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Application of HFACS (The Human Factors Analysis and Classification System) to the Korean domestic passenger ship accidents

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APPLICATION OF HFACS (THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM) TO THE KOREAN DOMESTIC PASSENGER SHIP ACCIDENTS

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature): ....

(Date): 19 Sep. 2017

Supervised by: *

World Maritime University

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ABSTRACT

Title of Dissertation: **Application of HFACS (The Human Factors Analysis and Classification System) to the Korean domestic passenger ship accidents**

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This dissertation aims to review the passenger ship safety in Korea by identifying human error causal factor in the investigation reports.

Although more than 80% of the causes of marine casualties reported as human error, research and application of human factors are still insufficient compared to the development of marine technology. The sinking accident of Sewol ferry that left 304 casualties is also an accident that is caused by a combination of various human errors such as cargo overload, cargo securing faulty, and inappropriate maneuvering. In order to prevent the further passenger ship accident, there is an urgent need to address the safety problems caused by human error.

The paper reviewed the 30 accidents investigation reports of Korean domestic passenger ship from 2014 to 2015. A total of 96 contributing factors were obtained from the accident reports, and classified under the category of Marine HFACS framework, which consists of three levels: organisational influences, precondition for unsafe acts, and unsafe acts. The Marine HFACS analysis identified the relationships between contributing factors of each level and the accident type of machinery failure, grounding, flooding, contact, and collision.

The finding from this study reveals that the preponderant contributory factor to the passenger ship accident was identified, and specific causal factors need further development. Additionally, the understanding of the accident trend through the causal relationship analysis assists to take measures to prevent the recurrence of the accident.

KEYWORDS: Domestic passenger ship, Human error, HFACS, Maritime-HFACS

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LIST OF ABBREVIATIONS

C/E	Chief Engineer
FRAM	Functional Resonance Analysis Method
IMO	International Maritime Organisation
ISM	International Safety Management
KCG	Korea Coast Guard
KMST	Korean Maritime Safety Tribunal
KOSWEC	Korea Seafarer's Welfare and Employment Centre
KSA	Korea Shipping Association
MOAF	Ministry of Oceans and Fisheries
Ro-Pax	Roll-on Roll-off Passenger
SOLAS	International Convention for the Safety of Life at Sea
HFACS	Human Factors Analysis and Classification System

1. Introduction

1.1 Background

The maritime safety is probably the most significant object in the shipping industry, particularly in the passenger shipping sector due to its unique characteristics that need more attention for safety. It is notable that the global ferry industry transports about 2.1 billion passengers per year and ferry transportation is important to millions of people as part of their daily lives (DNV-GL, 2016). However, world accident rate for passenger ship still stays the certain level indicating red signal, while the passenger shipping sector has been enlarged their portion among shipping industry each year (EMSA, 2016). As the passenger ship is engaged in the service business, the satisfaction of passenger could be the priority consideration to the passenger shipping company. For this reason, despite difficult circumstance such as heavy weather, the passenger ship could be forced to entry/departure. Especially the domestic passenger ferry does not make sure of enough time for maintenance of equipment due to the frequent entry/departure. Nevertheless, since the passenger ship is carrying dozens and thousands of people, the severity of accidents is so great that it is natural to pay more attention to the passenger ship safety.

International Maritime Organization (IMO), which is established for the purpose of maritime safety, is also making efforts for safer shipping and marine environmental protection through enacting mandatory instruments. They have adopted the International Convention for the Safety of Life at Sea (SOLAS) after the catastrophe of passenger ship *Titanic* in 1912. Apart from the development of technical regulations, the loss of the *Herald of Free Enterprise* brought about the approach to the human element as the cause of accidents and resulted in the International Safety Management (ISM) Code which was made compulsory throughout the 1974 SOLAS in 1998, by stipulating international standards for the safety management system of shipping company for the safe operation of ships and for pollution prevention.

Recently, the world has been alerted once again about the safety of passenger ships as a result of the *Costa Concordia* accident and the *Sewol* accident. However, there are still many serious and minor passenger ship accidents over the world due to lack of fundamental risk reduction or measures to diminish. On 16 August 2013, a roll-on/roll-off ferry called *St. Thomas Aquinas* collided with a cargo ship near the southern Philippine island of Mindanao mainly caused by the human error of the Captain. On 1 June 2015, the 76-meter-long passenger ship called *Dong Fang Zhi Xing* capsized and sank on the Yangtze River in the Wuhan, China. Total 442 deaths were confirmed and 12 rescued after the accident. The cause of the accident was the massive downburst in the thunderstorm and ignorance of weather precautions by Captain of the ship.

The aftermath of the *Sewol* accident, the Government of Republic of Korea has focused on improving ship particulars (e.g., Limit of ship's age and alteration) and the reliability of maritime safety system, but the accident rate is continuously increasing. The vessels that had been in the accident, excluding fishing vessels, were 562 ships in 2010 yet, they increased to 741 ships in 2015, especially for the passenger ships, the number of accident vessels has tripled, accounting for 66 ships in 2015 compared to 2010 (KMST, 2016).

In that case, why we could not considerably reduce the risk of accidents, despite all these improvements. Rothblum (2000) noted the reason is that ship particulars and safety system reliability are a relatively small part of the safety equation. As the maritime safety system is constructed by the human, the failure in the safety system would be a human error, not a mechanical error. The numerous studies also clarify that human error contributes to 80 - 96% of the accident (Aas, 2008; Rasmussen, 1997; Rothblum, 2000). Therefore, it is important that to understand in detail about human error causal factors contributing to the previous accidents in order to set the appropriate controls in place (Madigan, Golightly & Madders, 2016).

Based on Reason’s (2000) study, the human error problem can be viewed in two ways: the person approach and the system approach. The person approach concentrates on the unsafe behaviour such as negligence, moral weakness, and violence. The countermeasures considered as reducing unwanted variability in human behaviour. The system approach focuses on the condition of an individual workplace and the organizational process and human errors consider as not a cause but a result of accidents. The countermeasure is the system defence. When an accident happened, the point is to find out why and how the system has a failure.

The *Sewol* sinking accident, which has been entangled not only by the negligence of the crew but also by the company organisation and the absurdity of the social system, has led to the vibrant discussion and study about the systematic approach to the marine accident. The Korean maritime industry recognized the importance of organisational system and is actively studying the organisational factor that affects the work environment of the ship rather than the simple mistake of the seafarers (Baik, Park, Choi, & Oh, 2016; Kim, 2015; Yoon, 2014).

However, while the unsafe act of workers can be found out easily through the personal approach, the deficiencies of organisational procedure often hidden beneath the main factor. Reason (1990a) distinguished these two kinds of error: active errors and latent errors. Active errors, whose consequences are revealed almost immediately, but latent failures may lie dormant within the system for a long time. Although the workers frequently may make some errors in the process of recovering the failure of the system, the root cause of an accident has been laid in the system before the active errors were executed.

For this reason, it is important for the accident investigators to find out all contributing factors not only active errors but also latent factors laid in concealments within the organisational system. By eliminating the error causes identified thorough accident investigations, it is necessary to prevent repeated occurrences of the same disasters, prevent similar accidents in the future, and improve safety management and safety systems. On the contrary, insufficient accident investigation reports can lead to the wrong lessons by committing errors during the process of cause analysing and by failing to identify underlying causes of accidents, which can be a threat to the safety system. Therefore, a study of analysis of the active failures and latent failures contained in the existing investigation reports may be significant in identifying the human error causal factors and it could be the unique opportunity to review the quality and the depth of information of the accident investigation report.

1.2. Objectives

In order to analyse the human error causal factors on the passenger ship accident investigation reports, this paper presents an application of the Human Factors Analysis and Classification System (HFACS) framework. The purpose of this study to distinguish the active failure and latent failures on the accident reports, and to analyse the prevailing factor and accident trend. By analysing the accident pattern, this paper provides the recommendations for diminishing human error on the passenger ship. Linked to this, the paper will find answers to the following questions.

i) Is the HFACS tool effective to identify the active errors and latent failures in the organisational system on the accident investigation reports?

ii) Are there any differences within causal factors according to the different categories of accident and is it possible to identify the accident mechanism?

iii) Do the accident investigation reports contain sufficient information in order to identify the latent conditions?

1.3. Scope of work

This paper concentrates on the actual and latent factors that threaten the safety of passenger ship. For this purpose, it utilises 30 cases of passenger ship accident investigation reports in Korea during the period of 2014-2015. These investigation reports are obtained from the Korean Maritime Safety Tribunal (KMST). This paper will study the method of analysis of the human factors that have been investigated in various industrial fields up to now and the model to analyse the cause of the accident through this analysis methodology. The utility of the HFACS selected by the methodology of this study will also be verified by the process of analysis of investigation reports. The contents of each chapter are as follows.

Chapter 1 presents the motivation to study the actual and latent factors that contribute to the passenger ship accident. It informs the seriousness of passenger ship accident and highlights that the exact identification of causal factors by a thorough analysis of accident can detect the underlying factors and prevent the recurrence of the same or similar accident in the future. To clarify this, the aim and direction of this study are presented.

Chapter 2 describes the status of Korean domestic passenger ship transport and maritime accidents. It will clarify the definition and division of passenger ships defined by the Korean domestic law and explain the present condition of domestic passenger ships and operator. Further to this, based on statistics of marine accidents, it will examine the current situation and causes of accidents.

Chapter 3 reviews the previous different theories and researches about human errors and accident causation models. Among the human factor analysis methodologies, the general concept of HFACS and Maritime HFACS selected as the main model for this study will be introduced in detail.

Chapter 4 provides the information about the methodology of this study. It describes the database of passenger ship accident investigation reports collected for this study, and how to classify the identified contributing factors in these accidents and integrate these factors into categories of HFACS framework.

Chapter 5 covers the results from the analysis of accident investigation reports based on the HFACS framework. It reviews the outcomes of the analysis to see if we can find the answers to the questions proposed in the *Objectives* and discuss the implications of these results, including the limitation of this study.

Lastly, chapter 6 presents the conclusion of this study based on the analysis of HFACS framework. In addition, recommendations regarding the accident investigation reports will be given for the improvement of passenger ship safety.

2. Passenger ship transport and status of maritime accidents

2.1. Passenger ship transport

2.1.1. Concept and classification of passenger ship

(1) Concept of passenger ship

According to the Korean Ship Safety Act, Article 2 (Definition), passenger ship has defined a ship designed specifically to transport 13 fare-paying passengers or more. More precisely, the term of passengers means “persons on board a ship, except the following persons: (a) Crew; (b) An infant under one year of age; (c) A person prescribed by Ordinance of the Ministry of Oceans and Fisheries, who is temporarily on board, such as a customs officer”. Passenger ships defined in this way are the vessel used in “marine passenger transportation services”, and it is necessary to clarify the range of passenger ships used in this study by looking at the concept and kind of maritime passenger transport business.

In the Korean Maritime Transport Act, Article 2 (Definition), "marine passenger transportation services means such business as transporting passengers or passengers and goods by any passenger ship or any wing-in-ground ship as defined in Article 1-2 (1) 1 of the Ship Act (hereinafter referred to as "passenger ship, etc.") on the sea or along inland waterways contiguous to the sea or such business as providing ancillary services to the former, which refers to any business other than harbour transport-related business as prescribed in Article 2 (4) of the Harbour Transport Business Act”.

Furthermore, in the Maritime Transport Act, Article 3 (Categories of Services), Marine passenger transportation services is classified into the following categories: i) Scheduled coastal passenger transportation services, ii) Non-scheduled coastal passenger transportation services, iii) Scheduled overseas passenger transportation services, iv) Non-scheduled overseas passenger transportation services, v) Cruise passenger transportation services, and vi) Combined marine passenger transportation services.

Among the above-mentioned marine passenger transportation services, the vessels used for “Scheduled coastal passenger transportation services” and “Non-scheduled coastal passenger transportation services” are generally referred to as “Domestic passenger ships.” In this study, domestic passenger ships will be targeted, and this will be abbreviated as passenger ships.

(2) Classification of Passenger Ship

The purpose of the stipulation and classification of passenger ship in the regulations such as Ship Safety Act is that to guide, supervise and regulate the passenger ships which are required to secure the safety of passengers’ lives compared to the cargo ships.

Passenger ships can be further classified as shown below, based on speed or type of transport. Firstly, the passenger ship that utilized only for the purpose of accommodating passengers and not carrying cargo or vehicles. Passenger ships are subdivided again based on their speeds as follows[1] (Park, 2015).

i) General Ship: Passenger ship with a speed of fewer than 15 knots
ii) High-Speed Craft: Passenger ship with a speed of more than 15 knots and less than 20 knots

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[1] Definitions for classifying passenger ships by speed or type are not prescribed by Korean national law. However, the Ministry of Oceans and Fisheries divides passenger ships on the basis of speed, etc. in “the regulations on the notification of rates and fares for domestic passenger ship” issued based on the Marine Transport Act, and specifies separate fares.

iii) Super Speed Craft: Passenger ship with a speed of more than 20 knots and less than 35 knots
iv) Super High-Speed Craft: Passenger ship with a speed of 35 knots or more

Secondly, cargo ferry that in addition to transporting passengers are also utilized to carry vehicles from one destination to another. Cargo ferry is divided into Enclosed Ro-Pax and Opened Ro-Pax depending on the type of ship (MOAF, 2015b).

i) Enclosed Ro-Pax (Roll-on Roll-off Passenger) means a car ferry that can load or carry a vehicle in the *enclosed vehicle area* as it is used for land transportation.
ii) Opened Ro-Pax means a car ferry that can load or carry a vehicle in the *opened vehicle area* as it is used for land transportation.

Figure 2-1. Enclosed Ro-Pax (Left) and Opened Ro-Pax (Right)

Most of the passenger ships in Korea correspond to such transportation ships as above, but there is another type of passenger ship, cruise ships. Thirdly, the cruise ship is a passenger ship with convenient facilities such as accommodation, food and beverage facilities, amusement facilities and so on. Passengers on cruise ships will give great significance to the boarding per se, but in the case of marine passenger transportation, the main purpose of the vessel is to be used as a means of physical transport for passenger, so that this study will focus on the function and system of transportation for the passenger.

2.1.2. Status of passenger ship transport

(1) Status of passenger ship operators

As of the end of 2016, there is total 58 passenger ship service operators, managing 167 passenger ships, committing 108 service routes in the coastal of Korea. Figure 2-2 shows the presence of service routes of the domestic passenger ship, and Table 2-1 presents the number of service lines and operating vessels over the past three years. Among the 108 routes, there are 81 general lines operated by the operators as profitability is secured, and 27 subsidized lines[2] that are supported as a semi-public system by the government due to the lack of profitability. Compared to the record in 2014, while the service route increased by 13 routes on 95 routes, one operating ship decreased. This can attribute to an increase in the number of operation required per vessel.

