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Development of a Human Factors Investigation and Analysis Model for Use in Maritime Accidents: A Case Study of Collision Accident Investigation

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Abstract : *In the shipping industry, it is well known that around 80 % or more of all marine accidents are caused fully or at least in part by human error. In this regard, the International Maritime Organization (IMO) stated that the study of human factors would be important for improving maritime safety. Consequently, the IMO adopted the Casualty Investigation Code, including guidelines to assist investigators in the implementation of the Code, to prevent similar accidents occurring again in the future. In this paper, a process of the human factors investigation is proposed to provide investigators with a guide for determining the occurrence sequence of marine accidents, to identify and classify human error-inducing underlying factors, and to develop safety actions that can manage the risk of marine accidents. Also, an application of these investigation procedures to a collision accident is provided as a case study This is done to verify the applicability of the proposed human factors investigation procedures. The proposed human factors investigation process provides a systematic approach and consists of 3 steps: 'Step 1: collect data & determine occurrence sequence' using the SHEL model and the cognitive process model; 'Step 2: identify and classify underlying human factors' using the Maritime-Human Factor Analysis and Classification System (M-HFACS) model; and 'Step 3: develop safety actions,' using the causal chains. The case study shows that the proposed human factors investigation process is capable of identifying the underlying factors and indeveloping safety actions to prevent similar accidents from occurring.*

Key words : *Human Error, Marine Accident Investigation, Human Factors, Cognitive Process, HFACS*

1. Introduction

Many statistical studies indicate that there has been a downward trend in the number of shipping accidents over the past few decades. On the other hand, the data in the statistical studies show that shipping accidents still occur on a regular basis, and most of the studies also highlight that human error remains a root cause of most incidents (AGCS, 2017; Butt et al., 2013; TSB, 2016).

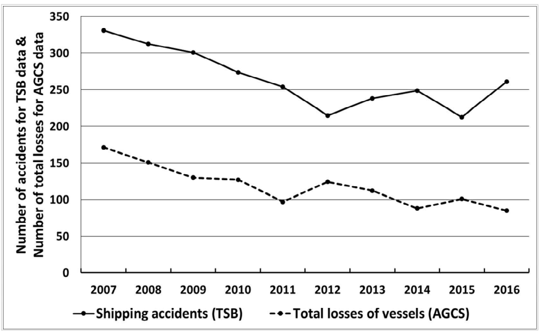

Fig. 1 Shipping accidents and Total losses by year, 2007-2016

As an international regulatory body responsible for providing measures to improve the safety and security of international shipping and to prevent marine pollution, the International Maritime Organization (IMO) has continuously dealt with safety problems. As one of the ways to solve the safety problems, the IMO adopted the Casualty Investigation Code: *Code of the International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident* in order to prevent similar accidents from reoccurring in the future (IMO, 1997). The Code was also adopted to promote a common approach in the safety investigation of marine casualties and incidents, and to promote co-operation between states in identifying the contributing factors leading to marine casualties (IMO, 2000; IMO, 2008). In 2000, the IMO enhanced the Code by providing guidelines for the investigation of human factors (IMO, 2000), and due to the increased interest of the states substantially concerned, such as the flag state, the coastal state, etc. (see chapter 2

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of the Casualty Investigation Code, Res. MSC.255(84) for more information), in the process and outcomes of marine safety investigations, a new Casualty Investigation Code was adopted in 2008 and entered into force in the beginning of 2010 (IMO, 2008). If properly implemented, the investigation of marine accidents could reveal the details of a chain of accident causation, such as the underlying factors, the unsafe acts and the unsafe situations (the causes and contributing factors) of any such casualty which might pose the risks to life, property or to the environment.

However, conventional investigation approaches applied to maritime accidents have tended to focus on finding the immediate causes of accidents (Kletz, 2002). There are many factors which contribute to marine accidents such as communication, competence, culture, experience, fatigue, stress and working conditions (IMO, 2000). This means that just eliminating the immediate causes cannot guarantee that the rates of occurrence of similar accidents will be reduced. In order to prevent or reduce the occurrence of marine accidents, with respect to the investigation of human factors, investigators have to know the causes of the accidents exactly and to understand the interaction between the underlying factors and the immediate events. For this reason, IMO adopted guidelines for the investigation of human factors in marine casualties and incidents and included it in the Casualty Investigation Code by resolution A.884(21) (IMO, 2000). In 2013, new guidelines to assist investigators in the implementation of the new Casualty Investigation Code were adopted, and the resolutions A.849(20) and A.884(21) were revoked by resolution A.1075(28) (IMO, 2013b). The IMO guidelines provide practical advice for the systematic investigation of marine casualties and also allow the development of effective analysis and preventive action (IMO, 2000; IMO, 2013b). With all the advantages of the IMO guidelines, it has been recognized that there is a need to provide a specific procedure for accident investigators to assist them to conduct the human factors investigations properly and effectively in practice (refer to e.g. Schröder-Hinrichs et al., 2011).

IMO encourages the member states to implement the guidelines as soon as practicable, as far as the national law allows, with the goal to improve the quality and completeness of casualty investigations and reports (IMO, 2000).

The guidelines proposed was developed at the request of the Korean Maritime Safety Tribunal (KMST) which is a subsidiary body of the Ministry of Oceans and Fisheries (MOF) under the Marine Accident Investigation and Tribunal Act in Korea. During the research work, the following concepts have been considered;

• Purpose of adopting the Casualty Investigation Code by IMO should be maintained, and

• Procedures of the investigation of human factors should be simplified and much easier to carry out.

In order to retain the meaning of adopting the IMO code and guidelines, the basic theories used in the IMO guidelines were kept to be used in the proposed guidelines. In each step, a graphical model of human factors investigation method was provided and each of them was converted into a tabulated form which can be used as an investigation worksheet.

In this paper, the procedures of the human factors investigation proposed are simply described in Chapter 2. Secondly, the methods and the models used at each step of the modified human factors investigation framework are discussed in detail with a case study. And then, a couple of major comments raised by the investigators who conducted several trial applications of the proposed human factors investigation procedures to marine accidents, and some discussions, are presented. Lastly, Chapter 7 provides general conclusions and recommendations.

