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The Development of Marine Accidents Human Reliability Assessment Approach: HEART Methodology and MOP Model

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ABSTRACT: Humans are one of the important factors in the assessment of accidents, particularly marine accidents. Hence, studies are conducted to assess the contribution of human factors in accidents. There are two generations of Human Reliability Assessment (HRA) that have been developed. Those methodologies are classified by the differences of viewpoints of problem-solving, as the first generation and second generation. The accident analysis can be determined using three techniques of analysis; sequential techniques, epidemiological techniques and systemic techniques, where the marine accidents are included in the epidemiological technique. This study compares the Human Error Assessment and Reduction Technique (HEART) methodology and the 4M Overturned Pyramid (MOP) model, which are applied to assess marine accidents. Furthermore, the MOP model can effectively describe the relationships of other factors which affect the accidents; whereas, the HEART methodology is only focused on human factors.

1 INTRODUCTION

According to the Japan Transport Safety Board (2015), there are distinctions between marine accidents and marine incidents. The term *marine accident* refers to the event wherein there is damage to a ship or facilities other than a ship, related to the ship operation, or causing death or injury to people concerned with the construction, equipment or operation of a ship. Furthermore, *marine incident* refers to the situation wherein the ship experiences loss of control due to navigational equipment failure, listing of the ship, and shorts in the element system for engine operation.

The marine industry is a great global market, and it is one of the most capital-intensive industries due to the tremendous cost of the developed equipment used (Ashmawy, 2012). Therefore, to increase the productivity of this industry, it is essential to apply effective safety measures. However, marine accidents are still common (EMSA, 2015). Human error is one of the largest causes of marine accidents. Hence, nowadays, studies are being conducted with the objective of reducing the probability of human error in the marine industry. In recent years, international organizations that engaged in the maritime activities, particularly authorities, such as the International Maritime Organization (IMO), the International Labor Organization, and Ship Classification Societies (IACS), have shown greater concerns regarding human error (Akyuz, et all, 2016).

Human Reliability Assessment (HRA) is the analytical tool used to assess the cause of accidents. In general, the methodology of HRA consists of two steps: the qualitative method and the quantitative method. However, there are also HRAs which consist of more than two steps, or of only one step.

Indonesia as an archipelagic country uses ships as their means of transportation to connect each island. Moreover, the vision of Indonesia is to become a global maritime axis. In contrast, the quality of safety at sea in Indonesia is still low, which has led to the occurrence of several accidents (Bowo, Furusho, 2016).

The objective of this research is to compare the HRAs in the marine industry, and to find a proper methodology that can be applied to the marine industry, especially with respect to accidents.

The remainder of this paper is organized as follows. The second chapter is a literature review about HRA generations and the characteristics of marine accidents. The third chapter presents an explanation about Human Error Assessment and Reduction Technique (HEART) methodology and the 4M Overturned Pyramid (MOP) model. Results of this paper will be presented in the fourth chapter; and the discussion and conclusions will be presented in chapter five and chapter six, respectively.

2 LITERATURE REVIEW

2.1 *HRA Generations*

Since the 20th century, researchers have been developing HRA. Essentially, HRA has three functions, namely the identification of human errors, the prediction of their likelihood, and the reduction of their likelihood, if required (Kirwan, 1996). Those HRA functions were developed to assess the probability of error in nuclear power plants.

Hollnagel summarized HRA development from 1975–2005, as shown in Figure 1 below. In the 1980s, the development of HRAs had the largest growth, when compared with other years. Moreover, this period represents the first generation of HRAs. Furthermore, in the 1990s, there was also development of HRAs, although not as significant as in the 1980s. Moreover, this period represents the launch of the so-called second-generation (Hollnagel, 2005).

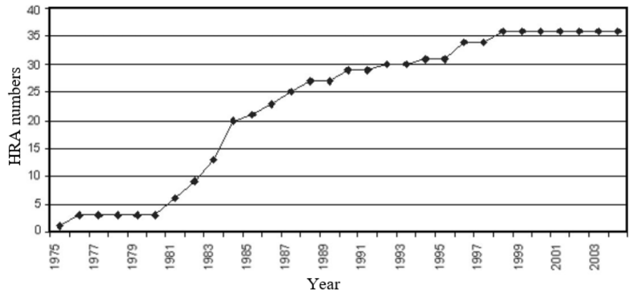

Figure 1. Cumulated Number of HRA Methods publication (Hollnagel, 2005).