Table 2-1. Number of service lines and operating vessels (KSA, 2017)

	Number of Lines			**Number of Vessels**			**Number of Company**
	Total	General Lines	Subsidized Lines	Total	General Lines	Subsidized Lines	
2016	108	81	27	167	140	27	67(58)*
2015	112	85	27	169	143	26	69(60)
2014	95	69	26	168	142	26	69(62)

Note: * exclude duplicated company

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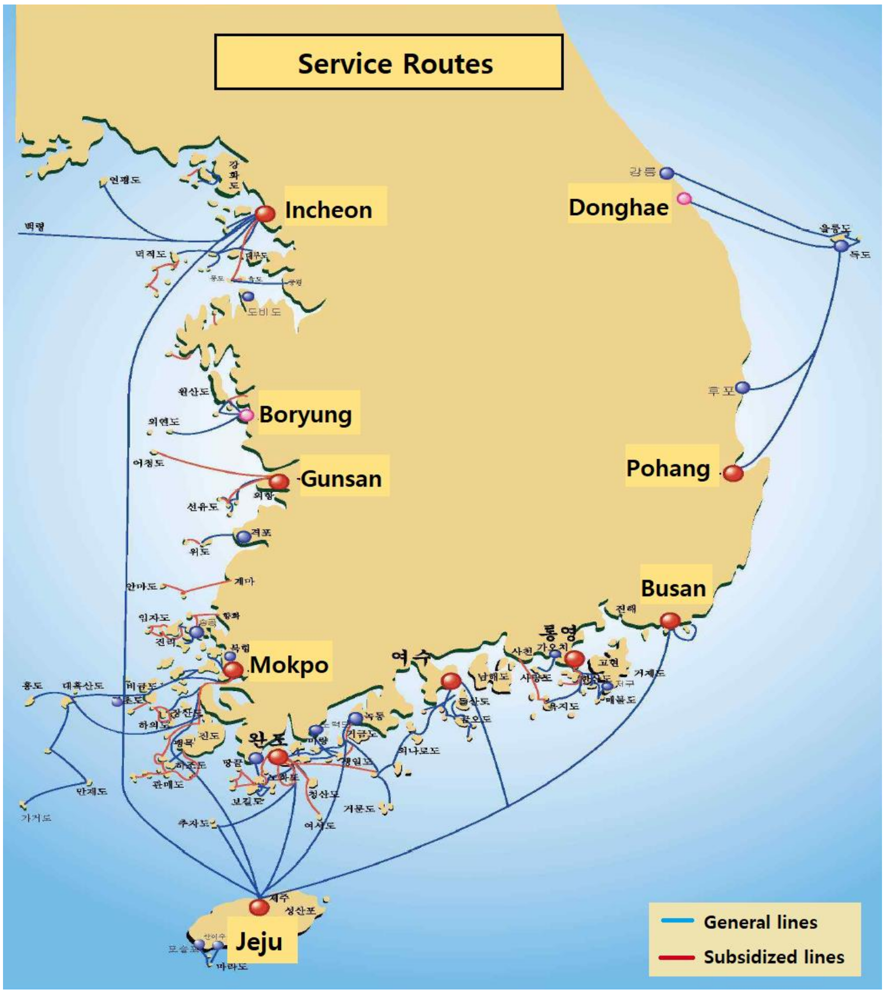
[2] A subsidized line means a route which receives government aid for the operating loss. In case of small island area, due to the absolute shortage of passengers and low fares, shipping operators are avoiding the operation of passenger ships. In order to provide transportation convenience for those residents, the government orders the ship to be operated, and support subsidy to the shipping operators.

Figure 2-2. Service routes of Korean domestic passenger ship (KSA, 2017)



For the subsidized lines, however, since the government supports the deficit of operation, the operators tend to neglect effort to improve their balance and service quality. Furthermore, unlike international passenger transport service operators, domestic passenger transport service operators are relatively small-scale company and low profitable (Kang, 2016).

According to the report of KSA (2017), 8 of the 58 domestic passenger transport service operators with less than 300 million won in the capital amount to 13.8% of the total. Figure 2-3 shows that the number of operators per capital amount, and Figure 2-4 describes the number of operators per possessing number of vessels. The number of operators with less than a billion won ($ 900,000) in capital is 32, accounting for 55.2% of the total, and the number of companies operated by one or two vessels is 32, accounting for 55% of the total. For this reason, the plowback for the ship safety management is so small that it is difficult to assure the passenger ship safety.

Figure 2-3. Number of operators by capital amounts (KSA, 2017)

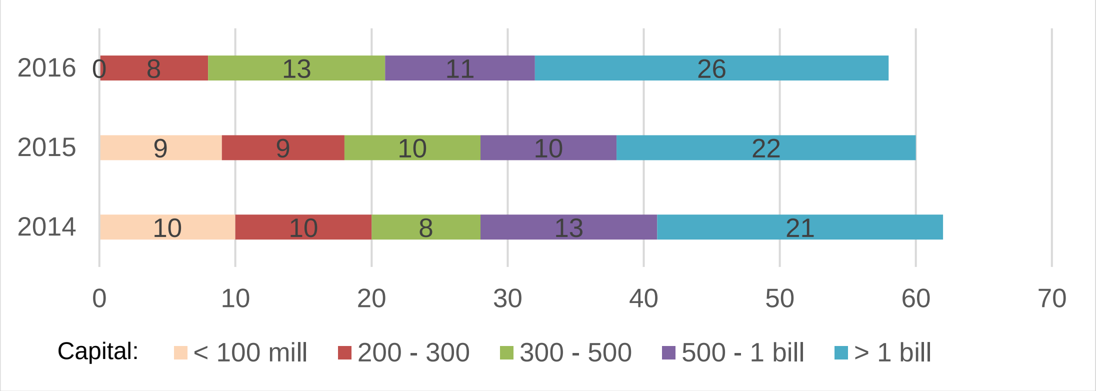
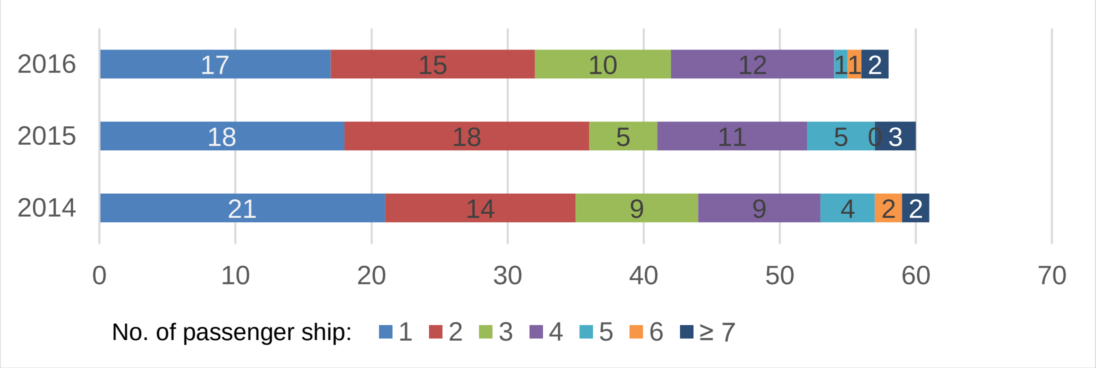


Figure 2-4. Number of operators by passenger ship retention (KSA, 2017)

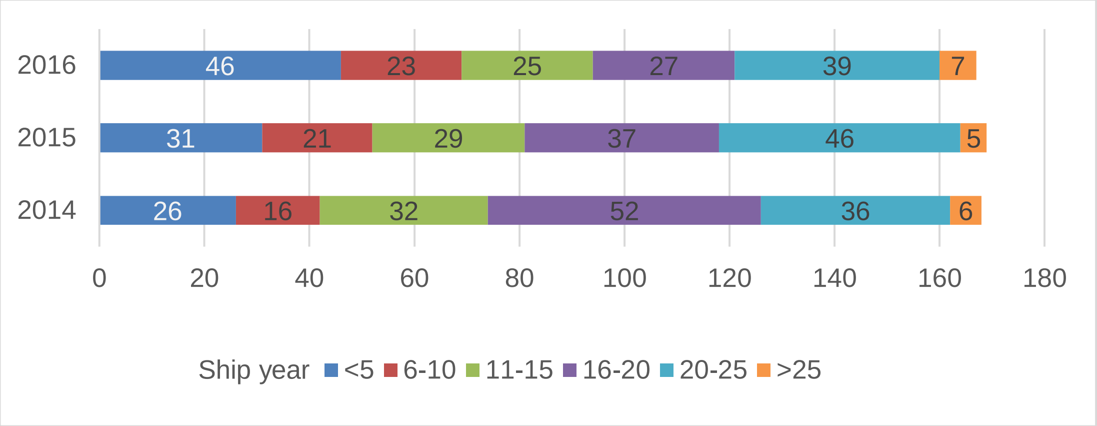


(2) Status of Passenger Ship

As seen in Figure 2-5, the ratio of passenger ships with more than 20 years of age was 14% in 2011 but increased to 27% in 2016. In terms of the number of vessels, the total number of vessels in 2011 and 2016 was same as 167, while the number of vessels with more than 20 years doubled from 23 to 46 vessels.

In addition, there are seven vessels over 25 years of age in 2016 since the maximum age of passenger ships has increased from 20 year to 30 year with the amendment of the Enforcement Regulations for Shipping Act in 2009. The regulation for the age of ship amended once again after the *Sewol* accident in 2014 by reducing the ship-year standard for cargo ferry from 30 year to 25 year. However, the ship-year standard for passenger ship only for passenger has been maintained the 30 year (KMST, 2016).

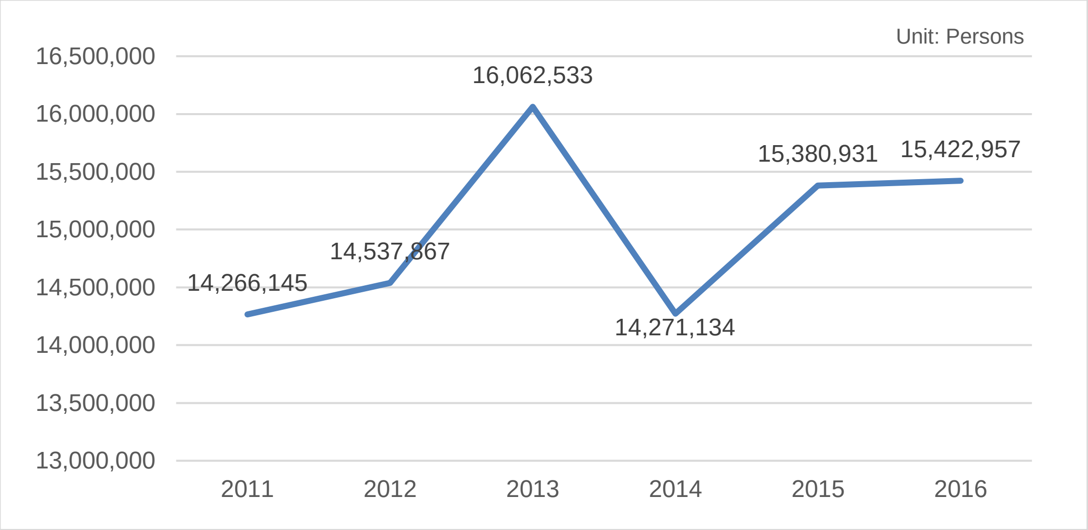
Figure 2-5. Number of passenger ship per ship year (KSA, 2017)



According to a result of the study (KMIFT, 2008), the passenger ship's age is not related to the occurrence of the maritime accident, especially machinery failure. However, the higher the ship's age, the more it is to affect the normal operation of the safety device, such as an emergency stop device. Also, due to vibration of hull, there is a high possibility of fire onboard caused by damage of fuel oil and lubricating oil of piping system. Therefore, the ship safety can be maintained at a considerable level when strengthening the ship management system and investing in maintenance and repair of the machine.

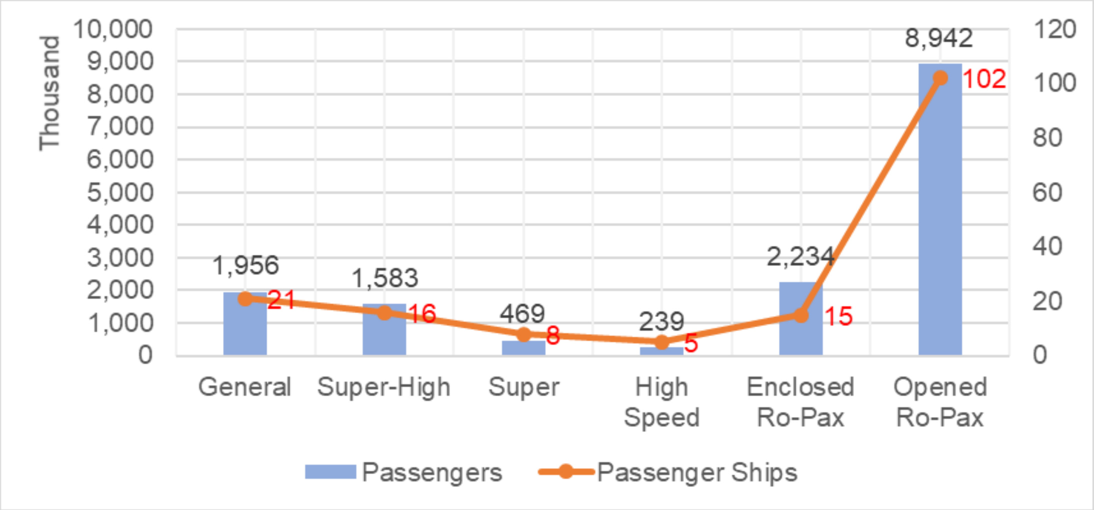
In terms of the number of passengers of ships in Korea, Figure 2-6 shows the trend of utilization ratio of passenger ship since 2011. 16 million passengers used the passenger ship in 2013 before the *Sewol* accident, and 14 million passengers in 2014 and then slightly increased to 15.4 million as of the end of 2016. Looking at the average usage rate over the past five years, it shows an increase of 1.9%. Among them, general users (except island area resident) are 76% of the total passengers, which is 11.7 million. It means that more than one-third of the whole population is on-boarding passenger ships at least once a year (KSA, 2017).

Figure 2-6. Number of passengers per year (KSA, 2017)



Regarding the proportion by the type of passenger as shown in Figure 2-7, opened Ro-Pax occupied more than half of the total. The ratio increased from 54% in 2011 to 61% in 2016, accounting for 90 and 102 vessels, respectably. Following this, 21 General Passenger Ships (13%), 16 Super High Speed Craft (10%), 8 Super Speed Craft (5%), and 5 High Speed Craft (3%) formed, as of the end of 2016. The proportion of passengers by ship type showed a similar pattern according to the ratio of ship type, with the highest rank of nearly nine million passengers on Opened Ro-Pax (KSA, 2017).

Figure 2-7. Number of passengers and passenger ships by ship type (KSA, 2017)



(3) Status of Seafarers on Passenger Ship

As of the end of 2016, 824 seafarers are working on passenger ships. As described in Table 2-2 below, the number of seafarers has increased steadily from 751 in 2005 to 988 in 2013, but it dropped to 774 in 2014 and then increased again. Out of 824 seafarers as of 2016, officers account for a high proportion of 565 people (68.6%), of which the ratio of deck and engine officer is similar. In the case of ratings, the crew belonging to deck section accounts for 73.4%. Especially, among the 167 passenger ships, the small ship less than 500 tons occupies the majority with 139 vessels.

Table 2-2. Number of seafarers engaging in domestic passenger ships (Korea Seafarer's Welfare and Employment Center (KOSWEC), 2017)

Year	**Grand Total**	**Officers**			**Ratings**			
		Total	Deck	Engine	Total	Deck	Engine	Cook
2016	824	565	314	251	259	190	64	5
2015	765	544	298	246	221	165	48	8
2014	774	560	309	251	214	163	48	3
2013	988	699	383	316	289	196	72	21

2005	751	499	275	224	252	149	94	9

According to the statistics of the KOSWEC as shown in Table 2-3, there are currently 167 passenger ships, and with an average of 4.9 seafarers per ship. Compared to other vessels, the number of passenger ship seafarers per ship is rather smaller than that of 8.8 persons for the chemical tanker, 8.2 persons for LPG carriers, 6.4 persons for the general cargo vessel, and 5.1 persons for oil tankers. In addition, the number of passenger ship seafarers is much lower than that of 14.8 persons per ocean-going passenger ship. It can be seen that a few seafarers on domestic passenger ships are in a harsh working condition compared to other domestic ship types and ocean-going passenger ships.

Table 2-3. Average number of seafarers on domestic vessels (KOSWEC, 2017)

Ship Type	Vessels	Seafarers	Seafarers per vessel
Chemical Tanker	46	404	8.8
LPG	15	123	8.2
General Cargo Vessel	201	1293	6.4
Oil Tanker	168	862	5.1
Bunker Supply Vessel	64	227	3.5
Domestic Passenger Ship	167	824	**4.9**
Ocean-going Passenger Ship	8	119	14.8

The aging of the seafarers can also be a threat to passenger ships. As described in the following Table 2-4 of the age range of seafarers on the domestic vessels, while 25.5% of those over 50 years old and 51.9% of those over 60 years old, only 5.4% are under 30 years old. However, compared to year of 2010, the younger-than-25-year-old seafarers have increased from 2.0% to 2.4%. The proportion of elderly seafarers has increased compared with young seafarers. Regarding the age of seafarers, as older group over the age of 60 will soon be out of ship operation, it is urgent to foster and provide the young seafarers to have a positive effect for the maritime field.

