	Total
M2-01	Cannot place the object on Radar	2	0	2
M2-02	Lack of communication tools	0	1	1
M2-03	The anchor could not be placed	0	1	1

Table 5. Number of failures for each causative factor of the MTS accidents in Japan and Indonesia categorized as M3

Code	Causative Factors	Japan	Indonesia	Total
M3-01	Rain	3	0	3
M3-02	Insufficient visibility	2	0	2
M3-03	Strong wind	1	1	2
M3-04	High/Strong wave	1	0	1
M3-05	Insufficient light	9	6	15
M3-06	Tidal stream	1	1	2
M3-07	Low Tidal	0	1	1
M3-08	Traffic route was crowded	0	1	1

There are some classifications in Table 3 and 6. When classifying the failures for the man and management factors, M1-01 until M1-07 can be classified again into slipshod workmanship. This classification is only for making it easy to divide and analyze the failures. Failures that caused accidents in Indonesia and Japan can be broadly classified into slipshod workmanship and incapability of seafarer. Then, in terms of the management factors (Table 6), the failures were poor management of personnel on board, poor communication, poor management of emergency drill, and poor application of safety management system.

Only observing the number of failures is not sufficient to obtain the characteristic of the accidents for each country because the number of analyzed accidents in Indonesia and Japan are different. The ratio of occurrence from among the analyzed report should be known. Figures 3–6 show the occurrence ratio (on the horizontal axes) of each causative factor on the vertical axes.

Table 6. Number of failures for each causative factor of the MTS accidents in Japan and Indonesia categorized as M4

Code	Causative Factors	Japan	Indonesia	Total
POOR MANAGEMENT OF PERSONNEL ON BOARD				
M4-01	Seaman has an expired certificate/ no certificate	2	2	4
M4-02	In understanding the passage plan (in new area)	0	2	2
M4-03	Lack of personnel	0	3	3
M4-04	In rotating personnel	1	3	4
POOR COMMUNICATION				
M4-05	About traffic route from the company (onshore)	3	1	4
M4-06	In monitoring and supervising from onshore	2	2	4
M4-07	Among onshore and other vessels utilizing radio	0	1	1
M4-08	Poor management of emergency drilling	0	1	1
M4-09	Poor application of safety management system	1	2	3

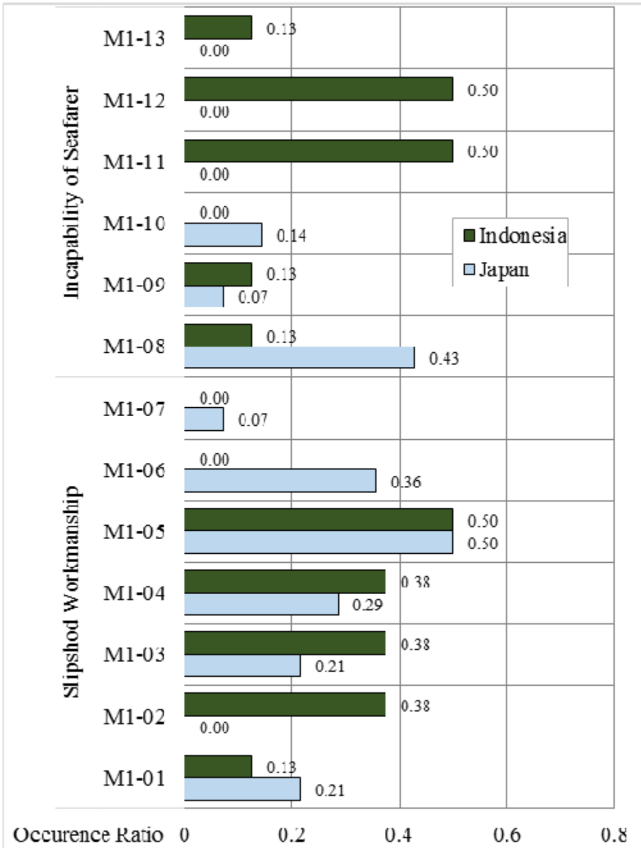

Figure 3. Comparison of occurrence ratio between Japanese and Indonesian MTS accidents for each causative factor categorized as the man Factor (M1)

To understand the figure 3-6, the following example will explain how to calculate the ratio. A total of 11 failures were attributed to the improper lookout causative factor in the man factors. From the 14 reports, improper lookout was the reason for 7 cases. This means that the occurrence ratio for this causative factor is 0.5 (7 divided by 14). In the case of Indonesian collisions, improper lookout was the cause for 4 of 8 accidents. Thus, the occurrence ratio of improper lookout in Japan and Indonesia is the same.