However, as of recent, all industrial sectors, such as the railway, airplane, medical, and marine sectors, use HRA to identify the errors that cause accidents and incidents. Therefore, the development of HRAs is still ongoing. Owing to the large number of HRA methodologies, the methodologies are classified by the differences of viewpoints of problem-solving, as first generation and second generation.

2.1.1 *First Generation*

The first generation of HRA was first developed in the 1980s. These HRAs were developed to help risk assessors predict and calculate the likelihood of human error. Furthermore, the first-generation methods focus on the skill and rule base level of human action, and are often criticized for failing to consider aspects such as the impact of context, organizational factors, and errors of commission (Bell & Holroyd, 2009). The methodologies which are included in the first generation are as follows: THERP (Technique for Human Error Rate Prediction), ASEP (Accident Sequence Evaluation Program), HEART (Human Error Assessment and Reduction Technique), and SPAR-H (Simplified Plant Analysis Risk Human Reliability Assessment).

2.1.2 *Second Generation*

More modern methods, the second generation of HRA is carefully considered and models the influence of context on the error. Moreover, it utilizes findings and insights from the then developed cognitive movement (Boring, 2012). The development of this second generation began in the 1990s, and is going to be developed even further. ATHEANA (A Technique for Human Event Analysis) and CREAM (Cognitive Reliability and Error Analysis Method) are included in the second generation.

2.2 *Marine Accidents Characteristics*

In all sectors, the development of accident analysis can be determined using three techniques of analysis: sequential techniques, epidemiological techniques, and systemic techniques (Underwood & Waterson, 2013).

There are several differences between the three techniques, as described below.

2.2.1 *Sequential Techniques*

This is a simple, linear cause-and-effect model, where accidents are modeled as a series of falling dominos, which occur in a specific and recognizable order (U.S. Department of Energy, 2012). This method describes the events leading up to accidents, using physical component failures or the actions of humans (Leveson, 2011).

2.2.2 *Epidemiological Techniques*

An epidemiological technique can also be recognized as the latent failure model. With this technique, accidents are seen as a combination of unsafe acts (active failures) and unsafe conditions (latent conditions) (U.S. Department of Energy, 2012).

2.2.3 *Systemic Techniques*

A systemic technique describes losses as the unexpected behavior of a system. In other words, accidents are not created by a combination of active failures and latent conditions, but are rather the result of humans and technology operating in ways that seem rational (Underwood & Waterson, 2013).

These are some HRA methods that are already classified as the three-analysis technique, as shown in Table 1 below.

Table 1. Methods for Sequential Techniques, Epidemiological Techniques and Systemic Techniques (Underwood & Waterson, 2013, U.S. Department of Energy, 2012)

Techniques	HRA Methods
Sequential	Fault Tree Analysis (FTA), Even Tree Analysis (ETA), Critical Path Model.
Epidemiological	Swiss Cheese Model, Human Factors Analysis & Classification System (HFACS).
Systemic	Systems Theoretic Analysis Model and Process model (STAMP), Functional Resonance Analysis Method (FRAM), Accimap.

Based on Figure 2, marine accidents are located in the 1st quadrant, which has high manageability and tight coupling. The manageability itself means that the principles of the function of the system are known, and that system descriptions are simple, having few details. Further, the system does not change while it is being described (Underwood & Waterson, 2013).

Moreover, a tight coupling system can be described as having process sequences that are invariant. In addition, the substitution of supplies, equipment, and personnel is limited and anticipated in the design as tightly coupled systems are difficult to control (Underwood & Waterson, 2013).