Table 2-4. Status of seafarers' age group on domestic ships (KOSWEC, 2017)

		< 25	**25-29**	**30-39**	**40-49**	**50-59**	**>60**	**Total**
2010	Total	166	138	521	1071	3,073	3,093	8,062
	Ratio	2.0	1.7	6.4	13.3	38.1	38.3	100.0
2016	Total	189	239	521	821	2,006	4,078	7,854
	Ratio	2.4	3.0	6.6	10.5	25.5	51.9	100.0

2.2. Status of Maritime Accident

2.2.1 Definition and kind of marine accident

(1) Definition of marine accident

According to the Annex of IMO Res. A. 884(21), Article 4 (Definition), Marine casualty means *"an event, or a sequence of events, that has resulted in any of the following which has occurred directly in connection with the operations of a ship:*

- *(a) the death of, or serious injury to, a person;*
- *(b) the loss of a person from a ship;*
- *(c) the loss, presumed loss or abandonment of a ship;*
- *(d) material damage to a ship;*
- *(e) the stranding or disabling of a ship, or the involvement of a ship in a collision;*
- *(f) material damage to marine infrastructure external to a ship, that could seriously endanger the safety of the ship, another ship or an individual; or*
- *(g) severe damage to the environment, or the potential for severe damage to the environment, brought about by the damage of a ship or ships"* (IMO, 1999).

When we look at the Korean Act on the Investigation of and Inquiry into Marine Accidents Article 2 (Definitions), the term of marine accident means *"any of the following accidents, which happen at sea and in the inland waters:*

- *(a) An accident in which a person dies, disappears or is injured, in connection with the structure, equipment or operation of ships;*
- *(b) An accident which causes damage to a ship or shore or marine facilities, in connection with the operation of ships;*
- *(c) An accident in which a ship is lost, derelict or missing;*
- *(d) An accident in which a ship collides with another ship, is stranded, capsizes or sinks or it is impossible to steer a ship;*
- *(e) An accident that causes marine pollution damage, in connection with the operation of ships*;" (MOAF, 2014).

Compared to the definition of marine casualty used in IMO Resolution (IMO,) it is founded that the meaning of marine accident used in the Korean Act on the Investigation of and Inquiry into Marine Accidents is reflected in the same with internationally accepted meaning.

(2) Kind of Marine accident

Based on the annual accident report of KMST (2016), it is intended to analyse the status of marine accidents and causes of marine accidents, specifically, passenger ship accidents.

The kind of maritime accident that KMST has classified is as follow: collision, contact, grounding, capsize, fire/explosion, sunk, machinery damage, fatalities, and hindrance to safe navigation. Table 2-5 is shown the frequency of passenger ship accidents by accident category during the period of 2012 - 2016. The most occupied type of accident is machinery damage, accounting for 74 out of total 243 accidents, and the following accidents are the hindrance to safe navigation (53), collision (32), contact (19), grounding (9), fire/explosion (6), fatalities (6), capsized (2), and others are 42 cases.

Table 2-5. Frequency of passenger ship accidents by accident category (KMST, 2016)

	2012	2013	2014	2015	2016	Total
Collision	8	5	5	5	9	32
Contact	5	1	3	5	5	19
Grounding	-	1	5	3	-	9
Capsized	-	-	1	1	-	2
Fire/Explosion	1	2	1	1	1	6
Sunk	-	-	-	-	-	-
Machinery Damage	**7**	**5**	**16**	**25**	**21**	**74**
Fatalities	-	-	2	2	2	6
Hindrance to Safe Navigation	6	8	11	12	16	53
Others	5	7	7	12	11	42
Total	32	29	51	66	65	243

2.2.2. Statistics and causes of maritime accident

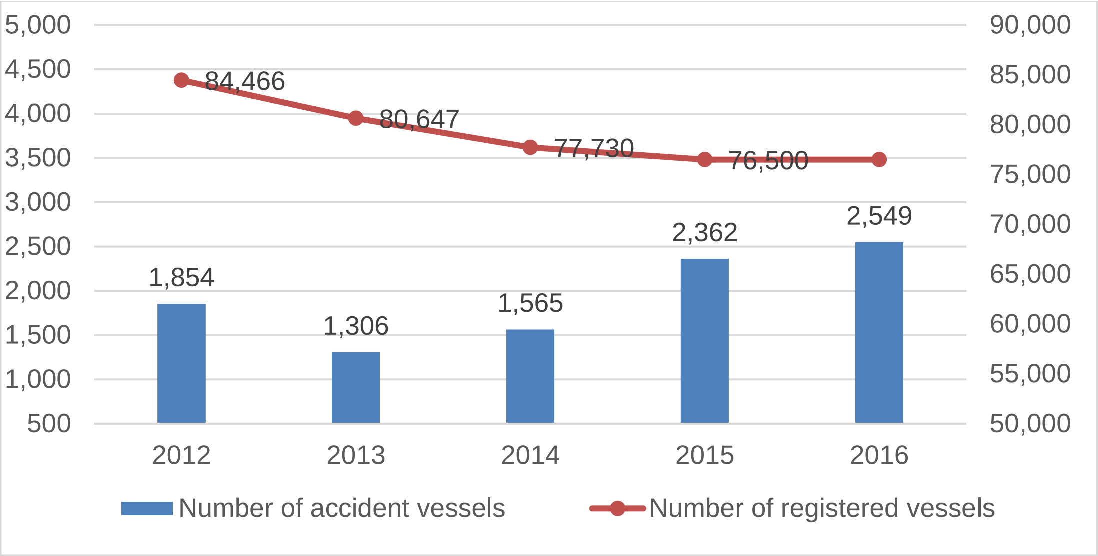
(1) Statistics of maritime accident

The maritime traffic safety environment in Korea coastal sea is so critical that there are many risks of marine accidents. The coastal waters are complicated and narrow in geographical form, and are often weathered by typhoons in summer, low pressure in winter, and heavy fog. In addition, marine traffic volume is increasing continuously in a limited space. While the number of high-speed crafts, very-large ships with sub-standard vessels is increasing, the qualities of the crew members operating on these vessels and the motivation for boarding are also continuously deteriorating (Cho, 2002).

Due to these poor marine surroundings, recently the rate of marine casualties is increasing each year compared to the number of vessels registered in Korea. As seen in Figure 2-8, even though the registered vessels continue reduction trend from 84,466 in 2012 to 76,500 in 2015, the number of accidental vessels is raising up from 1,306 in 2013 to 2,549 in 2016, and the passenger ship also shows the same trend of increasing from 29 to 65 in recent years. During the period of 2012 to 2016, there have been 9,636 of accidental vessels, averaging 1,927 marine accidental vessels annually, of which passenger ship accidents account for 2.52%, with 49 accidents annually on average (KMST, 2016).

Remarkably, the number of marine accidental vessel in 2013 dropped significantly to 1,306, approximately 600 vessels fewer than the average annual maritime accidental vessels, which had recorded over 1,800 vessels at the previous year. This can be contributed to “The Project to Reduce Marine Accidents by 30%,” of the Ministry of Oceans and Fisheries and the Korea Coast Guard (KCG). The Project has focused on the prevention of marine accidents, of which fishing boats and small ships less than 100 tons accounted for approximately 66% and 71.1% of maritime accidents, respectively (Kim, 2015).

Figure 2-8. Status of Marine Accident in Korea (KMST, 2016)

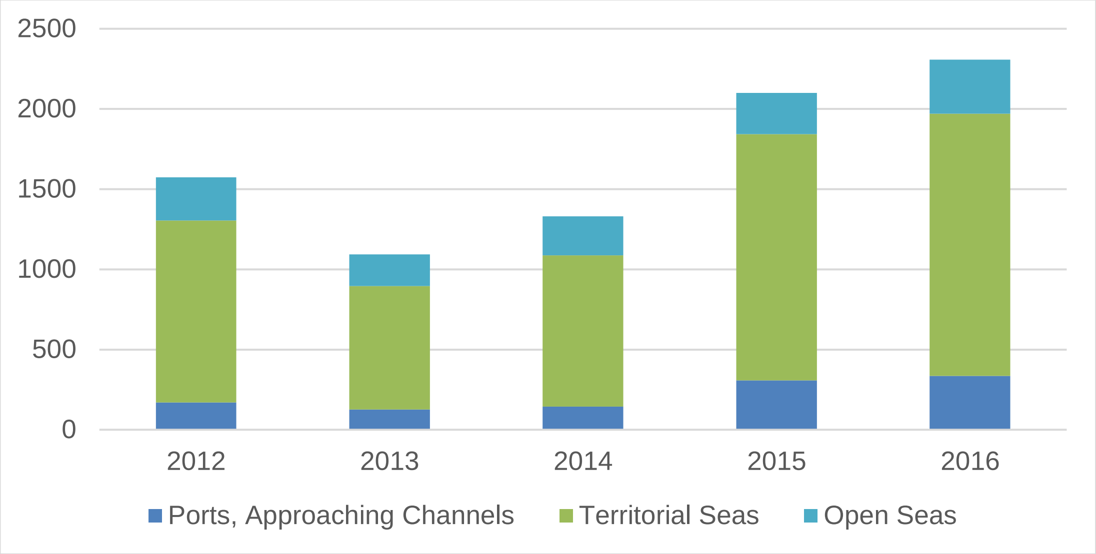


	2012	2013	2014	2015	2016	Total
Registered Vessels(A)	84,466	80,647	77,730	76,500	-*	-
No. of Accident vessels(B)	1,854	1,306	1,565	2,362	2,549	9,636
Rate of Accident (B/A)	2.19%	1.62%	2.01%	3.09%	-	-
Passenger Ship Accident	32	29	51	66	65	243

Note: * Not recorded

In addition, Figure 2-9 describes the marine accidents rate by accident area over the past five years. The accident area was divided as ports, channels, territorial Seas, and open seas. Overall, the accident rate in the territorial waters is considerably higher than that of open seas. The average of marine accidents occurred in the open seas in the last five years is 15.5% whilst that within the ports and territorial waters is 84.5%. Therefore, it can be concluded that the geographical area should pay attention to coastal waters (KMST, 2016).

Figure 2-9 Status of maritime accidents by accident area (Source: KMST, 2016)



	2012	2013	2014	2015	2016	Average
Ports, Approaching Channels	171 (10.9%)	126 (11.5%)	145 (10.9%)	308 (14.7%)	335 (14.5%)	217 (12.9%)
Territorial Seas	1,134 (72.1%)	769 (70.4%)	942 (70.8%)	1,535 (73.1%)	1,636 (70.9%)	1203 (71.6%)
Open Seas	268 (17.0%)	198 (18.1%)	243 (18.3%)	258 (12.3%)	336 (14.6%)	261 (15.5%)
Total	1,573	1,093	1,330	2,101	2,307	1,681

(2) Cause of Maritime Accident

According to KMST, the major causes of marine accident are following; operational error such as violation of collision regulations, negligence of lookout, insufficient courses checking, and poor fixing/keeping of courses, handling mistakes or inappropriate maintenance of machinery, inappropriate performance for prevention of accident, inappropriate working condition, defect of safety, inappropriate facilities, defects of hull/engine room machinery, inappropriate management of ship operation, force majeure of the sea, others, and unknown cause.

Table 2-6 describes the passenger ship accident frequency by the cause of accident during the period of 2012 – 2016. The primary cause involved in the registered passenger ship accident is the *operation error*, with 44 cases. Of which, the *violation* of general navigational laws occupied the highest frequency, accounting for 26 cases. The next most frequent cause of accident was the *inappropriate maintenance or handling mistakes of machinery*, with 40 cases during the past five years. Other causes of violation of collision regulations, non-observance of order, inappropriate takeover, inappropriate performance for prevention of accident, defects of hull/engine room machinery, and force majeure of the sea were found one case, respectively, including defect of safety with 2 cases.

Table 2-6 Frequency of passenger ship accidents per accident causes (KMST, 2016)

Accident Causes		**Frequency**
Operational Error	Violation of collision regulations	1
	Violation of general regulations (lookout, fixing of ship's position, and fixing/keeping of courses, etc.)	**26**
	Poor preparation of departure (securing openings, checking of loading condition, Furnishing of Chart & Publication, etc.)	**12**
	Non-observance of order, inappropriate takeover	1
	Others of operational error	4
	Operation Error Sub-total	**44**
Inappropriate maintenance or handling mistakes of machinery		**40**
Inappropriate performance (Loading/unloading, working on board, etc.) for prevention of accident		**1**
Inappropriate working condition (Rest time, maintenance of facilities for prevention of danger)		-
Defect of safety (Structure or quality of machinery)		**2**
Inappropriate facilities (Waterway, port, navigation aids)		-
Defects of hull/engine room machinery (Electronics, cargo handling, etc.)		**1**
Inappropriate management of ship operation		-
Force majeure of the sea		**1**
Others		-
Unknown cause		-
Total		**89**

On the other hand, none of the cause of the Inappropriate working condition, Inappropriate facilities, and Inappropriate management of ship operation was not identified. Though these causes have not had an immediate impact on the accident, it could be the underlying conditions which can lead to the active failure such as operational errors or handling mistakes. Therefore, it is necessary to look deeply into the investigation report, and if it reveals that these causes also affected to the accident even indirectly, they should be considered to eliminate the potential risk factors.

2.3 Summary

This chapter provided the current status of passenger ships and related accidents in Korea. In summary, most of the passenger ship operators are small scaled with a small number of ships and capital amount, and the year of those ships are mostly over than 15 years. Moreover, the average number of seafarers who are employed on the passenger ships are much less than ships in the different type of domestic vessel or international voyage passenger ship. Current identified issues of passenger ships obviously show the correlation with the underperformance of Korean passenger ships.

3. Theoretical frame of human error

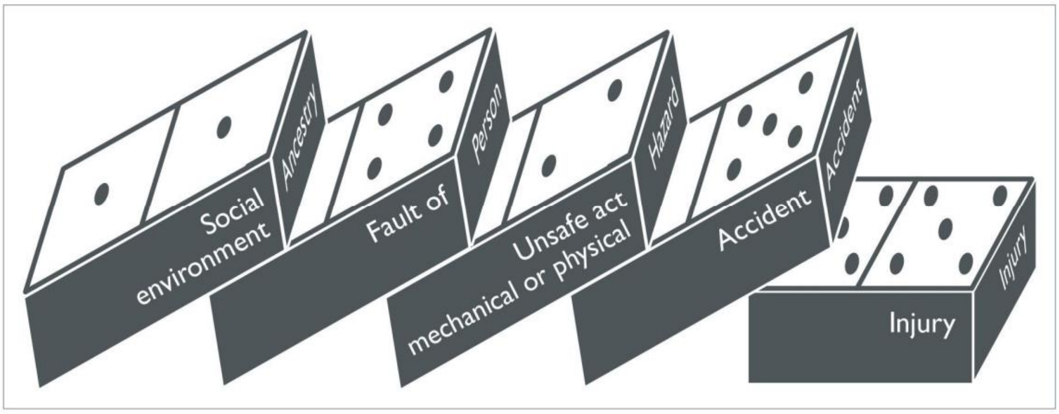
3.1. Historical analysis of human error

As the complexities confronting the people in their work or social relations has begun to emerge, behaviourism researchers of psychology have studied the realm of ‘human factors’ that deal with the relationships of human and human, human and machine, system, procedure, and human and environment to understand the complicated situation. This study has gradually developed into the interdisciplinary research and applied in different sphere including business administration, medicine, engineering and so on. Human error is a phenomenon that results from inappropriate behaviour in human interaction with these peripheral factors and has implication for the degradation of performance, safety, and efficiency of the system.