2. Human factors investigation procedure

Contrary to the guidelines adopted by IMO Res. A.884(21), the new guidelines adopted by IMO Res. A.1075(28) (the guidelines to assist investigators in the implementation of the Casualty Investigation Code) recommend to choose the optimal set of accident analysis methods to meet the characteristics of particular casualty or incident, and the guidelines also stipulate that the method or the combination of methods used in each investigation should, as a minimum requirements, support (IMO, 2013b):

• Reconstruction of the casualty or incident as a sequence of events;

• Identification of linked accident events and contributing factors at all appropriate levels; and

• Safety analysis and development of recommendations.

The human factors investigation process presented in this paper consists of the steps as follows:

① Step 1: Data collection & occurrence sequence determination;

② Step 2: Human factors identification and classification; and

③ Step 3: Safety actions development.

In Step 1, related information regarding the personnel, tasks, equipment and environmental conditions involved in the occurrence of accidents is gathered using the SHEL model. The SHEL model is commonly depicted graphically to display not only the four components but also the relationships or interfaces, between the 'Liveware' and all the components, i.e., Software (S), Hardware (H), Environment (E), and Liveware (L). Then the occurrence sequence is developed by arranging the information gathered using the cognitive process model. Step 2 involves classifying the type of human error and violation identified in Step 1, and identifying the underlying factors using the Maritime-Human Factor Analysis and Classification System (M-HFACS) model. Lastly, Step 3 focuses on identifying safety actions in order to reduce the occurrence rates of marine accidents or to mitigate their effects.

3. Data collection & occurrence sequence determination

During a human factors investigation, it is likely that the investigators will collect all the information and apply a systematic methodology to analyze the relationships between those errors people made and the accident, and between the underlying causes (including the human behaviour that lead to those errors) and those errors that the underlying factors may have caused. To begin developing the critical relationships between the underlying factors and the immediate events, investigators should first establish the correct sequence of events and any of unsafe actions. The SHEL and Reason Hybrid Model can help to identify missing pieces of evidence or different lines of enquiry that may otherwise have gone undetected, however, the model might not be a sufficient tool for determining the critical relationships between those factors identified. Errors made by humans are closely related to mental models: why humans behave the way they do should be understood by analyzing their mental models and the environmental factors affecting their decision making (IMO, 2000; Skogdalen and Vinnem, 2012). Thus, there should be an additional model in the investigation process for investigators which can help understand the mental models of the human operator. For the reasons above, this study proposed a cognitive process model, in order to determine the sequence of events and their relationships, to organize the information that will be continuously collected throughout the investigation process in a tabulated form, and to identify the unsafe acts and decisions or conditions that caused the accident to occur.

3.1 The circumstances surrounding the accident

The objective of this stage of the human factors investigation is to collect as much information related to the accident which may be of interest in determining possible causes, using the SHEL model. For fact-finding purposes, an additional interview can also be conducted. In order to explain the human factors investigation procedures proposed in this paper, a simple case of collision accident is provided as a case study (see Fig. 2).

• **Brief description:** In a head-on situation, the northbound Sand pump Carrier (Vessel A) collided with the southbound Tanker (Vessel B) in a visibility of over 3 miles at night. If both vessels had kept their courses and speeds, the collision accident would not have occurred. However, each vessel failed to stand a vigilant watch and did make unsafe decisions and did act unsafely.

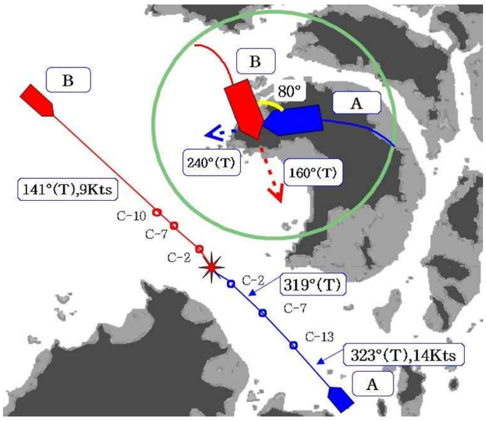

Fig. 2 Timeline of an accident

3.2. Cognitive process model

Once the information which may assist in the understanding of the incident and events surroundingit has been collected, the next stage is to develop a sequence of events and circumstances. In this stage, underlying factors that could cause unexpected action and decision or dangerous situations can be identified using a cognitive process model. The model has been developed based on a modified concept of the cognitive framework for TRACEr (technique for the retrospective and predictive analysis of cognitive errors) in Air Traffic Control (ATC) (Shorrock, 2002). The cognitive process model, in this paper, is made up of 6 steps including 'Pre-task planning', 'Risk Perception', 'Situation Awareness', 'Planning & Decision-making', 'Action Execution', and 'Execution Analysis' (see Fig. 3).

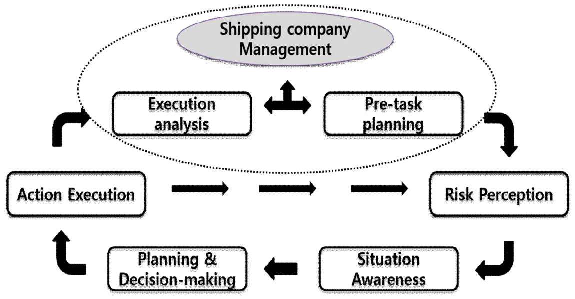

Fig. 3 Cognitive process model

In order to identify unsafe acts and unsafe decisions or conditions, the operator's behaviour should be analyzed by considering the following steps of process (Na et al., 2010).

- **Pre-task planning:** plan for the task considering ship's state, crew member's ability, task features, external factors, etc.
- **Risk perception:** detect dangerous situations or events that could affect pre-planned normal tasks. Check if a dangerous situation or an event was detected at a proper time, and an appropriate method or system was selected for the detection by the OOW (Officer Of Watch-keeping).
- **Situation awareness:** comprehend the dangerous situation causing a threat to the safety of the vessel based on the operator's ability and experience. What kinds of methods (including OOW's knowledge and experience) or systems were used to comprehend the dangerous situation? Check if the OOW understood the situation clearly. If not, what was the reason?
- **Planning & Decision-making:** identify all possible actions that could have avoided the dangerous situation and choose the most appropriate one. Check if all the plans to avoid the dangerous situation were identified properly and if the most appropriate one of them was selected to avoid the dangerous situation. If not, what was the reason?
- **Action execution:** the most appropriate actions must be initiated and performed at the appropriate place and time, and periodic checks should be made to ensure that the action sequence is proceeding as intended. Check if action was taken properly at a proper time. If not, what was the reason?
- **Execution analysis:** analyze the operator's actions performed and the dangerous situations or events that had occurred.