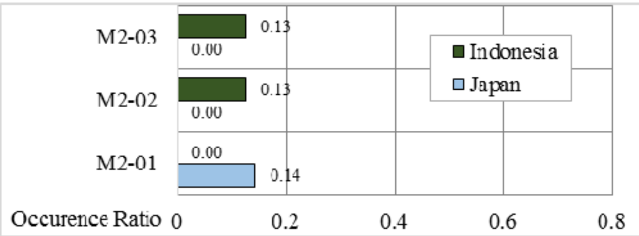

Figure 4. Comparison of occurrence ratio between Japanese and Indonesian MTS accidents for each causative factor categorized as the machine Factor (M2)

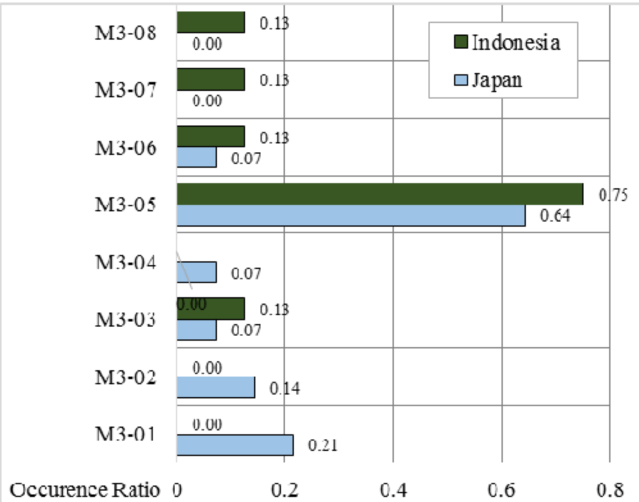

Figure 5. Comparison of occurrence ratio between Japanese and Indonesian MTS accidents for each causative factor categorized as the media Factor (M3)

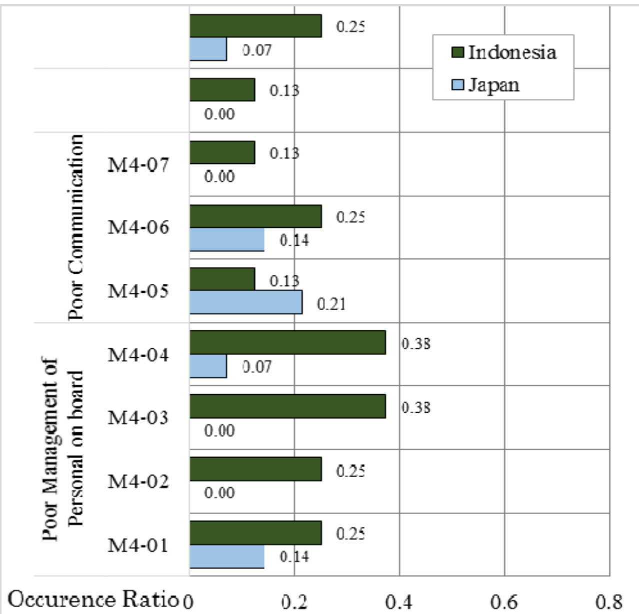

Figure 6. Comparison of occurrence ratio between Japanese and Indonesian MTS accidents for each causative factor categorized as the management Factor (M4)

4.2 *Line Relation Analysis*

Causative factors written in Tables 3–6 are not pure belongs to one corner. This line relation analysis step connects one corner to the other corners that are related to the causative factors that occurred. The causative factor in a corner that is related to another corner is marked to the related corner, and then, the line relation that connects these corners is obtained. The line relation that connects the man factor (M1) to the machine factor (M2) is labeled as M12. Therefore, M23 implies the line relation that connects the machine factor (M2) to the media factor (M3).

In this step, of all the causative factors listed, the relationship among the corners of the MOP model is explored. By performing line relation analysis, we can understand which line relation is the most vulnerable to failure for each country or in both countries. The causative factors listed in Figures 7–10 show the comparison of the line relations causing ratio that connects causative factors to several corners of the MOP model between Indonesia and Japan.