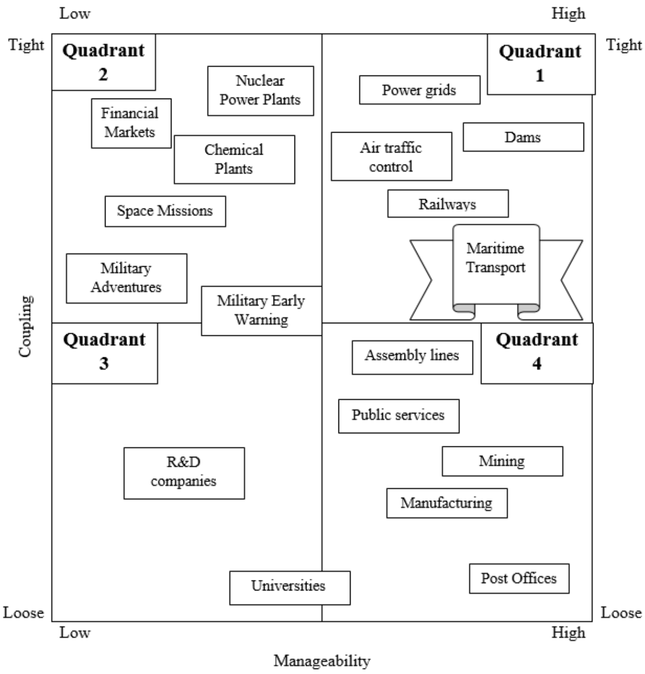

Figure 2. Accident Model Categorization (adapted from (Underwood & Waterson, 2013))

According to the accident model categorization, there is an analysis tecnique which is suitable for each quadrant. In the first quadrant, the epidemiological technique is suitable. Moreover, the systemic technique is sutable for application to the second quadrant, whereas the sequential technique works well when applied in Quadrant 4.

3 METHODOLOGY

3.1 *Human Error Assessment and Reduction Technique (HEART) Methodology*

Human Error Assessment and Reduction Technique (HEART) methodology was first developed by Williams (1986). This technique is based on the human factors literature; it uses a set of basic error probabilities, modified by the assessor, by structured Performance Shaping Factors (PSF) considerations (Kirwan, 1996).

The HEART methodology generally consists of two assessment process steps. The first step is the qualitative process, wherein the assessor has to find the general task of the accidents, which consists of eight points of the general task. After finding the general task, it then breaks it down to smaller parts called Error-producing conditions (EPCs). Furthermore, EPCs represent unsafe acts of the seafarers, which lead to accidents. The second step of this methodology is the quantitative method, wherein Human Error Probability (HEP) is calculated. To obtain the HEP using the HEART methodology, first obtain the nominal human unreliability (NHU), which belongs to the generic task. When the EPCs are determined, the multiplication number of each EPC is obtained. Thereafter, the assessed impact value (AIV) can be calculated using the following formula:

$$AIV = \left(\left(EPC\ Multiplier - 1\right) \times APE\right) + 1 \quad (1)$$

The assessed proportion effect (APE) is highly judgmental, and no guidance is given in the current HEART documentation (Kirwan, 1996). The result of this calculation will be used to calculate the HEP, in order to determine the overall probability of failure for each case. The formula is as follows:

$$HEP = NHU \times AIV_1 \times AIV_2 \times \ldots \times AIV_n \quad (2)$$

The final result of the HEP calculation is between 0 and 1; where if the result is more than 1, it can be assumed that the accident was definitely caused by human factors (Bowo & Furusho, 2016).

If the HEP results of the assessed accidents are between 0 and 1, there is a probability that the accidents are influenced by other factors.

3.2 *4M Overturned Pyramid (MOP) Model*

The MOP model is a new HRA methodology, which was developed by Mutmainnah and Furusho in 2014. This model is the development of the IM model. The basic concept of IM model is the individual (self) centered properties, and the relationships between others factors: man, machinery, media, and management (Furusho, 2002).

Currently, the MOP model has already been developed to assess the qualitative data of accidents. The first step is to observe and break down the unsafe acts, based on the accident data; namely as causative factors (CF). In this step, it breaks them down into 4 factors: man factors, machine factors, media factors, and management factors. Afterwards, each CF is related to another CF which influences the accidents. This relation is called Line Relation (LR). The basic idea of LR is the relationship between the accidents occurred.

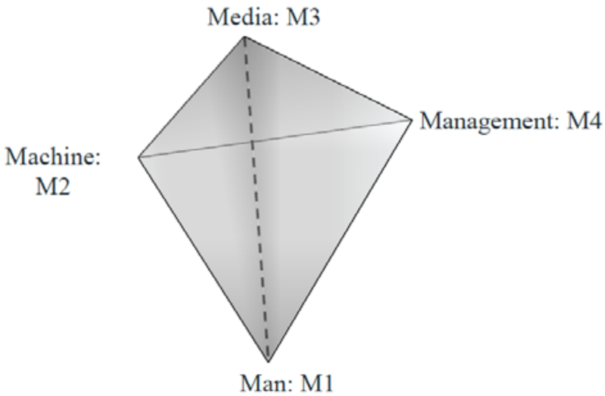

Figure 3. The 4M Overturned Pyramid (MOP) Model (Mutmainnah & Furusho, 2014).