Generally, the human error has been considered the cause of an accident and to be in the inaccurate assessments, wrong decisions, and bad judgments. The classic approach to the accident causation originated from Heinrich (1931), which is a “Domino Theory,” emphasizing the chain of adverse event. This model has affected to the change of focus on from the unsafe working condition to human error. The five factors of Domino Theory are:

- Social environment and Ancestry
- Fault of Person
- Unsafe acts and conditions (Mechanical and psychical error)
- Accident
- Injury

Figure 3-1. Domino model of accident causation (modified from Heinrich (1931), Sabet, Aadal, Jamshidi, and Rad, 2013)



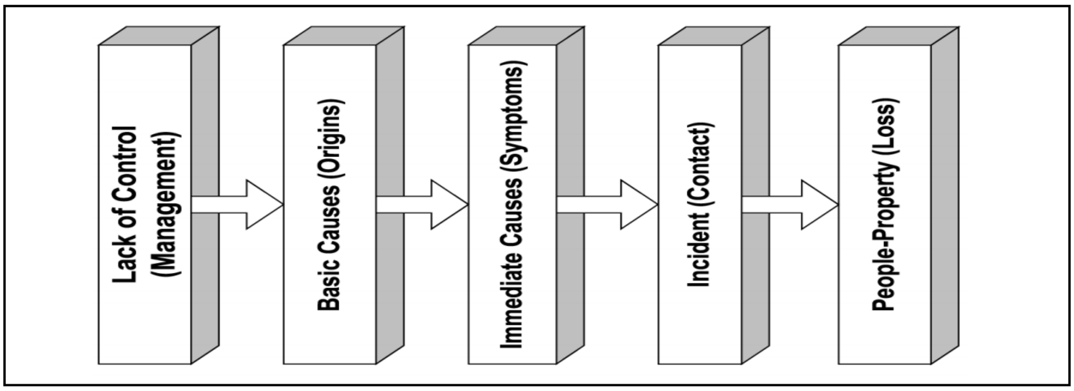
Based on the domino model, “accident” is the one factor that leads to an injury, and occurs only because of “Mechanical error”. For this reason, Heinrich proposed that the accident can be prevented by removing the unsafe act/condition or mechanical/physical hazard among the errors, and they should be received the most attention. However, this theory has a weakness that only individuals are responsible for the accident, not considering the problem of social environment or organisation (Sabet, Aadal, Jamshidi, and Rad, 2013).

To supplement Heinrich’s theory, Bird and Loftus (1976) acknowledged that the accident can be prevented by eliminating the basic cause rather than an immediate cause, and represented the accident occurrence process by the following five steps:

- Lack of control-management (inadequate program, inadequate program standard, inadequate compliance to standard)
- Basic cause-origins (personal and job factor)
- Immediate causes-symptoms (sub-standard act and condition)
- Incident (contact with energy and substance)
- Injury-damage-loss

Bird recognized that since immediate causes are only a symptom of the basic causes, eliminating the defects of control or management that suppress the occurrence of root causes is a more fundamental prevention measure (WZS & ETC, n.d.a.).

Figure 3-2. Updated Domino sequence of accident causation theory (Bird, 1976)



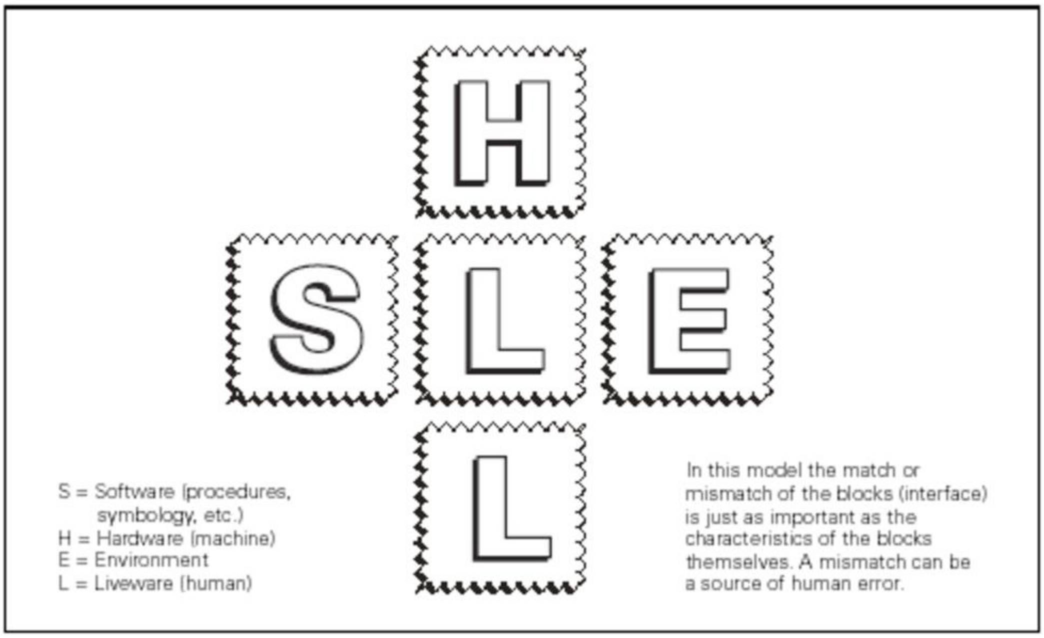
After that, as the point of view of human error changes, many researchers have perceived that human error is a symptom of the system and its design, and tried to find how people's assessments and actions made sense at the time, given the circumstances that surrounded them (Dekker, 2001; Lee, 2002; Reason, 1990a; Woods, Dekker & Cook, 1994). The typical model of human factor and elements showing the concept of systems perspective is the SHELL model.

Hawkins's SHELL model (1983), modified SHEL model first developed by Elywyn Edward (1972), constructed a human factor model, which polysynthetically and systematically shows the interaction between humans and systems. The center of the SHELL model, "L", is human (liveware), which is regarded as the subjects that perform their duties. It is the most flexible and effective in the system, but it depends on the individual’s ability to perform their work, which can cause many differences and restrictions. “H” is hardware, which represents all devices operated by humans. "S" is software, which is not an external element of the system, but rather laws, procedures and computer programs. "E" is an environment that refers to all surrounding elements of the system such as lighting, humidity, and temperature. Finally, "L" represents another human who affects work (HP Repository, 2012).

Regarding human error, human factors related to center located L include personality, attitude, and motivation. If there is a lack of understanding of relations between “L” and each factor, errors may be caused. In L-H model, poor user experience occurs in the man-machine system. Errors due to incorrect regulations and procedures can be explained in L-S model. The error in L-E model is due to work circumstance or weather factors. In the L-L model, errors occur due to miscommunication among workers, lack of cooperation, misunderstandings, emotions, and inadequate work loading.

However, this model is only constructed to understand human factors, so that it has a limitation that it cannot cover the interface which is external human factors (H-H, H-E, S-H) (HP Repository, 2012).

Figure 3-3. Hawkins's SHELL model (1983)



(Source: http://www. tgpilotrecruitment. Com /?page_id =78)

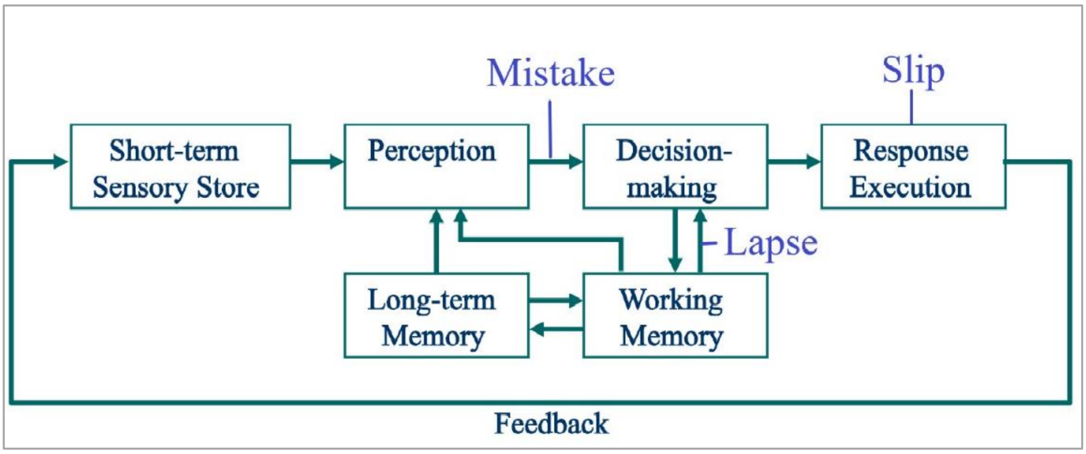
The analysis of human error is largely divided into quantitative analysis and qualitative analysis. Quantitative analysis is a method to determine the occurrence probability of human error in a specific work, but it is not suitable for the planning of the countermeasure for prevention of recurrence of the accident because the description of the cause of the accident is not presented. The qualitative analysis compensating the defect of quantitative analysis is an in-depth analysis of the actual process of the event, so it is possible to classify the human error, to identify the cause, and to establish countermeasures (Park, 1993).

In the qualitative analysis, the focus has been on the analysis method considering the cognitive processes of workers. By replacing repetitive, time-intensive tasks with the high-tech automation system, the role of workers has been changed from the actor to the information processer that performs the task of resolving the problem through decision-making. Accordingly, there is an increasing demand for the development of error analysis method considering human decision-making process (Choi, Kim Y., & Kim C., 2002).

Representative models that approach human errors from a cognitive perspective include the model of human information processing by Wickens & Hollands (2000) and the Generic Error Modelling System (GEMS) by Reason (1990b). The model of Wickens & Hollands (2000) is classified the type of human error in terms of information processing. Errors that arise in the planning phase occur in the perception and cognitive processes, which can occur when the goal or situation is mistakenly recognized. These errors are caused by exceeding the limits of memory or by bias and may be due to the perceptual problems or cognitive vulnerabilities. Specifically, mistakes are divided into knowledge-based mistakes and rule-based mistakes.

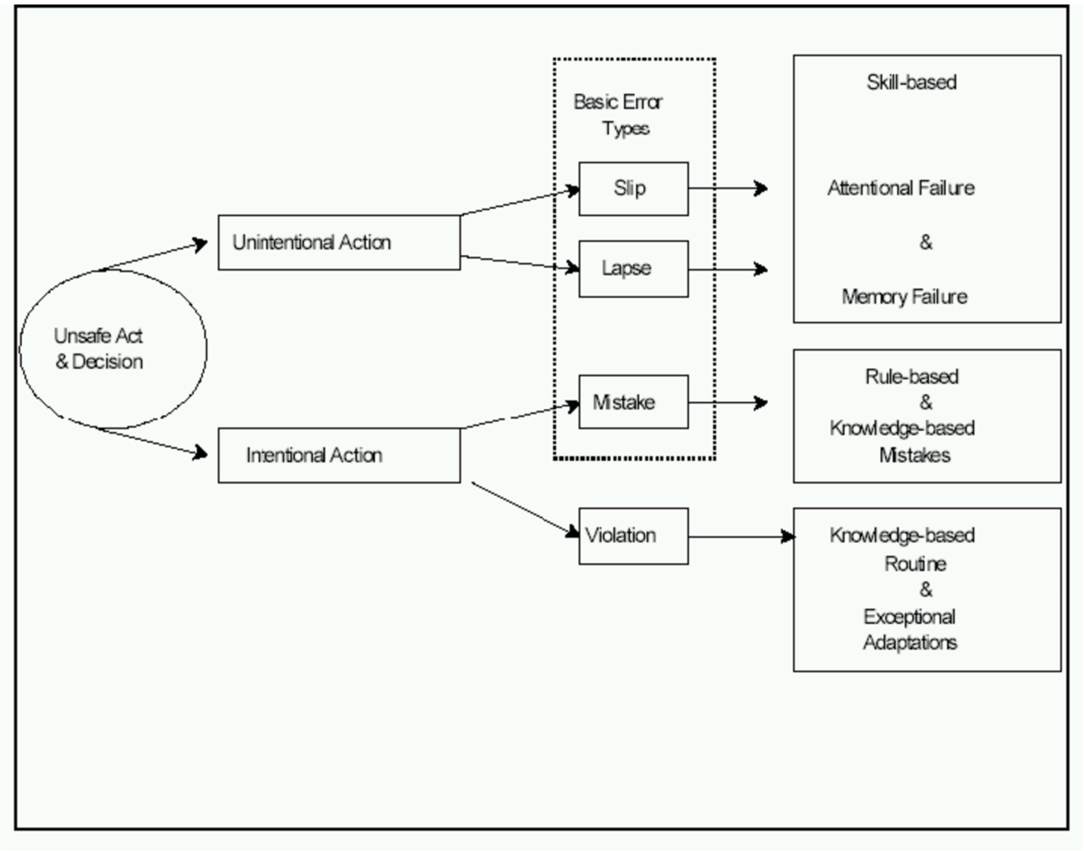
Knowledge-based mistakes occur in case of excess information or a lack of knowledge to interpret the information. Rule-based mistakes are errors in rules, procedures, etc., and can be divided into two cases: a misjudgment of rules, procedures, etc., and a case where a wrong rule is applied to the current situation. Errors in the memory phase happen in a form that is not followed the interactions that occur in various processes due to the lost in memory. It is not a mistake in behavior, but an unconscious mistake and the main cause is excessive work or interference. Errors in the execution phase are cases where the situation recognition is correct but the behavior is different from the intended behavior. The main cause is that to deviate from the repetitive behavior or habituated behaviors are not carefully handled (Wickens & Hollands, 2000).

Figure 3-4 Model of Human Information Process (Modified from Wickens & Hollands, 2000)



The Generic Error Modelling System (GEMS) of Reason (1990b) divided human error into four categories: slip by attention failure, lapse by memory failure, mistake and violation of the failure of intended behavior. It is based heavily on Rasmussen's (1983) three major categories of errors: skill-based slips and lapses, rule-based mistakes, and knowledge-based mistakes (SRK model). Slips are unintentional behaviors that are caused by lack of attention or excessive attention in the cognitive process or are caused by automated behavior in the process of execution. Lapses by memory failure occur due to a mere memory failure by unintended behavior. It is more difficult to identify than a mistake, more dangerous due to the internality, and can be exacerbated when you think that further checking is unnecessary after completing a task. The rule-based mistakes result from the selection of an inappropriate rule by the distorted view of the state. The knowledge-based mistakes are due to the inaccurate comprehension of the system, ascertainment bias, and overconfidence. A violation is a case of intentionally deviating from the rules and procedures for safe and efficient work.

Figure 3-5. The Generic Error Modelling System (GEMS) of Reason (1990b)

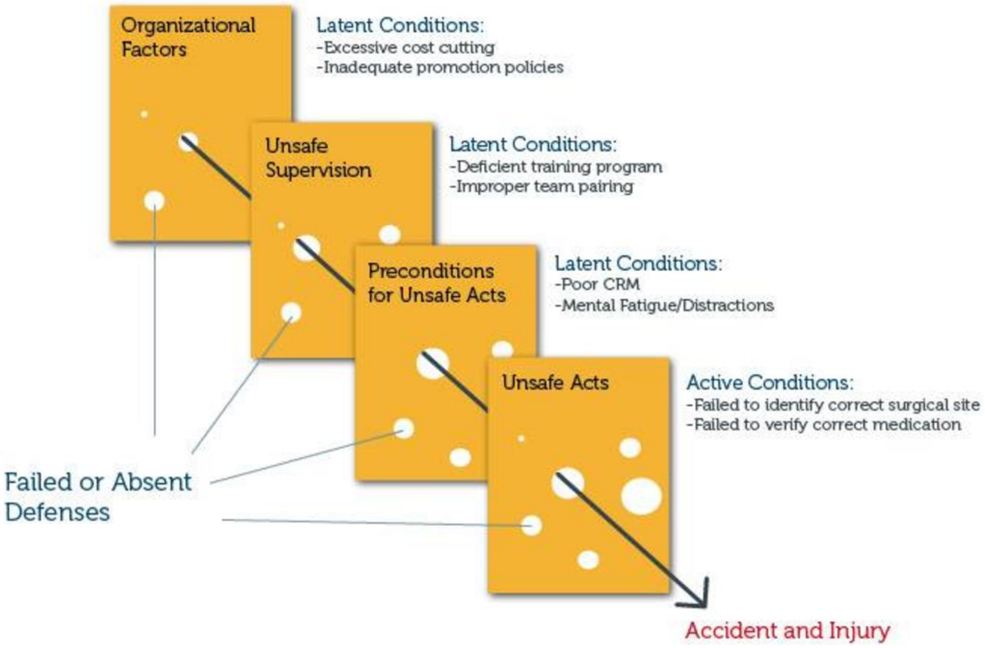


(Source: https://www.maifa.org/resolution/resolutions/A.884(21)_APP_2_1.htm)

Reason (1990b) also systematically described the accident process with swiss cheese with small holes in the middle of the accident. The hole means the deficiencies of organizational levels. In this theory, Reason presented the theoretical basis that if the accident occurred due to a series of human factors, the human error should be extended to the overall problem including the organizational and regulatory factor.