The causing ratio for a corner is obtained by dividing the number of causative factors that are related to other corners with the total number of causative factor in that corner.

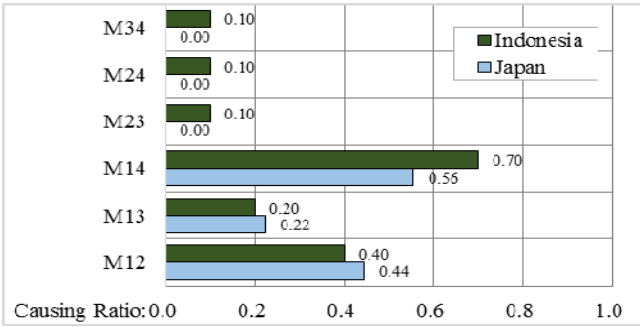

Figure 7. Comparison of the line relation causing ratio between Japanese and Indonesian MTS accidents in which the causative factors are categorized as man factors (M1)

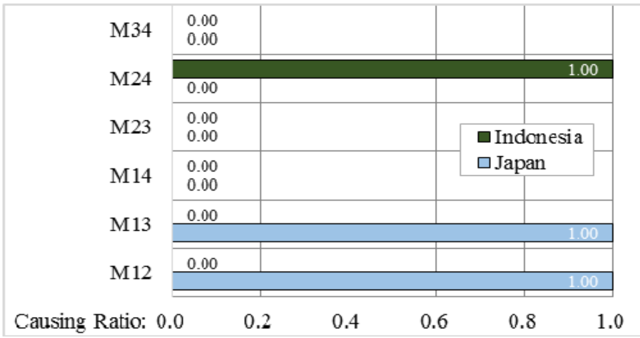

Figure 8. Comparison of line relation causing ratio between Japanese and Indonesian MTS accidents in which the causative factors are categorized as machine factors (M2)

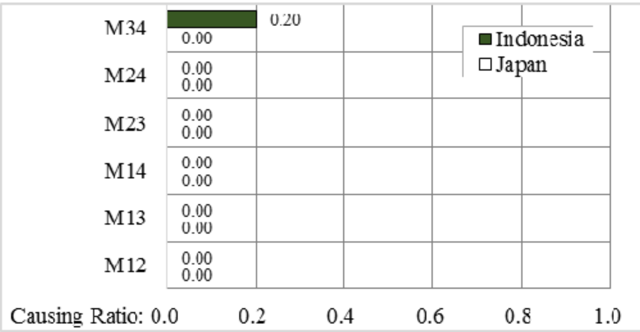

Figure 9. Comparison of line relation causing ratio between Japanese and Indonesian MTS accidents in which the causative factors are categorized as media factors (M3)

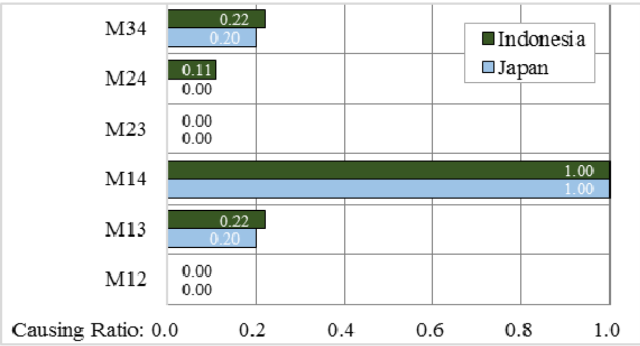

Figure 10. Comparison of line relation causing ratio between Japanese and Indonesian MTS accidents in which the causative factors are categorized as management factors (M4)

The following example can help reader to understand how to calculate by seeing in the man factor corner. There are 13 causative factors in total in this corner. However, not all causative factors caused the accidents in Indonesia or Japan. In Indonesia, for the corner man factor there were 9 causative factors (refer Table 3). Of these 9 factors, 5 were related to the management factor, i.e., M1-04, M1-05, M1-8, M1-9, and M1-10. Thus, the M14 line is causing the man factor corner with a ratio of 0.56 (5 divided by 9).

5 DISCUSSION

The characteristics of ship collision accidents in any country should be known to prepare preventive actions to decrease the number of accidents. In this research, we propose a new method, called the MOP model, for obtaining these characteristics. We analyzed accidents for two countries to demonstrate how the MOP model can explore the characteristics as well as the differences in the accident characteristics for each country or for both countries. However, this research does not aim at debating which country is better.