Often in the real world, one or more steps of cognitive process can be skipped depending on the situation. The situation will vary based on a number of factors including vessel traffic conditions (e.g. traffic intensity, navigational aids, radio communication, etc.), navigation area (e.g. coastal waters, open seas, etc.), weather conditions (e.g. water depth, current, sea state, wind, visibility, etc.), voyage plan, ship types, manning level, crew competency, etc. For example, when an operator is in an emergency situation with an urgent decision making is needed or a situation in which there is a familiar routine task to be performed, operator's action is likely to be initiated without assessing the situation and possible alternative actions.

There are some well known decision models which are developed to deal with identifying and selecting the best decision among several alternatives. Rasmussen (1983) explained the fact that decision makers perform at different levels of expertise which refer to distinctions between skill-based, rule-based and knowledge-based behaviour and he proposed the decision ladder template which includes supporting activities like situation analysis, option evaluation and goal selection, planning, scheduling, and executing action (Rasmussen, 1976; Naikar, 2010). In addition, rather than identifying and then selecting the best decision among alternatives, Klein (1993) emphasized that recognitional decision making is much more common than analytical decision making by proposing the Recognition-Primed Decision (RPD) model. The model, which was developed following a number of studies of expert decision making, explains how people can make decisions without having to compare options, especially in high time pressure situations. According to his study, it was found that experienced decision makers did not usually think about alternatives, very few decisions were made using analytical processes, or did not consider advantages and disadvantages of the different options. Instead, they rely on their abilities to recognize and appropriately classify a situation (Klein, 1993; Naikar, 2010; Strauch, 2009).

However, because the purpose of this step of the human factor investigation procedure is mostly to develop a sequence of events and to identify underlying factors that led to unsafe acts and decisions or conditions, the cognitive process model will help the investigators focus on identifying the factors that could affect operator's decision making and the factors that could possibly create a dangerous situation.

3.3. Determination of occurrence sequence (case study)

The findings of the investigation are presented on the occurrence sequence worksheet given below in Tables 1 & 2. In order to determine the occurrence sequence and to identify unsafe acts and unsafe decisions or conditions, the following steps are required:

① Determine the occurrence sequence (fill the occurrence sequence column);

② Fill the remark column with the important factors / additional information;

③ Identify action executions from the occurrence sequence column;

④ Analyze the actions executed using the cognitive process model; and

⑤ Identify unsafe acts and unsafe decisions or conditions for use in Step 2.

Table 1 Occurrence sequence worksheet (Vessel A)

YY.MM.DD	XX.XX.XX								
Time	17:00	21:45	22:40	22:50	?	23:15	23:25	23:31	23:32
Risk Perception / Situation Awareness	-	-	-	-	-	Saw on the radar the echo of a vessel	Saw her green light with binoculars	a close-quarters situation was developing	-
	-	-	-	Capt. judged: 2/O has experience on similar vessels	-	-	Misjudged: as crossing situation	the risk of collision	-
Planning & Decision-making / Action Execution	-	-	-	-	Proceeded along the center of the narrow channel	-	Small alteration of course to port	-	-
	2/O came aboard: Unqualified OOW on board	Departure	Reported to VTS (ship's position)	Handed over the duties to 2/O	Altered course to 320	Failed to maintain proper lookout (normal lookout)	Watched from static position, Failed to take action to avoid collision	Left full rudder	-
Occurrence Sequence	2/O onboard	Departure	Report to VTS	Capt. left the bridge	Altered 320 deg. (TC 322)	Saw a vessel on the radar	Saw her green light with binoculars	Left full rudder, stop engine	collision
Remarks	Workload: No Fatigue: Normal Voyage plan: Normal Safe manning: - 2/O not qualified, - C/O is vacated, - Crew list not approved			Misjudgment (Capt. judged: 2/O has experience on similar vessels)	2 radar on (3, 6 mile range), speed: 13 kt	Saw on the radar the echo of a vessel distant about 3 miles and bearing ahead or very slightly on her starboard bow	Deck crane obstructed navigation bridge visibility, watch from static position, didn't know how to do radar plotting, misunderstood another vessel's intention		

Vessel Name: A Person Involved: Capt., 2/O

Table 2 Occurrence sequence worksheet (Vessel B)

YY.MM.DD	XX.XX.XX						
Time	16:15	21:00	23:00	23:25	23:28		23:32
Risk Perception / Situation Awareness	-	-	-	Saw her red light	-	a close-quarters situation was developing	-
	-	-	-	Misjudged: port to port crossing (could not see Mast light)	-	Risk of collision	-
Planning & Decision-making / Action Execution	-	-	Proceeded along the center of the narrow channel	Normal lookout	-	-	-
	Departure	Handed over the duties to C/O	Altered course to 141 (C/O: steer the ship himself)	Failed to maintain proper lookout (Normal lookout)	Stuck on the mobile phone	Right full rudder	-
Occurrence Sequence	Departure	Handed over the duties to C/O	Altered course to 141 deg.	Saw her red light (distant about 2.6 miles)	Stuck on the mobile phone	Right full rudder	collision
Remarks	Workload: Yes Fatigue: Yes Voyage plan: Normal Safe manning: vacancy - 2/O, helmsman (requested supplement the personnel-orally)	C/O: slept 5 hours out of the last 24 hours TC: 185 deg. Speed: 11 kt	* Helmsman: lookout (inexperienced) * C/O: Steer the ship Speed: 9 kt	* Saw her red light * didn't know how to do radar plotting * predicted: port to port crossing	Helmsman steer the ship	-	-

Vessel Name: B Person Involved: Capt., C/O, Helmsman

When the accident information has been collected, the occurrence sequence can be developed by arranging the information regarding occurrence events and circumstances according to the time column; then all the important factors identified should be written in the remark column. Once the occurrence sequence has been developed, the actions executed can be identified and analyzed using the cognitive process model. Tables 1 and 2 show the results of the cognitive process analysis. Identified unsafe acts and decisions related to Vessel A are as follows:

- Failed to maintain proper lookout: misunderstood another vessel's intention / situation (2/O);
- Kept watch from a static position (2/O);
- Small alterations of course (2/O);
- Proceeded along the center of the narrow channel (2/O);
- Did not verify the qualification of OOW (Capt.); and
- Had an unqualified OOW on board (2/O).