The quantitative process of the MOP model is the calculation of the probability percentage from each factor, compared with the summation of all the factors. Thereafter, the percentage contribution of each factor to the accidents is obtained.

In this research, the fire and explosion accidents in Indonesia from 2008–2013 were assessed. The data of the accidents in Indonesia were obtained from Indonesia National Transportation Safety Committee. Subsequently, these data were assessed using the HEART methodology and MOP model.

4 RESULTS

The results show the comparison of EPCs using the HEART methodology, and CFs using the MOP model, and the HEP.

4.1 *Unsafe acts*

Unsafe acts are the actions which lead to accidents. For each HRA method, the names of unsafe acts are different. This step consists of the qualitative method of the Human Reliability Assessment (HRA). In HEART methodology, unsafe acts are known as EPCs, and in the MOP model it is known as CFs.

There is a total of 38 EPCs and 13 types of EPCs discovered using HEART methodology to assess the fire and explosion accidents in Indonesia, wherein operator inexperience is the largest cause of accidents.

Moreover, by using the MOP model, there are 69 CFs obtained from this accident; where man factor has a total of 18 points, machine factor has a total of 35 points, media has only one point, and management has a total of 15 points. Therefore, the machine factor is the main cause of the accidents, because it has the largest number of points, when compared with the other factors. These results are shown in Table 2 for HEART methodology and Table 3 for the MOP model, respectively.

Table 2. Error Producing Conditions (EPC) by HEART Methodology

Error Producing Conditions (EPC)	Total
Operator inexperience	5
Poor environment	4
Spatial and functional incompatibility	3
Performance ambiguity	3
Impoverished information	3
Inadequate Checking	3
Unreliable instruments	3
Unclear allocation of function	3
Low morale	3
No diversity	2
Inconsistency of displays	2
Task pacing	2
Unfamiliarity	1

Table 3. Causative Factors (CF) by MOP model

4M Factors	Causative Factors (CF)	Total
Man	Irresponsible crew or passengers	6
	Slipshod workmanship	5
	Incapability of seafarer	4
	Lack of utilizing equipment	3
Machine	Equipment failure	11
	Improper utilization equipment	10
	Damage ship construction	5
	Insufficient layout	4
	Flammable material existence	3
	Equipment overload	2
Media	Wind	1
Management	Poor cargo management	5
	Poor management of personnel on board	2
	Poor communication	2
	Poor application of SMS*	2
	Poor management of maintenance	1
	Poor management of berthing schedule	1
	Lack of some navigation and safety equipment	1
	Poor management of monitoring and supervising from company or port	1

* Safety Management System (SMS)

4.2 *Human Error Probability (HEP)*

The HEP for each methodology is shown in the figure below. From 12 fire and explosion cases that were already assessed using HEART methodology, the final result of the HEPs are mostly below 0.5, which indicates the involvement of humans as the cause of accidents where distract by other factors. Moreover, there is only one case that is genuinely because of human factors. The average result for the HEART methodology HEP reveals that 23% of the accidents were caused by human factors.

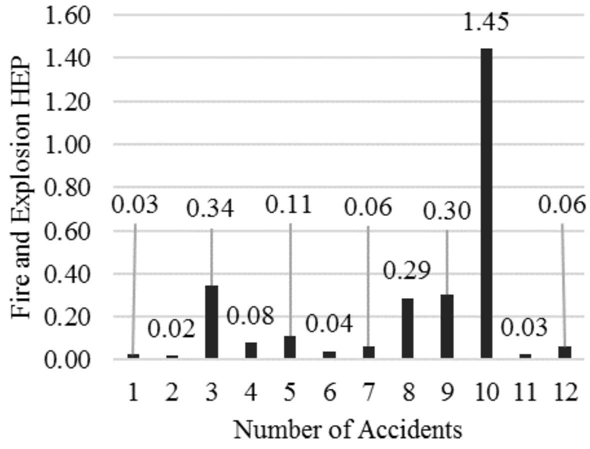

Figure 4. Human Error Assessment and Reduction Technique (HEART) Methodology Human Error Probability (HEP)

Moreover, the MOP model has divided the probability for every factor. *Machine factors* has the biggest percentage, about 51%; then followed by *man* (it can be assumed as human error probability), 26%; *management*, 22%; and *media*, 1%. Figures 4 and 5 show the result of HEP using HEART methodology, and error probability using the MOP model.