Figures 3–10 illustrate the comparison of the occurrence ratio for the corner and line relation analyses between Indonesia and Japan. These figures indicate that there are several causative factors that affect each country differently; there are factors that affect both countries equally as well. In subsection 5.1, the result of each will be discussed. In the last part, this discussion also provides the characteristics of the failure events in each stage of accident development.

5.1 *Characteristics of MTS accidents in Indonesia*

A total of 54 failures occur in the 8 cases of collisions. 25 of these failures are related to man factors with 10 types of causative factors, 2 failures are related to machine factors, 10 failures are related to media factors with 5 types of causative factors, and 17 failures are related to management factors with 9 types of causative factors. These numbers indicate that failures in the man factor are dominant among the 8 collisions accidents.

Several causative factors only occur in Indonesia. For example, slipshod workmanship in deciding course, incapability of seafarers in communicating with other vessels, understanding how to avoid collision, and conducting abandoned ship measures (categorized as man factors), lack of communication tools and the anchor could not be placed (classified as machine factors), low tidal and traffic route was crowded (classified as media factors), and poor communication among onshore and other vessels utilizing radio and poor management of emergency drilling (classified as management factors). Among all causative factors mentioned above, the most common is the incapability of seafarers in communicating with other vessels and in understanding how to avoid collision with the occurrence ratio of 0.5 (Figure 3). This implies that there were 4 out of 8 collisions that were caused by these causative factors.

However, these two causative factors do not entirely belong to the man factor. They are related to the management factor as well, for example, the term of training. As shown in Figure 7, the M14 line is the most causing line to the man factor corner, with a causing ratio of 0.7. If we see Figures 7–10 carefully, the most causing line for Indonesia is the line that is connected to the management factor, such as M14 causing man factor, M24 causing machine factor, M34 causing media factor. In the management factor itself, the most causing line is M14 with a causing ratio of 1, which means that all the causative factors in the management factor are related to the man factor.

From another perspective, the characteristics of the accident can be seen from the failure that happens in the three stages of accident development. From the 54 failures that occurred, 33 failures occurred in the beginning of accidents, 18 failures occurred in the accident or in an effort to avoid the collision, and 3 failures occurred in the evacuation process. However, there were no failures in machine and media factors in Stages 2 and 3. All failures in Stages 2 and 3 are failures in the man and management factors.

The failures that occur in the evacuation process are also dangerous because they result in an increase in the number of people who are missing, who sustain injuries, or those that are fatally wounded. Two collisions had failures in Stage 3. The failures are slipshod workmanship in communicating among the seafarers (M1-04), incapability of seafarer in conducting abandoned ship (M1-13), and poor communication among onshore and other vessels utilizing radio (M4-07).

In Stage 2, 15 out of 18 failures belong to man factors with 5 types of failures/ causative factors. These causative factors are M1-01, M1-02, M1-03, M1-11, and M1-12. All common failures that occur in all 8 collisions in Indonesia occur in Stage 2. Thus, the incapability of the seafarers in communicating with other vessels (M1-11) and in understanding how to avoid the collision (M1-12) caused the collision. If these failures were addressed, the collisions could have been averted.

In Stage 1, most failures were in the management factor, which implies latent failures, and in the media factor. However, the most common failure that occurred in this stage also occurred in the cases in Japan.

Therefore, from the discussion above, the most vulnerable condition is the man factor corner, man–management line relation and Stage 2 of the accident development process. To avoid collisions, these three points must be considered for taking preventive actions.

5.2 *Characteristics of MTS accidents in Japan*

Japan had 60 failures in the 14 collision cases from 2008–2012. 32 of these failures belong to the man factor with 9 types of causative factors, 2 of them belong to the machine factor, 17 belong to the media factors, with 6 types of causative factors, and 9 belong to the management factor with 5 types of causative factors. Similar to Indonesia, the man factor dominates the system. The difference is the composition of the media and the management factors. Although the management factor in Indonesia is much higher than the media factor, in Japan, the media factor is much higher than the management factor.