Identified unsafe acts and decisions related to Vessel B are as follows:

- Failed to maintain proper lookout: stuck on the mobile phone (C/O);
- Failed to maintain proper lookout: misunderstood another vessel's intention (C/O);
- Failedto maintain proper lookout: doing helmsman's job (steer the ship) (C/O);
- Proceededalong the center of the narrow channel (C/O); and
- Breach of the rules – minimum safe manning level (Capt.).

4. Human factors identification and classification

One of the most important purposes of carrying out a human factors investigation is to uncover the underlying causes behind the immediate events, such as unsafe act or decision of an individual or group. Our experience shows that, intentional or not, those underlying factors can easily be left unrevealed during the investigation process. This can cause the underlying causes to occur again in the future, and this can also lead to unsafe acts or conditions which can result in the occurrence of similar accidents or even other kinds of accidents. This paper proposes to use a Maritime-Human Factor Analysis and Classification System, the so-called M-HFACS model, which can allow investigators to check if any human factors exist that are related to the unsafe acts identified, looking through all the categories of underlying factors provided in the model (Wiegmann and Shappell, 2003). For the sake of the convenience of the underlying factors identification work, a structured list of underlying factors, a so-called 'underlying factor code', is also provided in the manual of human factors investigation submitted to the Korean Maritime Safety Tribunal (KMST) as a set of guidewords to help investigators identify the related underlying factors.

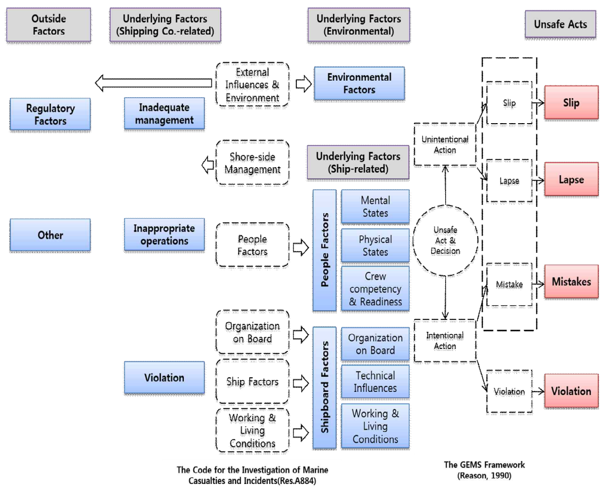

Fig. 4 M-HFACS model diagram & correlation with IMO guidelines A.884(21)

4.1. Maritime-Human Factor Analysis and Classification System

As shown in Fig. 4, the M-HFACS model was developed based on the human related factors classification diagram provided by IMO guidelines (Res. A.884) and the Generic Error-Modeling System (GEMS) frameworks (IMO, 2000). The diagram provided by IMO guidelines shows a number of factors that have a direct or indirect impact on human behaviour and the potential to perform tasks, such as people factors, ship factors, working and living conditions, organization on board, shore-side management, and external influences and environment. The GEMS framework is a broad classification of the causes of human errors that can be related to the Skill-based, Rule-based and Knowledge-based (SRK) concepts (Rasmussen, 1983; IMO, 2000). When an unsafe act or decision has been identified, firstly, it is necessary to determine whether the error or violation is an unintentional or intentional action. The second sub-stage is the selection of the error type or violation that best describes the failure. There are four potential error / violation categories, i.e., slip, lapse, mistake and violation (IMO, 2000; Reason, 1990). A slip is an unintentional action where the failure involves attention and a lapse is an unintentional action where the failure involves memory. These are errors in execution. A mistake is an intentional action, but there has been no deliberate decision to act against a rule or plan. These are errors in planning. A violation is a planning failure where a deliberate decision to act against a rule or plan has been made (IMO, 2000).

The reason for dividing unsafe acts or decisions into four potential error / violation categories is that safety actions may vary depending on the type of error / violation that occurred. Slips and lapses are errors at the skill-based level and usually occur when the routine and highly-practiced tasks are carried out. Those are related to actions that do not go as planned when the plan is adequate (Reason, 1997). For errors categorized as slip, those safety actions that can make the OOW pay more attention to what he is doing should be identified. For example, safety actions such as 'training of safety consciousness', 'improvement of working environment (noise / vibration reduction system, indoor temperature / humidity control, better displays, etc.)' or 'improvement of design considering ergonomics (design of controls to make it difficult to operate them accidentally, etc.)' will be effective. In order to prevent errors categorized as lapse, since it is associated with failures of memory, the safety actions should focus on helping the OOW remember things to do. Safety measures such as 'providing clear labeling and written instructions', 'alarms for indicating any omission', etc. will be effective. In order to reduce the probability of occurrence of mistakes, 'providing proper job training (improving operator competence) or clear guidelines', 'procedures and clear internal / external rules' can be the appropriate safety actions. Regarding a violation, measures such as 'improving safety culture' and 'tightening related rules' will be the effective safety actions.

Unsafe acts or decisions can be categorized according to the information provided by the cognitive processes model in Step 1 and by considering whether they are related to the planning or execution of the activity. Once the error type or violation is selected, the final stage of this step is the identification of underlying factors. In this study, underlying factors are classified into four categories, i.e., environmental underlying factors, ship-related underlying factors, shipping company-related underlying factors, and outside factors. Some examples of those underlying factors are as categorized in Table 3.