Accordingly, there are four stages that happen adverse events: i) Unsafe Acts, ii) Preconditions for Unsafe Acts, iii) Supervisory Factors, and iv) Organizational Influences. If at any time leading up to the adverse event, one of corrective action at any stage is not prevented, the accident can occur. When analysing the cause of the accident caused by human factors, although the active failure is directly attributable to the front-line operator, specifically analysing the causes reveals that there are latent conditions that increase the likelihood of active failure. Such preconditions of inappropriate behaviour, inadequate culture, and organizational influences can aggravate the effects of the unsafe acts upon the system's safety, restraints, and barriers (Reason, 2016). Therefore, it can be said that accidents are caused by human factors and system failures surrounding them, rather than technical defects.

Figure 3-6. Reason's Swiss Cheese Model (1990b)

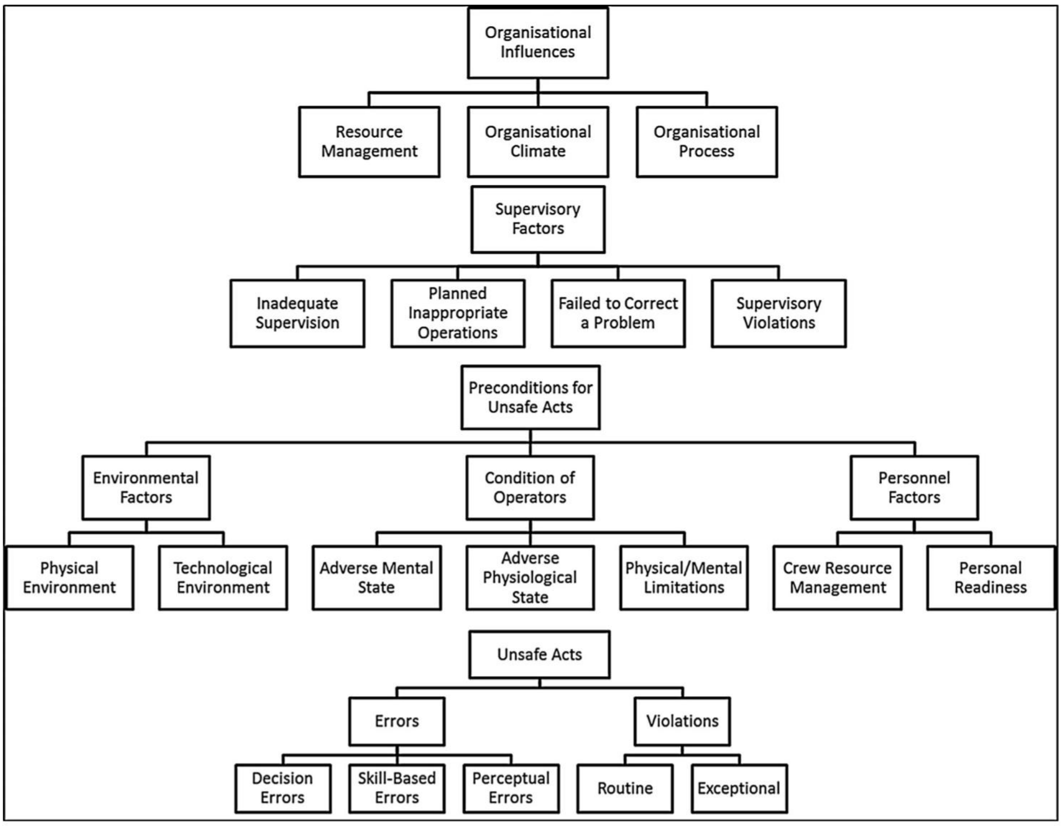


However, this model was not sufficient to identify and classify the actual and latent causes in a systematic method. In order to satisfy this need, the HFACS framework was generated.

3.2. Human Factors Analysis and Classification System (HFACS)

The Human Factors Analysis and Classification System (HFACS) (Shappell and Wiegmann, 2001) was originally developed and tested by the United States Navy to identify and classify the human errors of aviation accidents. The HFACS framework uses the same four levels of human failure presented by Reason’s model and advanced the causal sub-categories to identify the actual and underlying factors that occur accident. The HFACS framework assists accident investigators to systematically identify the active and latent failures within the organization that lead to an accident.

Figure 3-7. The HFACS framework (Shappell and Wiegmann, 2012)



Currently, the HFACS framework is one of the most common frameworks which adopted Reason’s theory on accident causation with active and latent failures. Originally, since HFACS was designed to apply to the aviation accident, it could be slightly revised to optimize for their industry field and utilised to analysis latent failures or organisational defect in the existing accidents; air traffic control (HFACS-ATC: Page, Wiegmann and Shappell, 2001; Scarborough, Bailey and Pounds, 2005), aircraft maintenance extension (HFACS-ME: Krulak, 2004), offshore helicopter transport industry (HFACS-HE: Omole and Walker, 2015), rail road (HFACS-RR: Reinach and Viale, 2006; Baysari, McIntosh and Wilson, 2008; Madigan, Golightly and Madders, 2016), health care (Diller, Dunning, Buchanan and Shappell, 2014; Hoffman, Segal, Foster and Rhoads, 2013), mining industry (HFACS-MI: Patterson and Shappell, 2010; Lenné, Salmon, Liu and Trotter, 2012).

The result of previous researches in the different industry fields appears that HFACS is a reliable retrospective tool to analysis the extensive accident investigation reports, identifying where and which errors and adverse events are underlying organizational system.

In the maritime field, there have been a lot of studies using HFACS framework. Celik and Cebi (2009) generated HFACS model, based on a Fuzzy Analytical Hierarchy Process (FAHP), to add the quantitative assessment of shipping accidents, and to order of priority the contributing factors to the accidents. The results present the need to recreate the safety guideline in the various industry field.

Furthermore, a dedicated Human and Organisational Factors (HOFs) framework for maritime accidents investigation and analysis was developed and named as HFACS-MA framework (Chen and Chou, 2012; Chen, Wall, Davies, Yang, Wang and Chou, 2013). This framework includes structures which in conformity with the main concept of HFACS, Reason 's Swiss Cheese Model, and Hawkins’ SHEL Model, combining with Why-Because Graph (WBG). This integrated model not only demonstrates the causation between factors but also presents the adverse affection between each level. Overall, using the HFACS tool, an organization identifies the hidden failure underneath the managerial control system that is likely to happen accident, and investigators could detect the reoccurring trend of human error and organizational deficiencies through the existing accident.

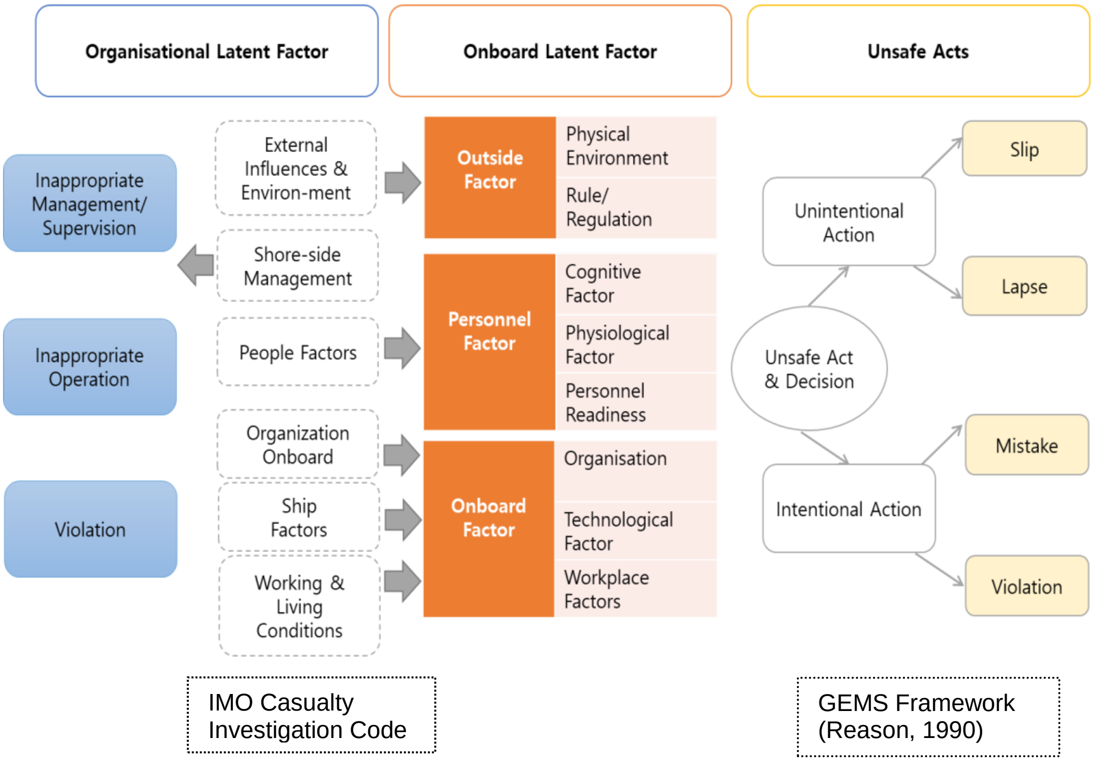
The HFACS also can be utilised as the framework that reviews and analyses the massive historical accidents and safety data. In addition, by breaking down the contributing factors on investigation records, analysists could distinguish unsafe acts and those related root causes so that the discovered factors could be helpful to improve the safety quality of the organizational system.

3.3. Maritime HFACS Taxonomy

This study applied the newly developed Maritime HFACS framework by Kim, Na and Ha (2011) for the purpose of analysing human factor related to the marine accident. The Maritime HFACS framework is currently used by the investigators of Korea Maritime Safety Tribunal (KMST), the marine accident investigation institute, when they identify human errors in categories of this framework on the phase of grasp and analysis of human error in the investigation of marine accident.

As described earlier, HFACS model of the aviation industry is divided into four stages: Unsafe Acts, Preconditions for Unsafe Acts, Supervisory Factors, and Organizational Influences. Combining the HFACS framework with six “Human elements” presented on the IMO Casualty Investigation Code (Res.A.884(21)) and the “GEMS” framework, the new model of Maritime HFACS was developed as Figure 3-8.

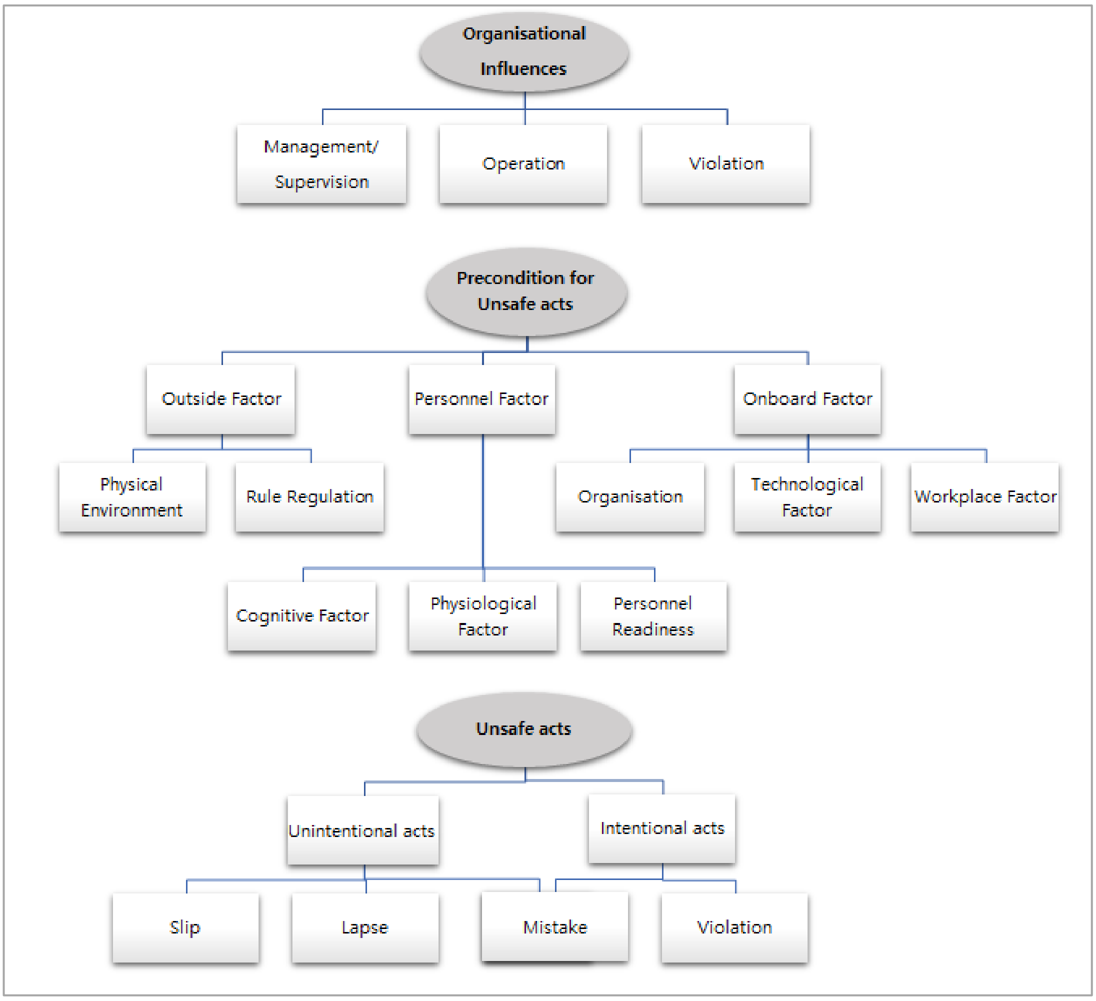
Figure 3-8. Detail Components of Maritime HFACS



IMO defined the latent factors affecting to human behaviour and working process as six elements of *People factors, Ship factors, Working and living conditions, Organization on board, Shore-side management,* and *External influences and environment*. Conjoining these six factors with organisational influences, supervisory factors, and precondition for unsafe acts of HFACS framework, the new category of Organisational latent factor and Onboard latent factor was constructed.

In addition, Unsafe acts category was compounded of *Unintentional action* and *Intentional action* of GEMS framework. In line with the result, a new Maritime HFACS framework classified into three levels of *Organisational influences, Precondition for unsafe acts*, and *Unsafe acts* was established as shown in Figure 3-9 (KMST, 2013).

Figure 3-9. Maritime HFACS taxonomy



First Level: Organisational Influences

The first level of the Maritime HFACS framework is the phase of Organisational influences by the shipowner/manager. Organisational failures are often hidden, so they do not reveal easily during the accident investigation unless the organisational scheme is understood clearly and the constant accident analysis framework is applied to the organisation. Unfortunately, identification of the errors at this highest level could be hindered because a company is reluctant to hold a liability for the failures with a fear of blame. These organisational influences generally include Inappropriate management/supervision, Inappropriate operation, and Violation.

Inappropriate Management/supervision

Allocation and maintenance of organisational resources are the most obvious decision-making of the shipowner/manager. Organisational resources encompass human resources, technological resources, and equipment/facility resources. Inadequate crew management/supervision, absence of training and mismanagement of equipment could create an unsafe situation.

Inappropriate operation

This category refers to cooperate decision-making that governs formal process of the organisation, including operations and procedures. The operation tempo, inappropriate operating system, improper operation plan, and absence of safety culture belong to this category. In addition, the case of the poor working condition such as improper punishment system, employment policy, etc. fall under the failure of inappropriate operation.

Violations

The acts that shipowner/manager deliberately violates the regulation or rule, e.g. of the unqualified crew onboard, violation of the safety manning, or acceptance of violation of the crew.

Second Level: Preconditions for unsafe acts

The active failures of unsafe acts are so obvious that it is likely to conclude them as the basic cause of the accident. However, accident investigators need to look deeper into precondition of the unsafe act that caused the active failures to know why the unsafe acts happened. The framework includes the second level of analysing the preconditions for unsafe acts, which involves the *Outside factors, Personnel factors,* and *Onboard factors*.

Outside factors

Outside factors consist of Environmental physical factors and Governance rule/regulations. Physical phenomena refer operational environment such as weather, port facilities, current, pilot, etc. Governance rule/regulations are intended to determine the compliance with safety regulation. This factor was added to the existing HFACS framework, because one criticism of HFACS has been failed to consider the external influences outside organizational level, such as government, regulators, manufacturer, social, environmental, political, economic and customers influence, etc. (Omole and Walker, 2015).