The number of causative factors that only occur in Japan is smaller compared to Indonesia; these factors are slipshod workmanship in misunderstanding condition/ wrong judgment (M1-06), lighting inappropriate navigational light (M1-07), and incapability of seafarers in communicating by VHF (M1-10) in man factor; cannot place the object on radar (M2-01) in machine factor; rain (M3-01), insufficient visibility (M3-02), and high/strong wave (M3-04) in media factor. There are no management factors that occur only in Japan. From all causative factors mentioned above, failures in misunderstanding condition/wrong judgment (M1-06) has the highest causing ratio in the system. The causing ratio was 0.36 (Please refer to Figure 3). There were 5 out of 14 cases that had this causative factor. The master on board judged something wrong regarding the opposite vessel. The master assumes that the other vessel will perform a maneuver that can avoid the accident, and therefore, only the master can perform an action that can positively avoids the accident.

In the line relation analysis of Japanese accidents, there is no special characteristics that can be extracted because the high causing ratio of the line relation in Japan is the same as in Indonesia. However, the causing ratio in Japan is smaller than that in Indonesia, except in the machine factor corner. In the machine factor corner, M12 and M13 entirely cause the machine factor failures with a causing ratio of 1. This means that all failures in the machine factor are affected by M12 and M13.

Now, let us discuss how the failures are divided into stages 1 and 3. Unlike Indonesia, the 14 cases in Japan do not have any failure in the evacuation process except because of bad weather (media factor). Only 1 accident out of 14 has 13 people missing. The collision happened at night, in a rainy, wavy, and extremely dark environment, and therefore, the ship suffered from fatal damage and no one was found at sea. Six hours after the collision, an evacuation vessel reached the accident point; however, it could not find the 13 missing people. Other than that case, the number of injury and death is not as large compared to the case in Indonesia when the seafarer could not carry out the evacuation process.

From the 60 failures, 16 failures occurred in Stage 2 and the rest occurred in Stage 1. Although the most common causative factors in Indonesia occurred in Stage 2, the accidents in Japan have different characteristics. The misunderstanding condition, which is the most common causative factor in Japan, occurred in both Stages 1 and 2. In addition, there are no special characteristics failures in Stage 2. Most failures occurred in Stage 1 where the man factor corner has 21 failures and there are no machine factors.

5.3 *Characteristics of MTS accidents in Both Indonesia and Japan*

In this subsection, we discuss the causative factors that occur in both Indonesia and Japan. These causative factors are listed in Tables 2–5. From all causative factors, the insufficient light (M3-05) from media factors is the most common causing factor for the system in both Indonesia and Japan. The second most common factor is improper lookout (M1-05) from the man factor. Insufficient light implies that at the time of the accident, it was too dark or the accident occurred at night. Indeed, this condition is more difficult. If it we note the occurrence ratio in Figure 5, the accidents that occurred had a higher occurrence ratio of 0.75 in Indonesia, while in Japan, the ratio is 0.64. In the case of improper lookout, both Indonesia and Japan have the same occurrence ratio (0.5) as can be seen in Figure 3.

In both Indonesia and Japan, the most causing line relation is the M14 Line in the management factor, as seen in Figure 10. It has a 1.0 causing ratio, which means that all failures in the management factor that occur in both Indonesia and Japan are related to the man factor.

6 CONCLUSION

From the result of utilizing MOP model, several collision accident in Japan and Indonesia have been characterized. There are several characteristics that only occur in Indonesia and Japan separately, and those which happen both in Indonesia and Japan.

From the study, we can draw the following conclusions:

1. Characteristic of Indonesian collision (not happen in Japan) is seafarer fail to avoid the accident.
   To avoid collisions, more attention needs to be paid to the capability of an Indonesian seafarer
   The most common failure of all causative failures in 8 collision cases in Indonesia occurred in Stage 2, that is, failure to avoid the accident. The most common causative factors are incapability of the seafarer in communicating with the other vessel (M1-11) and in understanding how to avoid collision (M1-12); these causative factors belong to the man factor.
2. Characteristic of Japanese collision (not happen in Indonesia) is misunderstanding condition (wrong judgment) from Masters.
   5 of the 14 collisions cases in Japan were caused by this causative factor, and it does not occur in Indonesia. In order to reduce the number of accidents that have the same causes, the seafarer needs to reconsider the judgment. It is necessary to communicate with the opposite vessel so that the right action can be performed to avoid collision.
3. Most accidents in Indonesia and Japan happened at night and the seafarers did not ensure a proper look-out.
   These two causative factors have high occurrence ratios compared with other causative factors. Therefore, paying more attention to the lookout is definitely required and when a transportation occurs at night, the seafarer should be more careful.

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