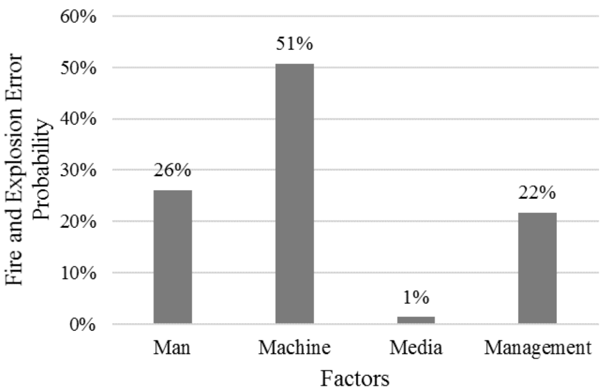

Figure 5. MOP model factor percentages

5 DISCUSSION

The results show that, there are similarities between the EPCs from the HEART methodology, and the CFs from the MOP model, which are obtained from the fire and explosion accidents in Indonesia. In the EPC of the HEART, there is *operator inexperience*, and this EPC is a rather general description of inexperience; whereas in the CF of the MOP model, the inexperience of seafarers is shown as *incapability of seafarer* and *lack of utilizing equipment*. Moreover, the CF of *Slipshod workmanship* is similar to the EPC of *performance ambiguity*, *impoverished information*, *inadequate checking* and *task pacing*. Furthermore, *the irresponsible crew or passengers* in CF can be equated to the *low morale* in EPC.

As for the communication problem in the HEART methodology, it is included in the impoverished information and spatial and functional incompatibility; whereas in the MOP model, they separate the communication problem from the man factor, and include it in the management factor. This is because according to the MOP model, the definition of management is all elements that can control the system and/or people, including communication (Mutmainnah & Furusho, 2014). There are *unreliable instruments* in the EPC that was already obtained in the accident assessment using HEART methodology. Moreover, it is related to the machinery problem in the MOP model.

In HEART methodology, there are 38 EPCs that were already established by Williams (1986). The determination of EPC to utilize is based on the assessor judgement (Kirwan, 1996). The development of EPCs was achieved by Akyuz et al. (Akyuz, Celik, & Cebi, 2016), to generate EPC values for marine transportation, by obtaining the new multiplication number of the EPC in order to be specified in terms of ship operational management.

Further, in the MOP model, the CFs have not been established yet, but there are several CFs which frequently appear during the assessment (Mutmainnah & Furusho, 2016, Mutmainnah & Furusho, 2016).

The final result of the HEP calculation of HEART methodology and the MOP model were quite similar; the average HEP of 12 cases that had been assessed for HEART methodology was 23%, and for the man probability itself in the MOP model, the average HEP was 26%. This shows that the MOP model as the new methodology of HRA is been appropriate for use in the assessment of accidents, such as the developed methodology.

In the case of marine accidents, marine accidents are included in the category of epidemiological techniques, having high manageability and tight coupling. The MOP model is a suitable methodology to be applied in the assessment of marine accidents, because the relationships between man and other factors are described and detailed. Furthermore, the MOP model is firstly proposed to be applied in the marine industry (Mutmainnah & Furusho, 2014). However, it is possible to develop the MOP model to assess the accidents in other sectors of industries.

In addition, HEART methodology was firstly proposed to solve the problem in the nuclear industry (Williams, 1986), which has a different category and characteristic from marine accidents. However, the HEART methodology has been successfully applied in many sectors of industries, such as the railway, aviation, and offshore industries (Deacon, et al., 2013), by the regeneration of EPCs and the generic task (Akyuz, et al., 2016).

6 CONCLUSIONS

By conducting this research, certain conclusions have been arrived at, as follows:

1 The 4M Overturned Pyramid (MOP) model can be applied to assess the human reliability in accidents.
2 In the case of marine accidents, the MOP model can describe all the relationships between factors which affect the accidents; whereas, HEART methodology is only focused on the human factors that affect the accidents.
3 However, the causative factors of the MOP model have not been established, and it is necessary to generate the HEART methodology in order to be suitable for certain industries.

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