Table 3 Examples of M-HFACS categories and simple comparison with other maritime applications

M-HFACS		HFACS-MSS, HFACS-Coll
Outside factors		**Outside factors**
Regulatory factors	Special rules made by an appropriate local authority, International regulations and codes, Survey and inspections etc.	Regulatory factors
Other	Economic pressures, Environmental concerns, legal pressure etc.	Other
Shipping company-related underlying factors		**Organisational influences, Unsafe supervision**
Inadequate Management	Supplies of articles for ship, charts etc., Crew manning, Education / Training, Crew management, etc.	Resource management, Inadequate supervision
Inappropriate Operations	Safety policy and philosophy (safety culture, attitude and trust), Policy on recruitment, Scheduling(operational tempo), SMSetc.	Organisational climate, Operational process
Violation	Breach of rules, etc.	Leadership violations
Environmental underlying factors		**Preconditions for unsafe acts**
Environment(External)	Weather conditions, Sea state, Port and transit conditions (VTS, Pilot etc.), Traffic density, Ice conditions etc.	Physical environment
Ship-related underlying factors (People Factors)		**Preconditions for unsafe acts**
Mental States	Emotional state, Complacency, Distraction, Haste / Panic etc.	Condition of operators
Physical States	Medical fitness, Drugs and Alcohol, Fatigue etc.	Condition of operators
Crew Competency & Readiness	Lack of experience, Poorly qualified etc.	Personnel factors (SRM, Personal readiness)
Ship-related underlying factors (Shipboard Factors)		**Unsafe supervision, Preconditions for unsafe acts**
Organization on Board	Composition of the crew (nationality, competence), Manning level, Workload, Complexity of tasks, On-board management and supervision (BRM), Planning (voyage, cargo, maintenance) etc.	Inadequate leadership, Planned inappropriate operations, Failure to correct known problems, SRM
Technical Influences	Design, State of maintenance, Equipment (availability, reliability), Cargo characteristics (including securing, handling and care) etc.	Technological environment
Working & Living Conditions	Level of automation, Adequacy of living conditions, Opportunities for recreation and rest, Adequacy of food, level of ship motion, vibrations, heat and noise etc.	Technological environment
Unsafe acts		**Unsafe acts**
Errors	Slip, Lapse, Mistakes	Errors
Violation	Violation	Violations

Those ship-related underlying factors are local workplace related factors, and those shipping company-related underlying factors and some of the outside factors are organizational factors (Reason, 1997). The M-HFACS model adopted the concept of organizational influences provided by Reason, and the model also considered the taxonomies of the Human Factor Analysis and Classification System (HFACS) framework, which was originally developed for use in aviation (Wiegmann and Shappell, 2003; Rothblum et al., 2002). The reasons to adopt Reason's model (Reason, 1990) and the HFACS taxonomy for the identification and classification of underlying human factors in this paper were that, as Schröder-Hinrichs et al. (2011) and Chen et al. (2013) stated in their paper, the HFACS framework was developed heavily based upon Reason's model of latent and active failures, and the IMO guidelines A.884(21) recommended mainly to use Reason's model. In this way, the HFACS framework satisfies the IMO guidelines to classify the causal factors for investigating marine casualties (Chen et al., 2013), and also it provides investigators with a user-friendly tool for identifying and classifying the human factors (Shappell and Wiegmann, 2000). The HFACS framework has been widely used in other areas such as railroad accidents (HFACS-RR) (Reinach and Viale, 2006), maintenance extension (HFACS-ME) (Krulak, 2004), mining incidents (HFACS-MI) (Patterson and Shappell, 2010) and there are also some cases when the HFACS framework was applied within the maritime domain, such as machinery spaces on ships (HFACS-MMS) (Schröder-Hinrichs et al., 2011), maritime accidents (HFACS-MA) (Chen et al., 2013), analysis of collision at sea (HFACS-Coll.) (Chauvin et al., 2013), and analytical HFACS model for investigating human errors (Celik and Cebi, 2009), etc.

Basically, for the identification of underlying factors in this step, the HFACS framework developed in the maritime domain was adopted. Comparing to the original HFACS framework, the modified HFACS framework has the additional fifth top-most level named "outside factors" which was introduced by Reinach and Viale (2006), and recently, was used by the work of Patterson and Shappell (2010), Schröder-Hinrichs et al.(2011), Chauvin et al. (2013), and Chen et al. (2013). Other minor modifications were made by different authors based on the purpose of their work. In addition, the shipping industry has its own specific characteristics that should be taken into account. The most noticeable characteristic is the mobile nature of seagoing ships. On account of the characteristic, the master has the power and the authority over the ship and its crew, even though the master receives orders and resources from ashore. This caused difficulties in adopting the HFACS taxonomies directly into maritime accident investigation. For example, as Chauvin et al. (2013) mentioned in their paper, the categories of unsafe supervision (unsafe leadership) level are related to both the persons ashore who have the responsibility and authority to monitor the safety of each ship and the master on board, thus the level must be divided into two different levels, shore-based supervision and shipboard supervision. Because of the reason above, this study provided 'shipping company-related (shore-based)', 'ship-related (shipboard)', and 'outside' underlying factor levels for failure classification, and the three levels of HFACS, such as 'Preconditions for Unsafe Acts', 'Unsafe Supervision', and 'Organizational Influences', and their categories were reorganized as shown in Fig. 4 and in Table 3.

4.2 Results of the M-HFACS (case study)

There is a significant difference between the 'Determination of occurrence sequence' stage (cognitive model) in Step 1 and the 'Human factors identification and classification' stage (M-HFACS model) in Step 2. At the 'Determination of occurrence sequence' stage, the factors and / or events directly related to the actions executed and / or situations are identified in a time sequence, whereas in Step 2, the factors and / or events indirectly related to the occurrence of the unsafe acts or unsafe decisions are identified by checking all the categories of underlying factors in the model. For example, the unsafe act 'Misunderstood another vessel's intention (vessel A-2/O)' is linked with the underlying factors below (see Fig. 5):

• Misunderstood another vessel's intention (improper lookout)

• Ship-related underlying factors (people factors - crew competency & readiness)

√ Lack of knowledge / poorly qualified

√ Inadequate prediction

• Shipping Co.-related factors (Inadequate management)

√ Inappropriate education / training

Fig. 5 and Fig. 6 show the results of the M-HFACS model. It should be kept in mind that, during an accident investigation, different types of uncertainties could exist especially in 'determination of occurrence sequence' and 'identification of underlying factors' stages. If any uncertainty exists, every effort should be made to avoid the uncertainty, and if this uncertainty cannot be removed, it must be properly defined, identified, and documented in the investigation report.