Accordingly, a lot of previous research applied the category of Rule/regulation to the fifth level of HFACS framework; HFACS-HE (Omole and Walker, 2015), HFACS-MA (Chen and Chou, 2012), HFACS-RR (Reinach and Viale, 2006), HFACS-MSS (Schröder, Baldauf, and Ghirxi, 2011). This factor will ensure that the regulator's regime does not adversely affect a ship safety. The regulations should follow the technical changes that contribute to the ship safety, and the process of establishing safety standards should detect potential risk that leads to a loophole in the regulations.

Personnel factors

If the crew resource management or self-imposed stressors create the precondition for unsafe behavior, these factors can be referred as *Cognitive factors, Physical factors* and *Personal readiness*. Conditions of seafarers are closely related to their behaviors. Cognitive factors include the individual's boredom, inattention, overconfidence, or a perceived absence of threat, and physiological state deals with the normal functioning of body. It is important to determine their physical condition to assure that not to increase the safety risk due to medical or physiological conditions. Personal readiness refers to a state in which the crew has a sufficient knowledge about navigation and machinery so that there are no obstacles or disabilities in the operation of the ship, and that the crew is properly trained and educated.

Onboard factors

The factors related to the ship largely divided into Organisation onboard, Technological factors, and Workplace factors. Organisational factors onboard cover organisational climate and crew interaction. An organisational climate refers to the variables working atmosphere within the organisation, including the structure, policies, and culture affects individual behavior. Inadequate chain-of-command structure, adversarial policies and inappropriate rules, attitudes and customs of the ship could contribute the manner in which the crew's task is carried out negatively. Good crew interaction can reduce the ineffective communication skill or a lack of teamwork. Poor team coordination leads to confusion in individuals' responsibilities, then results in the organisational breakdown. Technological factors encompass the design of ship or equipment, handling of cargoes, maintenance check-up status, ship's draft, etc. Workplace factors include the condition of work place such as lighting, noise, miasma, working tool, etc.

Third Level: Unsafe Acts

Unsafe acts that directly lead to marine accidents are divided into Intentional and Unintentional actions as follows; Slip, Lapse, Mistake, and Violation. Crew's behaviour is also divided into knowledge-based, rule-based and skill-based behaviours through learning and experience.

Unintentional acts include a Slip and Lapse caused by a skill-based error. A Slip refers to a situation where the understanding of the situation and the choice of behaviour are correct, but the action itself is misplaced due to momentary attention failure. A lapse refers to a behavioural failure due to a momentary memory problem. Intentional acts contain a mistake and violation. A mistake includes knowledge-based errors that indicate the uncomprehending acts or inaccurate behaviour by prejudice and rule-based errors due to excessive confidence. A violation represents a case of intentional disregard of a regulation, rule or procedure.

4. Methodology

4.1. Adoption of Maritime HFACS

The first step to analysis marine casualty investigation was to find a reasonable analysis tool for distinguishing the active and latent factor of human error. Qualitative methods can be more useful for identifying the human error and determining the cause of the accident. One of the most well-known tools for assessing the human causal factor is the HFACS framework. Many researchers have utilised the HFACS tool to measure the actual and latent conditions involved in the accidents. Given the previous success that HFACS, which developed in the aviation field, has been modified and optimised in a variety of industries, it seems reasonable to apply the HFACS framework to identify active and latent failures within the maritime accidents in hopes that similar results could achieve. The amended HFACS framework for the marine accident is called Marine HFACS.

As above mentioned, KMST adopted the Maritime HFACS framework as the analysis method of human elements to the *Guidelines for Maritime Accident Investigation* (2013) for their worksite operation of the marine accident investigation. According to the guidelines, when it is unclear whether the identified potential factors are affected, additional and repeated investigations are conducted to pinpoint potential factors that cause the unsafe acts.

Consequently, this study, which re-analyses the accident investigation reports that have identified human error in accordance with the Maritime HFACS framework, was estimated as a meaningful research to show that whether the latent factors contained in the accident report are sufficient to reveal the root cause of the accident, and the identified human error represents the trends in overall passenger ship accident.

For the demonstration of the application of the Marine HFACS category, the case of “Precondition for unsafe acts” (1st tier), “Onboard factors” (2nd tier), and “Technological factors” (3rd tier) can be given in terms of “Unsuitable equipment”. the “Technical factors” is one of three resources of 3rd tier category included in “Onboard factors” of the 2nd tier. The “Unsuitable equipment” such as spare parts not fitted to the specific machinery on board can cause an equipment and machinery malfunction. From the organisational point of view, it is required to look into how and why the unsuitable component is allocated, and whether the seafarers already knew that and reported to the upper level of organisation.

4.2. Database

Data was collected from marine accident reports released on the website of KMST. Accident investigation reports for the aim of this study were selected based on the following conditions; All cases of accidents are subjected to the completion of judgment for cause investigation and responsibility for it. The accident period is restricted to accidents that occurred from January 1, 2014 to December 31, 2015. The ship type is limited to the passenger ship, including high-speed craft, super speed craft, super high-speed craft, enclosed Ro-Pax, and opened Ro-Pax. A navigation area is bound to Korean coastal sea. Passenger ships less than 100 gross tonnages were removed from this object. The type of accident is selected by all kind of accident causing death, injuries, damages on human and ship, and the accident which had a potential to lead to these adverse events.

4.3. Data coding and analysis

Investigation reports were coded by the author with advice by two Human Factors experts. Before beginning the HFACS coding, details about each accident were extracted with ship name, ship age, ship type, gross tonnage, accident date, accident type, accident location, and the result of accident.

After that, the author looked through the investigation reports exhaustively, and the contributory factors stated on the reports discern and distributed on the specific category of Maritime HFACS framework. For this, the Maritime HFACS diagram (Figure 3.9) and the classified code table for latent factors of Level 1 and 2 specified in the *Guideline for Maritime Accident Investigation* (2013) (refer to Appendix B) were used, with reference to the description and table of HFACS taxonomy provided in Shappell and Wiegmann (2012). The total 96 human error causal factors were found out in the 30 investigation reports. This paper allowed the repetition of code to find as many human error causal factors as possible.

After all of the data was coded, the analysis stage commenced. First, the 96 contributing factors were classified under three levels of Maritime HFACS: *organisational influences*, *precondition for unsafe acts, and unsafe acts.* For the next step, the factors in each category were subdivided into sub-categories depending on their attribute. This stage allowed to confirm the contributory factors under each level of Maritime HFACS framework by the different types of accidents: *Machinery failure, Grounding, Flooding, Contact, and Collision*.

However, regarding the organisational influences of level 1, the author found that it is not possible to assign the contributory factor related to the organisational procedure such as procedural guidance or informational resources due to the lack of the code. Although, the code of *inappropriate procedure, regulations, instructions* is included in the *organisation* category of *onboard factor,* this is also considered to be a potential safety issue for the organisation. In the present study, the factor of organisational procedure was included in the category of *operation* at the level 1.

On completion of classification, the process of the relational analysis of contributing factors between each level was carried out by accident type. Chased the deployment process of each single accident, related causal factors between the level were linked to each other. This final step explored the specific pattern of the accidents and the contributing factors that need further inquest.

5. Results and discussion

5.1. Accident database

A total of 30 accident cases that occurred in the two years span between 2014 and 2015 were used in the analysis, involving five main types of accidents as follows (KMST, 2016).

- Machinery damage/failure (N= 16)
- Collision (with other vessels) (N= 5)
- Grounding (N= 4)
- Contact (to bridge or pier) (N= 3)
- Flooding (N= 2)

The highest frequency of *machinery damage/failure* shows the similarity with the passenger ship accident statistics over the past five years (Table 2-5), which recorded the largest portion of 30.4% concerning *machinery damage/failure.*

The average year of 30 accident vessels was 15.3 by the time of the accident, occurring mostly in 16 years and more, with 66.7%. The frequency of vessels by ship year as follows.

- 01 – 05year (N= 5)
- 16 - 10year (N= 3)
- 11 – 15year (N= 2)
- 16 – 20year (N= 13)
- Over 20year (N= 7)

With respect to the accident location, the 11 cases of accidents in ports or approaching channels occurred, accounting for 36.7%. This ratio is much higher than the result of statistics in the past five years, which accounted for 12.9% (Figure 2-9). Of the 11 accidents, six were accidents caused by machinery damage. This fact suggests that passenger ship with frequent inbound and outbound ports should pay particular attention to the use of the machinery.

Regarding the effect of the accidents, most accidents only suffered minor damage to the hull and equipment, except one person of drowning in a collision accident. In addition, the total 19 injuries occurred in contact and collision accidents. In the one case of the flooding accident, the discharge valve of the lubricating oil tank was opened due to flooded engine room, and 195 litres of lubricating oil and 5 litres of bilge water were discharged into the sea, resulting in marine pollution. The details about accident vessel list can be shown in Appendix A.

As mentioned earlier, Maritime HFACS is a contributory factor analysis framework that investigators of KMST use to refer to investigation reports presently, so there was no major difficulty in dividing the factors presented in the report back into the framework. The investigators examined contributing factors, focusing on unsafe actions and thoughts of the crew that had an impact on the immediate cause of the accident, and potential condition that affects to the active failures.

Accordingly, this coding work carried out only with the contents described in the accident investigation reports. As a result of the examination, the distribution of HFACS category in the 30 investigation reports is described in Table 5-1. A total of 96 contributing factors were identified, averaging 3.2 factors per investigation report. Grounding and flooding accident report were the highest, with an average of 4.5 factors, and machinery failure accident report were the lowest, with an average 2.4 factors.

Table 5-1. Distribution of number of causal factors by accident type

Type of Accident	Frequency of Accident	Number of Causal Factors	Number of causal factors per accident cases		
			Min	Max	Mean
Machinery failure	16	39	1	4	2.4
Grounding	4	18	4	5	4.5
Flooding	2	9	4	5	4.5
Contact	3	12	2	6	4.0
Collision	5	18	2	6	3.6
Total	**30**	**96**			

5.2. Causal factor coding

After all the contributory factors have been identified, the first step for coding was executed. These factors were classified by three levels of Maritime HFACS: *organisational Influences, preconditions for unsafe acts, and unsafe acts.*

Table 5-2 shows that the frequency of causal factors of 30 accident investigation reports and the percentage, which is the ratio frequency occurrence to the total 96 contributory factors. The category of the highest proportion of HFACS category is the unsafe acts (42.7%), followed by preconditions for unsafe acts (39.6%) and organisational influences (17.7%). Then, the contributory factors allocated in each HFACS category further classified into 15 subcategories.

At the level 1 of organisational influences category, the factors related to the company's management/supervision were higher than operation, with 12.5% and 5.2%, respectively. However, *violation* of the organisation was not mentioned in the accident report. Among the level 2 of pre-conditions for unsafe acts, onboard organisation factors show a highest ratio in the accident reports, accounting for 9.6%. personnel readiness in personnel factors and physical environment in outside factors were the highest as 8.3% and 7.3%, respectively. However, none of the reports referred to the causal factors involved in physiological state of seafarers. In the level

3 of unsafe acts category, the proportion of violations was the most frequent category, accounting for 25%, followed by mistakes as 15.6%.

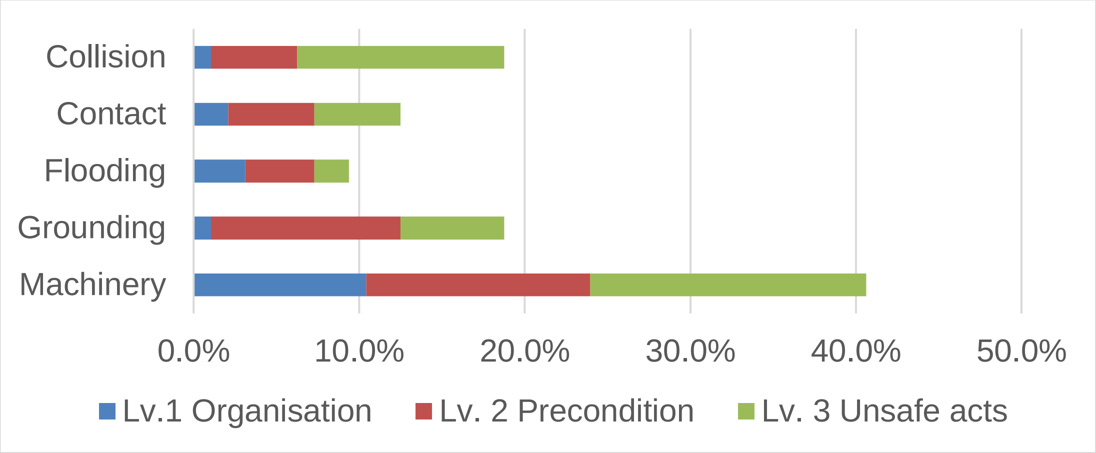
Table 5-2. Distribution of casual factors of HFACS category

	Category	Sub-category	Frequency	Percentage
Level 1	**Organisational Influences (17.7%)**			
		Management/Supervision	**12**	**12.5%**
		Operation	5	5.2%
		Violations	-	-
Level 2	**Pre-conditions for unsafe acts (39.6%)**			
	Outside factors	Physical Environment	7	7.3%
		Rule/ Regulations	1	1.0%
	Personnel factors	Cognitive factors	5	5.2%
		Physiological factors	-	-
		Personnel readiness	8	8.3%
	Onboard factors	**Organisation**	**10**	**9.6%**
		Technological factors	6	6.3%
		Workplace factors	1	1.0%
Level 3	**Unsafe acts (42.7%)**			
	Unintentional	Slip	1	1.0%
		Lapse	1	1.0%
	Intentional	Mistake	15	15.6%
		Violation	**24**	**25.0%**
Total			96	100.0%

5.3. HFACS category analysis

Figure 5-1 describes the percentage of casual factors by accident type. In all types of accident reports, it can be seen that each level's contributing factors have been found. The machinery failure accident as unsafe act of HFACS category was classified more often than other categories, accounting for 16.7%, whilst the organisation Influences factors of collision and grounding accident were the lowest proportion with 1.0%. In the grounding accident report, the proportion of precondition for unsafe acts factors was significantly higher than level 1 and level 3, accounting for 11.5%. As for the collision accident, the frequency of unsafe acts was significantly higher than other levels, with 12.5%.

Figure 5-1. Percentage of casual factors by accident type



Further analysis to examine the interrelation between the HFACS subcategory and accident types were conducted. The frequency and proportion of causal factors by accident type is demonstrated on Table 5-3 below.

In case of the machinery failure, the *violation* in the level 3 of *unsafe acts* was the highest (35.9%), followed by the *organisational management/supervision* (20.5%). Among the *preconditions for unsafe acts*, 12.8% were the onboard organisational factors.

In the grounding accident, *mistakes* of seafarers were the largest portion with 33.3% and *personnel readiness* with 22.2% and *physical environment* with 16.7% appeared at a high frequency.

In two cases of the flooding, one *lapse* and one *mistake* for the *unsafe acts* were identified. And, as the *precondition for unsafe acts*, onboard factors were most frequently founded, accounting for 44.4%. At the Level 1 of *organisational influences*, two factors of *management/supervision* and one factor of *operation* were discovered.

Table 5-3. Distribution of causal factors of HFACS subcategory by accident type

Category		Subcategory	Mach- #(%)	Ground- #(%)	Flood- #(%)	Contact #(%)	Collision #(%)	Total #(%)
Lv 1	Management/ Supervision		8 (20.5)	-	2 (22.2)	1 (8.3)	1 (5.6)	12 (12.5)
	Operation		2 (5.1)	1 (5.6)	1 (11.1)	1 (8.3)	-	5 (5.2)
	Violations		-	-	-	-	-	-
Lv 2	Outside factors	Physical Environment	-	3 (16.7)	-	1 (8.3)	3 (16.7)	7 (7.3)
		Rule/ Regulations	-	1 (5.6)	-	-	-	1 (1.0)
	Personnel factors	Cognitive factors	2 (5.1)	1 (5.6)	-	1 (8.3)	1 (5.6)	5 (5.2)
		Physiological factors	-	-	-	-	-	-
		Personnel readiness	2 (5.1)	4 (22.2)	-	1 (8.3)	1 (5.6)	8 (8.3)
	Onboard factors	Onboard organisation	5 (12.8)	2 (11.1)	2 (22.2)	1 (8.3)	-	10 (9.6)
		Technological factors	4 (10.2)	-	1 (11.1)	1 (8.3)	-	6 (6.3)
		Workplace factors	-	-	1 (11.1)	-	-	1 (1.0)
Lv 3	Un-intentional acts	Slip	1 (2.6)	-	-	-	-	1 (1.0)
		Lapse	-	-	1 (11.1)	-	-	1 (1.0)
	Intentional acts	Mistake	1 (2.6)	6 (33.3)	1 (11.1)	3 (25.0)	4 (22.2)	15 (15.6)
		Violation	14 (35.9)	-	-	2 (16.7)	8 (44.4)	24 (25.0)
Total			39 (100)	18 (100)	9 (100)	12 (100)	18 (100)	**96 (100)**

The contact accident report reveals three factors of mistakes and two factors of violation of seafarers, which are most occupied with 41.7%. The elements related to Level 1 and Level 2 were found to be very diverse; manage/supervision, operation of organisational influences and physical environment, cognitive factor, personnel readiness, onboard organisation and technological factor of precondition.