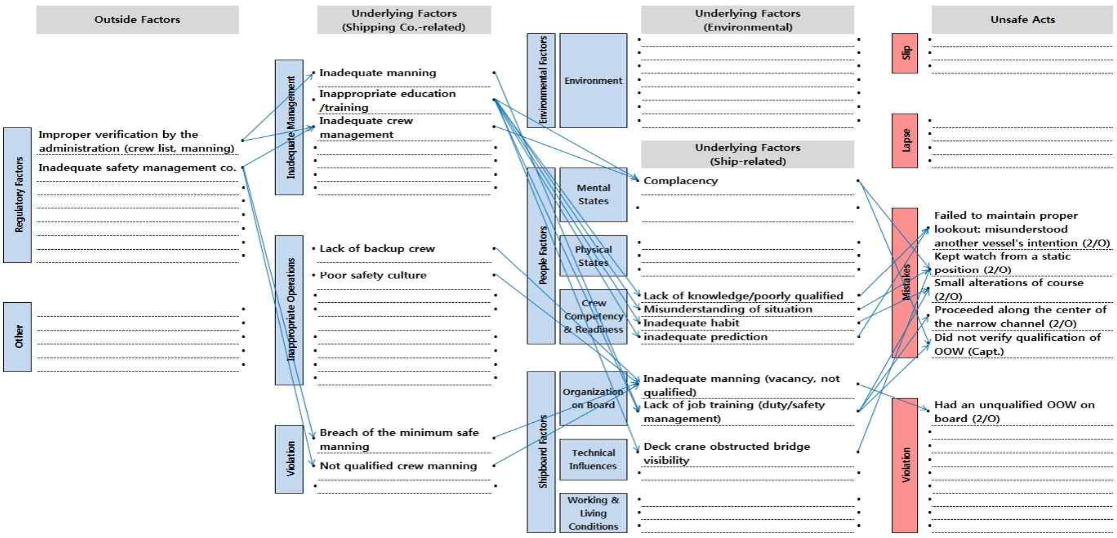

Fig. 5 Results of M-HFACS (Vessel A)

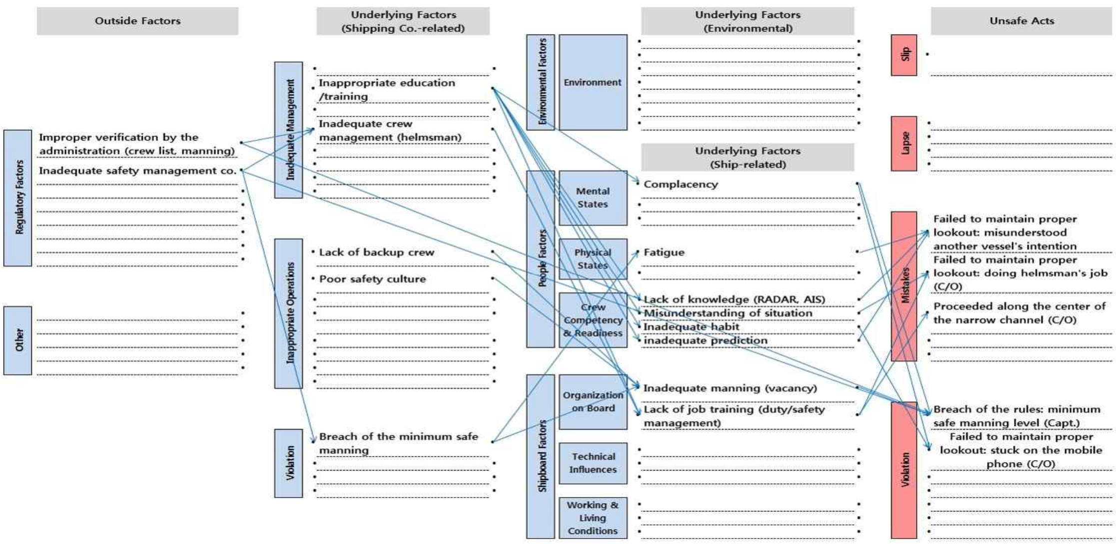

Fig. 6 Results of M-HFACS (Vessel B)

5. Safety actions development

The ultimate objective of the accident investigation is to enhance maritime safety and to protect the marine environment from pollution. This objective can be achieved by identifying safety deficiencies and recommending safety actions to correct these deficiencies. The recommended safety actions should clearly identify what needs to be done, who or what organization is responsible for implementing the safety actions (IMO, 2000). In this paper, the term 'safety action' indicates any kinds of safety measures that can be used to reduce associated risks. In this section, causal chains are proposed to identify the safety actions.

5.1 Causal chains

The final step of the human factors investigation is to identify potential safety problems and to develop safety actions in order to reduce the probability of occurrence of human error, and / or to mitigate the consequence of marine accidents. As shown in Fig. 7, causal chains can be used to assist the identification and selection of safety actions. The causal chains diagram was developed based on the expression, such as "causal factors – failure – circumstance – accident – consequences", in the IMO formal safety assessment guidelines (IMO, 2007).

In general, human error is the result of complex chains of events with a diversity of causes. The purpose of using causal chains is to facilitate a structured thought process in order to understand how a safety action works, how it is applied and how it would operate. In order to achieve this, in this step, techniques such as brainstorming can be used by experts.

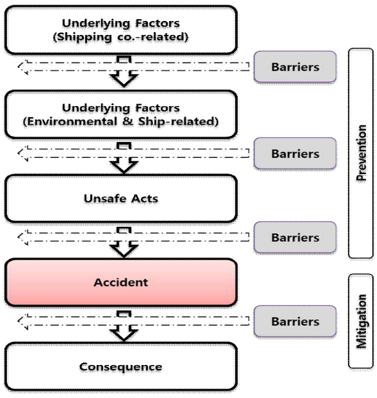

Fig. 7 Causal chains

5.2. Safety actions identified (case study)

The safety actions developed in Step 3 are the most important products of the human factors investigation process. The safety actions can be developed considering the following areas:

• Technical / Engineering: Ergonomic design (equipment, work spaces, man-machine interface etc.), Clear labelling and instructions, etc.

• Working environment: Working conditions (noise levels, temperature and humidity, vibration etc.) etc.

• Personnel: Training for crew members, Language and cultural issues, Workload, Motivational and leadership issues, etc.

• Organizational / Management: Organization policies (recruitment, training, crew levels, etc.), Operational procedures, Safety management systems, etc.

Tables 4 & 5 show the safety actions developed as a result of the case study. From the results of Step 2, six unsafe acts related to Vessel A and five unsafe acts related to Vessel B were identified. For example (Vessel B), the unsafe act 'Failed to maintain proper lookout: stuck on the mobile phone (C/O)' is categorized in Violation. The chief officer (C/O) of Vessel B answered the phone without considering his obligation to take proper lookout on the bridge. In Step 2, those underlying factors caused the unsafe act to occur were identified as 'Complacency' and 'Inadequate habit' in ship-related underlying factors and 'Inappropriate education / training' in shipping company-related underlying factor (see Fig. 6).

Table 4 Safety actions (Vessel A)

Categories			Underlying Factors	Potential Safety Problems	Safety Action
Outside	Shipping Co.	Ship			
		√	Lack of knowledge / poorly qualified	Crew competency & readiness	OJT (on the job training) (RADAR etc.)
		√	Inadequate prediction	Crew competency & readiness	OJT (bridge duty, navigation)
		√	Complacency	Mental states	OJT (bridge duty, safety), Crew management guide for Capt.
		√	Misunderstanding of situation	Crew competency & readiness	OJT (bridge duty, safety, navigation)
		√	Deck crane obstructed bridge visibility	Technical influences	OJT (bridge duty, safety), Lookout guide on bridge
		√	Inadequate habit	Crew competency & readiness	OJT (bridge duty, safety, navigation)
		√	Lack of job training (duty / safety management)	Organization on board	On board job training Checklist (duty), Individual duty checklist
		√	Inadequate manning (vacancy, not qualified)	Organization on board	Crew management procedure (qualification / job experience)
	√		Inappropriate education / training	Inadequate management	Revise the procedure (Training & items)
	√		Inadequate crew management	Inadequate management	Revise the procedure (Check the ability in performing duties before on board)
	√		Inadequate manning	Inadequate management	Revise the procedure (Check the ability in performing duties before on board)
	√		Lack of backup crew	Inappropriate operation	Secure the backup crew
	√		Poor safety culture	Inappropriate operation	Safety education (Including the safety culture related issues, health and safety leadership)
	√		Breach of the minimum safe manning	Violation	Enhanced safety management system, on board inspection
	√		Not qualified crew manning	Violation	Enhanced safety management system, on board inspection
√			Improper verification by the administration (crew list, manning)	Regulatory factors	Check the Crew list and minimum safe manning thoroughly
√			Inadequate safety management co.	Regulatory factors	Check the safety management system

Table 5 Safety actions (Vessel B)

Categories			Underlying Factors	Potential Safety Problems	Safety Action
Outside	Shipping Co.	Ship			
		√	Fatigue	Physical states	Develop duty hours management program
		√	Lack of knowledge (RADAR, AIS)	Crew competency & readiness	OJT (on the job training) (RADAR etc.)
		√	Inadequate prediction	Crew competency & readiness	OJT (bridge duty, navigation)
		√	Misunderstanding of situation	Crew competency & readiness	OJT (bridge duty, navigation), BRM
		√	Lack of job training (duty / safety management)	Organization on board	On board job training Checklist (duty), BRM
		√	Complacency	Mental states	OJT (bridge duty, safety), Forbid the use of personal equipment / belongings in bridge
		√	Inadequate manning (vacancy)	Organization on board	Develop duty hours management program
		√	Inadequate habit	Crew competency & readiness	OJT (bridge duty, safety)
	√		Breach of the minimum safe manning	Violation	Enhanced safety management system, on board inspection
	√		Inappropriate education / training	Inadequate management	Revise the procedure (Training & items)
	√		Inadequate crew management (helmsman)	Inadequate management	Revise the procedure (Check the ability in performing duties before on board)
	√		Lack of backup crew	Inappropriate operation	Secure the backup crew
	√		Poor safety culture	Inappropriate operation	Safety education (Including the safety culture related issues, health and safety leadership) e.g. including the effects of a positive safety culture
√			Improper verification by the administration (crew list, manning)	Regulatory factors	Check the Crew list and minimum safe manning thoroughly
√			Inadequate safety management co.	Regulatory factors	Check the safety management system

In order to reduce the occurrence of the unsafe act ‘Failed to maintain proper lookout: stuck on the mobile phone’, safety actions, ‘OJT in bridge duty and safety’ and ‘Forbid the use of personal equipment / belongings in bridge’ in ship-related level, and ‘Revise the training procedure’ in shipping company-related level were identified during a brainstorming session.

6. Discussion

Before this case study was conducted, several trial applications of the human factors investigation procedures proposed in this paper were carried out by KMST investigators. During the trial applications, a couple of key issues and several minor comments were raised by the investigators. Those minor comments have already been reflected in the procedures and models. Regarding the key issues, the investigators felt that the human factors investigation was a time consuming task, and the human factors theories and methodologies used were difficult to understand. This is because they are usually swamped with a heavy workload, and even more analysis work is needed to add the human factors investigation procedures to the conventional marine accident investigation procedures, and also because they are not specialized in the area of human factors.

Based on the above, some questions that should be considered are addressed here. Firstly, is the human factors investigation just a time consuming task? Is it worth the effort to conduct the human factors investigation procedures? These questions can be answered here as a large number of journal articles and publications have already dealt with these concerns. The articles indicate that human error accounts for a large portion of major claims and maritime accidents (e.g., refer to Hetherington et al., 2006; MCA, 2010). It is clear that human errors constitute a significant threat to the safety of shipping, and factors related to human errors should be investigated and then appropriate safety actions should be taken to reduce human errors so as to increase the safety of shipping. Apart from the reasons above, there is a clear requirement in the III Code (IMO Instruments Implementation Code) to build up statistical data, especially in human factor issues leading to accidents (IMO, 2013a).