With regard to the collision accident, the most common violation of unsafe acts was found (44.4%), and the next high frequency was the mistakes with 22.2%. The precondition that most affected the accident revealed the physical environment, accounting for 16.7%.

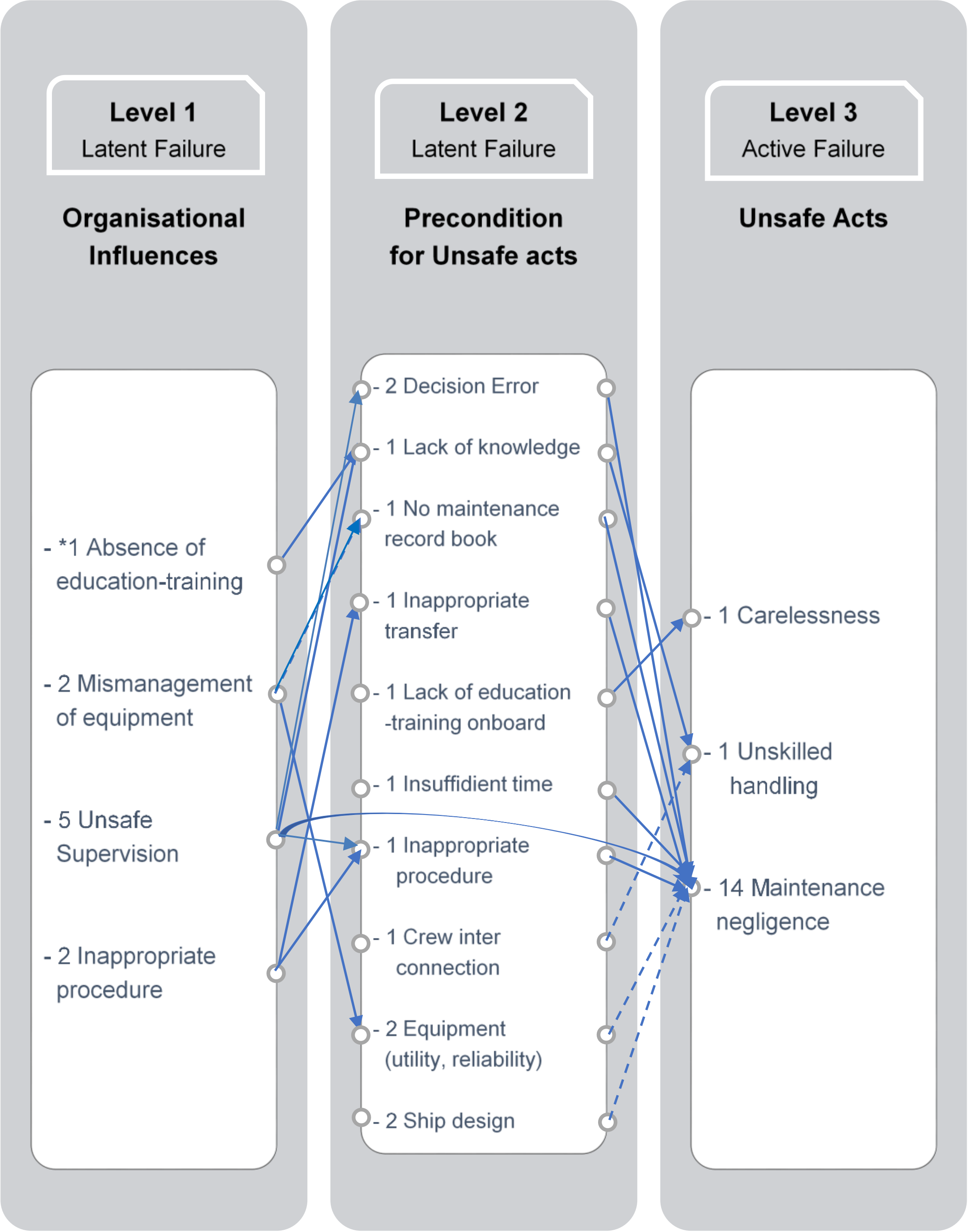
5.4. Factor relationship analysis by accident type

Based on the contributing factors identified in the subcategory by level, the author probed into the detailed conditions of single accident case and integrated into each level by accident type. In addition, the author inspected the relationship of contributing factors at each level to those at different levels to determine whether the latent failures of level 1 and 2 have been sufficiently discovered by investigators. For this purpose, the author found correlations by finding level 2 factors that could originate from level 1 or that level 1 affected, and then, determined the factors of unsafe acts that could be caused by the factor of level 2 and connected them to each other. For example, the absence of educational-training by the shipowner/manager triggered the lack of knowledge of seafarers as a latent error and unsafe acts that may occur due to lack of knowledge of level 2 is the operational inability of equipment.

Machinery Failure

16 accident reports of machinery failure have found out 39 contributory factors. Figure 5-2 exhibits a diagram of the relationships in which the contributing factors identified at each level are affecting contributing factors at different levels, in terms of machinery failure accident. In 14 of the 16 accident cases, the accident reports indicated that the active failure of the machinery defect was due to maintenance negligence of machinery by Chief Engineer (C/E) or Captain. In order to provide a more specific overview about the machinery failure resulted from improper maintenance, some technical casual factors involved in malfunctioning of a machinery are shown in Table 5-4.

_ Figure 5-2. Relations of Casual Factors between Levels (Machinery Failure)



*Note: 1. The number means the frequency of contributory factors.

2. Dotted line describes the relationships that did not directly affect the lower-level factors, but which, in combination with those factors, had an impact on the accident.

Table 5-4. Reported technical causes of machinery failure

- Main Engine
  - Piston Pin Bush to break loose
  - Breather valve breakdown caused Fresh water tank exploded
  - Turbo charger inhalation fixing spring to break loose
  - Stud fatigue scission
  - Impurities in cooling water system
  - Cylinder Fuel injection nozzle cap overtightening cause sealing damaged
  - Cylinder inhalation valve sheet faulty
  - Cylinder inhalation valve collet fatigue scission
- Steering Gear
  - Relay Switch breakdown
  - Steering Shaft to break loose
- Rudder
  - Leakage of Gland packing
  - Piston Pin Bush to break loose
- Miscellaneous
  - Impurities in Fuel oil filter cause Relief valve damaged
  - Spare Seawater pump fatigue scission

As illustrated in Figure 5-2, a variety of factors on the level 2 contributed to the latent cause of the maintenance negligence. Regarding the personnel factors, the different two cases showing the inability to judge the situation despite the perception of risk indicator and the failure to prepare a maintenance record imply that the C/E has an undesirable attitude to their duty. In the first event, however, the onshore supervisor also did not take any action against the identified risk on the main engine despite every week inspection, and in the second event, the shipowner operated the vessel without confirming the specific maintenance details since the purchase of the vessel. These inadequate systematic supervision and inspection were found to affect the unfavourable attitude of the seafarers.

The time constraints indicated as the other cause of the maintenance negligence are the potential factors that threaten the safety of passenger ship with frequent inbound and outbound port. Although, the investigation report no longer discussed this issue in detail, this problem should inquire the reason through multifarious approaches and eliminate the latent conditions by managerial control such as the redistribution of workload, new recruits, or a support from onshore.

The preterition of the takeover procedure and unavailable informational resources suggest that there is a problem within the operational system of the company as well as the direct responsibility of seafarers. These inappropriate management of company has a negative impact on the safety working onboard.

In addition, the inattentive maintenance of crew members can be eliminated in advance by thorough supervision of the company. Five investigation reports out of 16 referred the inadequate supervision of manager as the latent failure of Level 1. The role of the manager as a supervisor is to periodically check the company's overall operations, decisions, policies, and safety status of the ship to remove the hazards onboard previously.

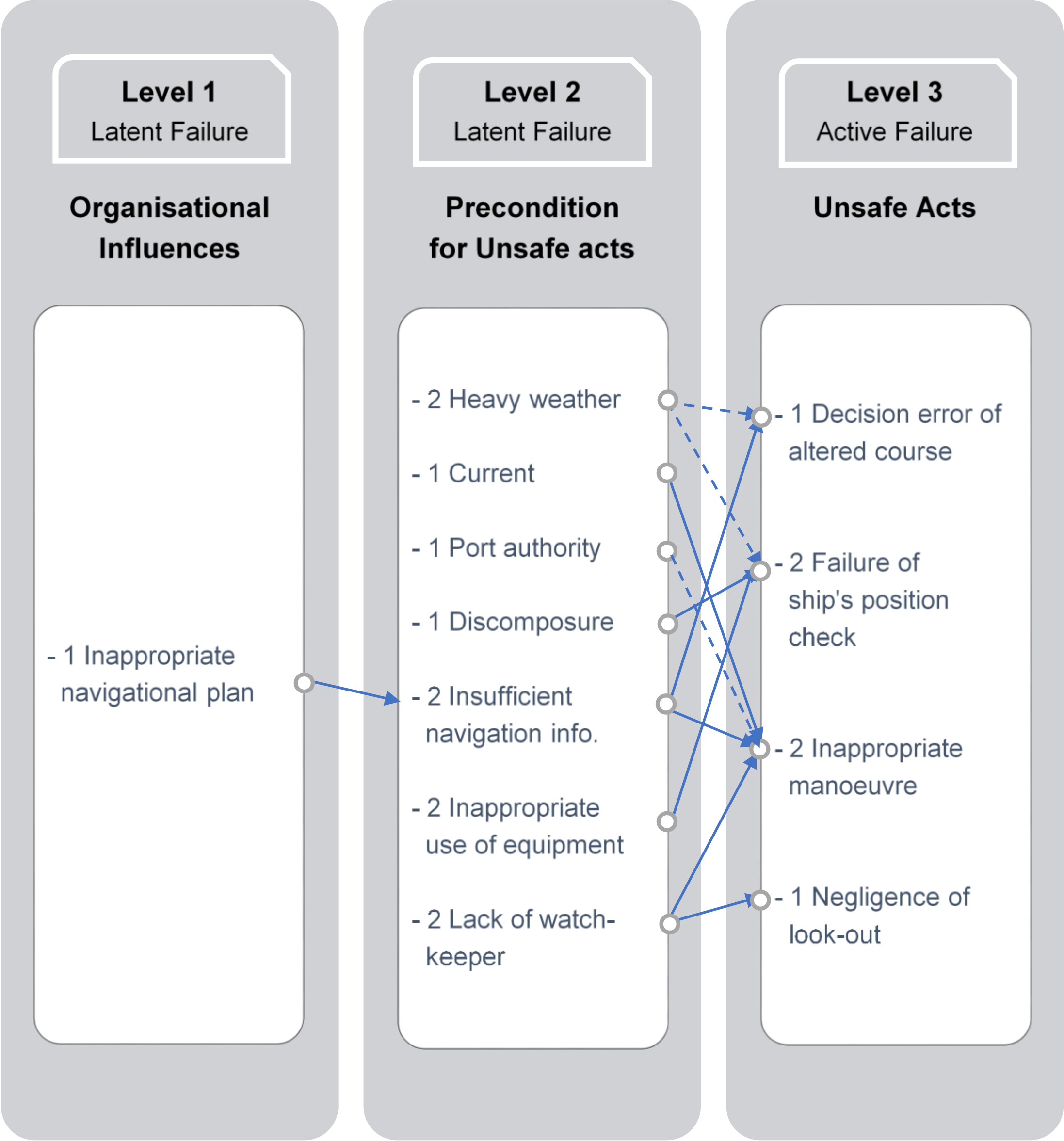
The insufficient information of equipment also brought about the machinery defect. The lack of safety education onboard made seafarers' careless action and the absence of technical knowledge caused the unskilled handling by seafarer. It is important to note that thorough training and skilful handling of equipment are essential for the seafarer onboard ship.

The responsibility for the actual management of the hull, machinery and equipment is on the captain and the C/E, but the ship owner is also obliged to maintain good condition of the ship so that the hull, machinery and equipment operate normally. To provide suitable human and equipment resources onboard, to establish appropriate performance standards, and to dispatch the qualified supervisors could be the barriers to avoid the machinery failure.

Grounding

Four investigation reports of the grounding identified 18 causal factors. Figure 5-3 demonstrates the casual factors of each level and those relationships with regard to grounding accident. In which, most of the factors related to the unsafe acts of the seafarers and latent factors related to the ship were identified.

_ Figure 5-3. Relations of Casual Factors between Levels (Grounding)



Active failure of grounding accident significantly revealed the failure of fixing on ship's position and improper manoeuvre. As the latent cause for the unknown ship's position, the improper use of navigational aids (e.g. GPS plotter, radar, etc.) and the discomposure of seafarers with heavy rain contributed to the unsafe acts. Regarding the latent factors that caused inappropriate manoeuvre, the combination of environmental factor (current) and operational factors (lack of watchkeeping) on board led the ship to the shallow water area. The lack of navigational information affects to the selection of safe course, resulting in the wrong decision. However, as the causal factors of inappropriate use of navigational aids and the lack of watchkeeper is insufficient on the investigation reports, it is needed to provide further investigation of organisational management or supervision.

Furthermore, the compelling ship manager to operate vessels without adequate port information was a threat to the preparation of seafarers for safe navigation, which in turn affects the unsafe acts of seafarers. In this case, the fact that the port authority, who had a dredging construction in the port, has not properly reviewed the dredging work in the process of approval of ship’s course and trial running was the one of the contributory factors.

A possible explanation for the main contributory factors to the grounding accident may be the lack of adequate navigation skill, planning, and heavy weather. For the organisational approach, it is required further investigation for use of the navigation equipment, the placement of watchkeeper, and operational procedure for the irregular circumstance.

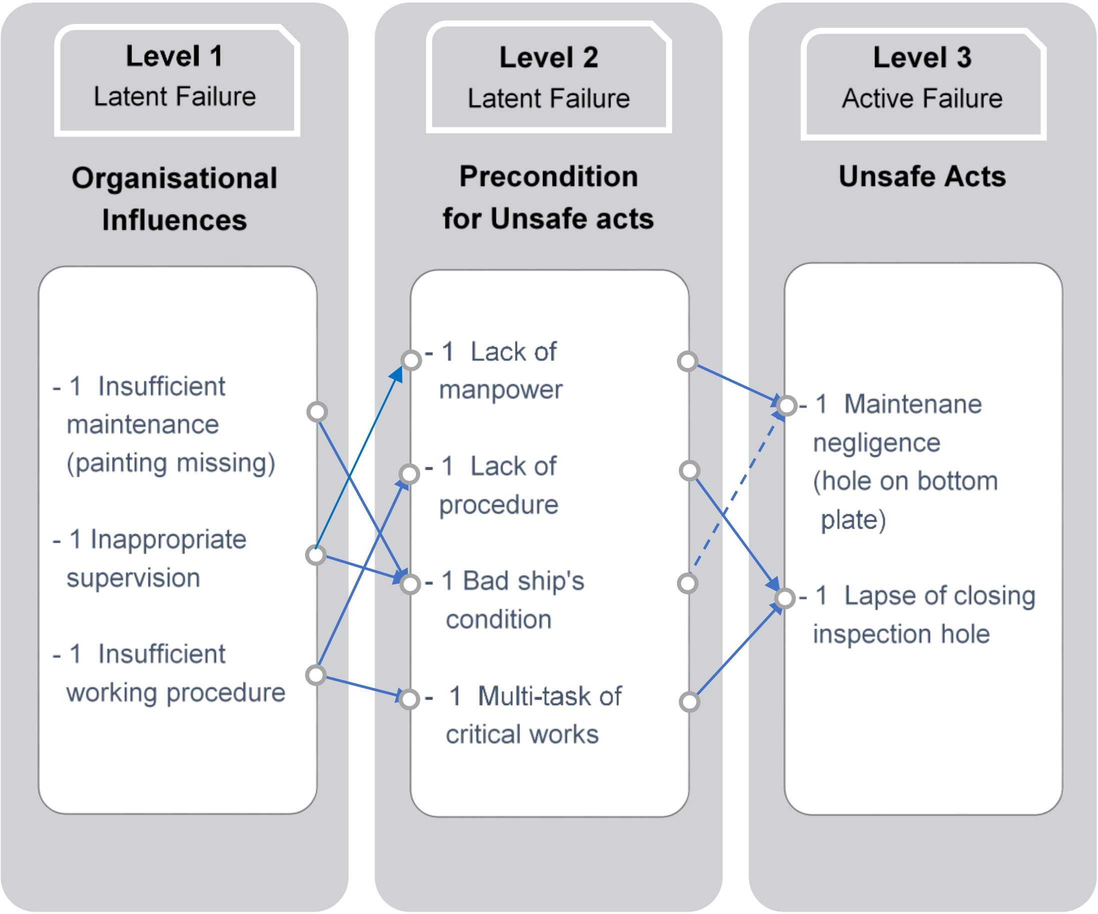
Flooding

Two flooding accident reports revealed nine contributory factors. The results of the interrelation analysis of contributory factors involved in Flooding accident are shown in Figure 5-4. These flooding accidents were caused by seawater inflow through hole on the hull. The first accident was resulted from the stagnant bilge and painting missing on the engine room bottom. This could be caused by the negligence of the management of the C/E, but it was also discovered as a potential cause of the insufficient maintenance and inappropriate supervision of manager.