Secondly, are those human factors theories and methods really so difficult for someone who is not familiar with human factors to understand? Sometimes human factors investigations can be uncommonly complex and intricate; especially when a very serious marine accident with lots of human factors involved is being investigated. The IMO Casualty Investigation Code requires that the flag state of a ship involved in a very serious marine casualty is responsible for ensuring that a marine safety investigation is conducted and completed in accordance with the Code (IMO, 2008). When a serious marine accident is investigated, some of the human factors experts should be included in the investigation team depending on the particular circumstances of the accident being investigated. Also, it should be understood that a human factors specialist may be of significant value in the investigation. On the other hand, there may also be a set of questions that should be considered relating to the investigation of non-serious marine accidents. When non-serious marine accidents with few human factors involved are investigated, can we just say that 'it is not necessary to have human factors experts in the investigation team', or 'those human factors in very serious marine accidents are more important factors than those human factors identified in non-serious marine accidents'? Indeed, it is not practically possible to have the human factors experts in every marine accident investigation, often the investigators have to investigate non-serious marine accidents and some serious marine accidents without any support from human factors experts. And, those human factors / underlying factors identified in non-serious accidents are also important because each one of the underlying factors can lead to a severe accident depending on the circumstances; that is to say, investigating non-serious marine accidents and identifying related underlying factors are just as important as investigating serious marine accidents. During the investigation (no matter how serious the accident is), identifying underlying factors and preparing safety actions to control the underlying factors are of great importance to prevent similar accidents or more severe accidents occurring in the future. Thus the investigators should have formal and specific training in the identification of human factors in marine casualties and incidents, so that they can understand the human factors theories and methodologies which are necessary in the human factors investigation. When they get used to conducting the human factors investigation procedures, they can carry out the human factors investigation work much faster and in a most effective way. It has also been shown, from extensive experience, that the training and qualifications of marine safety investigators is of great importance. The III Code (IMO, 2013a) and the IMO Casualty Investigation Code (IMO, 2008; IMO, 2013b) require that marine safety investigations should be conducted by impartial and objective investigators, who have expertise in marine casualty investigation and are knowledgeable in matters relating to the marine casualty or incident in order to achieve a systematic and effective safety investigation. Also, the IMO guidelines A.1075(28) emphasized the need to develop a formal training programme to ensure that investigators acquire the necessary knowledge, understanding and proficiency in marine safety investigation (IMO, 2013b).

Additionally, human factors and safety training should also be prepared for the interested parties, such as operators, managers, ship owners and so on. In general, human errors occur because of the underlying factors influencing an operator's abilities and the environments including the work conditions, the organization, and the management systems. The IMO guidelines for Formal Safety Assessment (FSA) have also defined the occurrence of human error as follows (IMO, 2007), *"Human error occurs onboard ships when a crew member's ability falls below what is needed to successfully complete a task. Whilst this may be due to a lack of ability, more commonly it is because the existing ability is hampered by adverse conditions."* From the case study, it was found that there were numbers of underlying factors associated with the management systems and the organization (around half of underlying factors identified (Vessel A: 53 %, Vessel B: 47 %) were categorized in 'shipping company related factors' and 'outside factors - regulatory factors'). For example, in Fig. 6 and Table 2, the ship owner (shipping company) and the safety management company were in breach of the minimum safe manning despite the fact that the captain already informed there was a vacancy of navigation officer that needed to fill (Vessel B) and the port state did not check the crew list and the manning level of the ship properly. Those factors caused the unsafe act 'Breach of the rules: minimum safe manning level (captain)'. Human factors and safety training will help the interested parties better understand human factor issues.

In order to reduce the probability of occurrence of human error leading to increased risk to life, property and environment and / or to mitigate their effects, various types of human error analysis techniques have been developed. Those proactive analysis methods rely highly on statistical data, and especially when carrying out quantitative human reliability analysis, it is essential to obtain a specific database which contains information on the number of opportunities for errors and the frequency of errors in each human error category. Nevertheless, in general, only limited data is available and even that data is frequently unreliable. In many cases, those human reliability analyses have mainly used extrapolated data from the most available sources (Embrey, 1994). The human factors investigation procedures proposed in this paper can possibly be used as a kind of data collection system because the M-HFACS model contains a human factors classification system. To achieve this, it is necessary to have a feedback system in place so that the methodology and the human error taxonomy used in the procedures can be developed. Also, it is important to use a common classification for human error data because this can allow a large number of errors in each error category to be collected (Embrey, 1994).

From the case study, it is shown that the proposed human factors investigation procedures are capable of identifying the underlying human factors and developing safety actions to prevent similar accidents from occurring. However, this case study has some limitations. Although the human factors investigation procedures including accident causation models were revised once as a result of the comments received from KMST investigators, who applied the procedures to the real accident investigation cases, considerable efforts, such as revising the underlying factors classification, validating (assessing if they are both valid and reliable) the procedures and accident causation models, etc. are still required to improve the investigation procedures.

7. Conclusion

Basically, a human factors investigation is not independent of maritime casualty investigation procedures. Since human factors include all the interactions between humans and other elements such as software, hardware, environment and other people, the human factors investigation is not a procedure for investigating only human errors of marine accidents. It can be said that the human factors investigation is one kind of detailed investigations of marine casualties and incidents. Thus, the human factors investigation procedures should be conducted whenever a detailed investigation of marine accident is required. For this reason, easier and more systematic investigation procedures need to be developed. In this study, an effort was made to satisfy this need and to develop a human factors investigation procedure that can be followed efficiently.

This paper presented a modified version of human factors investigation procedures which was developed to provide a guide for determining the occurrence sequence of marine accidents, to identify underlying factors that contribute to human error in marine accidents, and to develop safety actions that can manage the risks associated with shipping activity. It also provided an application of the modified human factors investigation procedures to a collision accident as a case study.

As a result of the study, some factors that should be considered further were highlighted. Firstly, a regular, formal training course which is designed to give investigators (and interested parties) an understanding of human factor issues in marine casualty investigation should be provided. Secondly, a feedback system should be organized so that the framework of the human factors investigation procedures proposed and the human error taxonomy used in the procedure can be developed. Thirdly, a common classification system for human error and underlying factors should be used. This will allow human errors and underlying factors to be collected in each category. Lastly, the human factors investigation procedures should be implemented properly and more applications of the human factors investigation should be obtained, so that lessons can be learnt effectively from maritime casualties, incidents and also near-misses. This can also help to accumulate data and to develop the data collection system.

It is most true that the study of human factors is a matter which is increasingly important to reducing maritime casualties and incidents and to enhance shipping safety. Thus, there is a need to conduct more research on the human factors investigation of marine accidents and to put more effort into identifying the underlying factors associated with marine accidents in order to reduce the occurrence and to mitigate the effects of marine accidents.

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