The second accident caused by the fact that the C/E did not close the inspection hole while simultaneously handling the important work. However, the factor that the shipowner did not set up a procedure for major work was a latent failure, which the

C/E handled the two tasks alone at the same time. Hence, in order to assure the ship's safety, proper management and supervision of the ship is required.

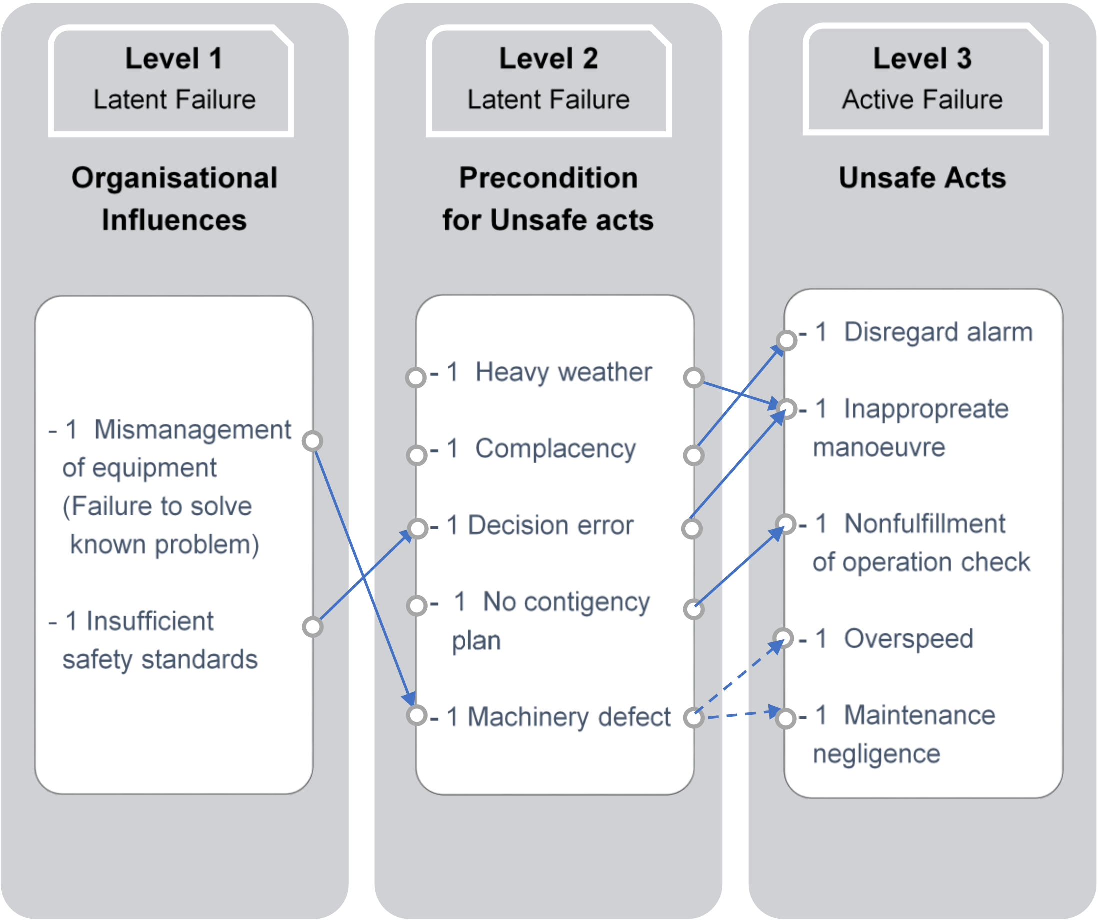
_ Figure 5-4. Relations of Casual Factors between Levels (Flooding)



Contact

Contact with pier or bridge accident occurred three events and 12 contributing factors were identified. Figure 5-5 below illustrates the relations of casual factors between levels of Contact accident. The active failure of contact is divided into the out of control due to mechanical failure (two cases) and improper manoeuvre due to contrary weather (one case). The defects that caused the engine failure were already recognized by the crew and the manager. To ignore the warning alarm with a complacency, or not to set an emergency plan in spite of recognizing the state of an unstable machine, was enough to bring about an accident.

Figure 5-5. Relations of Casual Factors between Levels (Contact)



At the organisational level, continuing to operate without sufficient action on the flaw is a potential cause of the accident. The insufficient safety standards of the shipowners make it difficult for the crew to judge the situation properly, which leads directly to improper operation. As for the overspeed of unsafe acts, it is needed to identify whether this problem is involved in the individual habit or is influenced by the operational tempo.

Looking at the pathway of contact accident, unsolved machinery damage, which combined with overspeed of engine or complacency resulted in the machinery failure, and insufficient safety standards for the heavy weather affected to decision error of inappropriate manoeuvre.

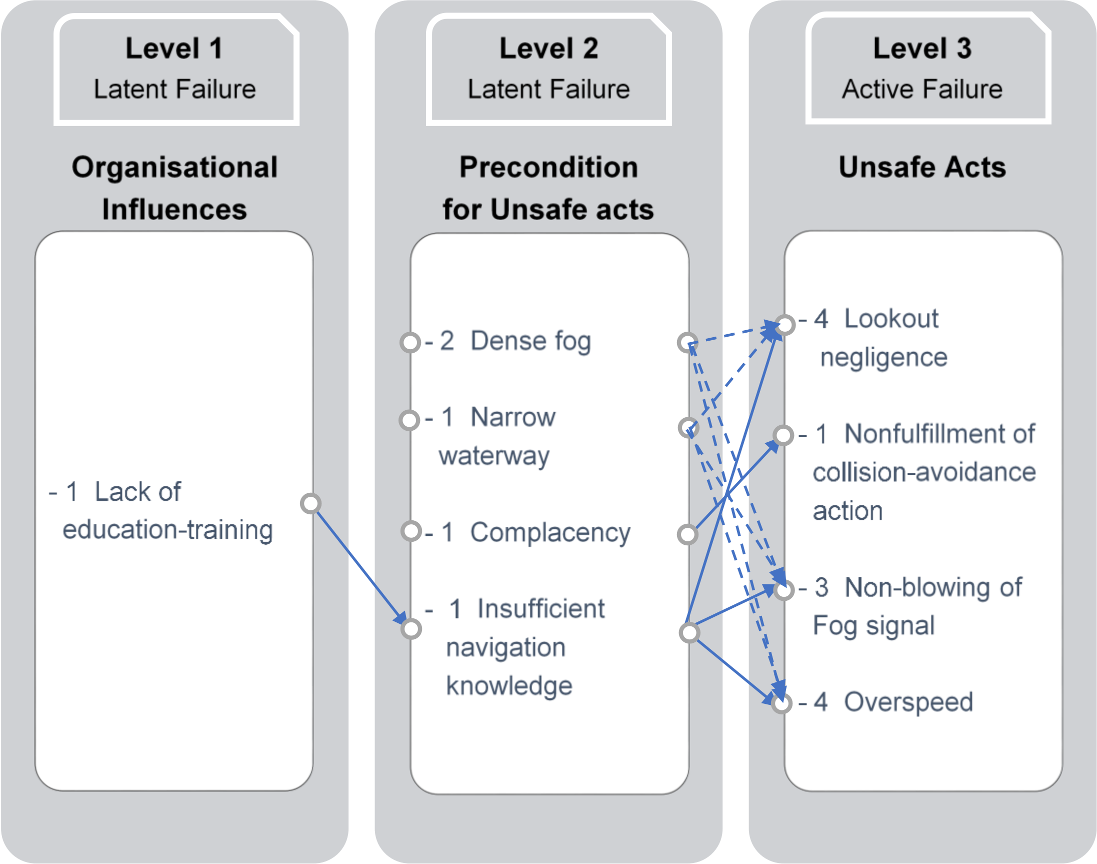
Collision

Five collision accident reports described 18 causal factors. Figure 5-6 provides the intercorrelations of casual factors between levels of Collision accident. All five Collisions were caused by violations of navigational laws. The violation of *Fog navigational regulations* (fog signal, look-out, etc.), overspeed, and the non-fulfilment of collision-avoidance action were the active failure of the collision accident.

These violations of regulation determined a latent failure of the lack of navigation knowledge of seafarers, which results from the insufficient education-training by shipowner/manager. In the non-fulfilment of collision-avoidance action, the complacency of seafarers affected to the unsafe acts.

Although collision accidents are highly influenced by the limited visibility, the navigational law observance and safety awareness development through education and training can reduce the risk of accident.

Figure 5-6. Relations of Casual Factors between Levels (Collision)



5.5. Discussion

An initial objective of this dissertation was to identify the active and latent failures of the existing investigation reports, the accident mechanism by accident type, and the quality of investigation reports.

The analysis of 30 investigation reports using HFACS tool has enabled to discovery of 96 human error causal factors involved in passenger ship accident. The relational analysis between active and latent failures has facilitated to understand of accident pattern from the latent factors of the organisational system through the latent factors of onboard to the unsafe acts of seafarers. Additionally, the relational analysis has suggested the causal factors that need further development.

5.5.1. HFACS Utility

The HFACS framework helps to distinguish active failures and latent failures involving in the existing accident reports. In this study, the category with the most common contributory factor in the level of unsafe acts is the violations by seafarers. Compared with an another HFACS analysis of tugboat collision accident in Korea (Kim et al., 2011), unsafe acts mainly related to mistake (48.4%) and violation (42.4%), which also are the highest portion among all categories. However, in the previous research in both maritime (Chauvin, Lardjane, Morel, Clostermann, and Langard, 2013; Schröder et al., 2011) and other industries (Griggs, 2012; Madigan, Golightly and Madders, 2016; Patterson et al., 2010), violation rarely accounts for the highest percentage of all categories, as well as at the level of unsafe acts.

At the precondition for unsafe acts, the condition of onboard organisation occupied the largest portion, followed by personnel readiness, physical environment, and technological factor. Li, Harris and Yu (2008) also identified *crew resources management* as the most common factor of precondition. However, the prevailing factor of precondition has been variously identified in the different research; *self-imposed stress* (Griggs, 2012), *adverse mental state* (Madigan et al., 2016), *technological environment* (Reinach and Viale, 2006; Schröder et al., 2011), and *physical conditions* (Patterson et al., 2010).

At the level of organisational influences, like the earlier studies, the analysis reveals a relatively less frequency of factors compared to other levels. However, the percentage of organisational influences found in the reports was 17.7%, which was relatively low compared to other research: Griggs (2012): 37%; Madigan et al. (2016): 21.6%; Schröder et al. (2011): 23.1%.

As mentioned earlier, one of key findings from the causal factor analysis was the lack of code for organisational procedure. Issues related to the inappropriate organisational procedure identified in the investigation reports are; the lack of duty transfer procedure, the machinery instructions written in foreign language, insufficient safety standards for heavy weather, and the lack of critical operation procedure (e.g., bunkering). Patterson et al., (2010) showed that *procedures* were most common

(77.2%) within organisational process category, and argued that the lack of standard procedures makes the crew select the accomplishing method, which is not always the safest way to complete. This study also described that the procedural errors of organisation affected a variety of factors of precondition e.g., improper duty handover, inappropriate procedure on board, and estimate of the situation inability. Moreover, the code of inappropriate procedure of *onboard factor* category can be considered to be the responsibility of Captain or C/E, not the safety manager or shipowner. Therefore, the addition of organisational procedure category to the Maritime HFACS framework would provide an additional opportunity to understand the impact of improper procedure at the organisational level on the ship safety.

Overall, these analyses demonstrate that the types and frequency of contributory factors may vary by the research field, but the most obvious finding to emerge from the HFACS analysis is that there are latent failures in all actual failures. This focus attention to the importance of violations of seafarers and onboard organisational factors to the passenger ship safety and demonstrate where supplement (organisational procedure) is required.

5.5.2. Pattern of accident cause

The analysis of investigation reports facilitates to establish the typical pattern of accident cause, although the case by accident type is small and the contributory factors at upper levels are not sufficient to know their influences the lower levels. Based on the relationships of contributory factors at each level by accident type, in total nine patterns are identified with active failure and latent failure. With regard to the presence of pattern, the relative risk associated with these failures are accessed, and the countermeasures to mitigate the failure are given to the Table 5-5.

Table 5-5. Pattern of passenger ship accident cause

Accident Type	Pattern #	Active Failure	Latent Failure	Implications	Counter-measures
Machinery Failure	#1	Maintenance Negligence	Operating procedure	Lack of procedure/ guideline caused the unawareness of machinery condition	Reassess present procedure/ checklist, and Provide training
	#2	Unskilled handling	Resource Management (Human)	Unqualified seafarers	Provide instructions for mechanical operation and training
	#3	Maintenance Negligence	Unsafe supervision	Failure of risk assessment	Assign qualified supervisor
Grounding	#4	Inappropriate manoeuvre	Operational tempo	Lack of navigational information	Provide education-training
Flooding	#5	Maintenance negligence	Unsafe supervision	Failure of risk assessment	Assign qualified supervisor
	#6	Lapse	Operating procedure	Imperfection of duty	Develop working procedure
Contact	#7	Maintenance Negligence	Resource Management (Equipment)	Machinery deficiency	Revaluate the present procedure
	#8	Inappropriate manoeuvre	Operating procedure	Lack of procedure/ guideline caused decision error	Establishment of operational procedure
Collision	#9	Violation of navigation rule	Resource Management (Human)	Unqualified seafarers	Provide education-training

What stands out in the accident pattern is that there are various latent factors that affect the maintenance negligence, which is the most common active cause, and the implications and countermeasures against them are also different. This result argues that the high maintenance should be supported by the appropriate operating procedure, safety supervision, education-training and sufficient resource management for equipment at the organisational level.

5.5.3. Quality of investigation reports

One of the objective of this study is to examine whether the investigation reports reflect enough detail organisational causal factors underlying within the managerial control system. As expected, however, like in previous studies, the data contained in the investigation reports was a few in quantity to discover the root cause of the accident. The major shortcomings of HFACS framework for identifying the contributory factors are the need of the massive database of factors, since lots of previous studies demonstrate that systematic approaches depend on the quality of the data provided (Madigan et al., 2016).

Marine accident has a difficulty to investigate causal factors unlike the accident within land, as it is difficult to gather and secure evidence, such as preserving the accident site, recreating the accident and securing witnesses. In addition, the cause of the accident is fundamentally complex and diverse. Thus, it is not a simple task to discover the latent cause of the accident, unless the investigator conducts an in-depth investigation of the organisation.

However, according to the other research, since the KCG and KMST, who are responsible for the investigation and judgment of marine accidents in Korea, identify causes of accidents mainly for the purpose of identifying violation of the law and estimating the ratio of responsibility, it is considered that the accident investigators do not pay careful attention to establish the root cause of an accident to prevent further accident (SNAK, 2015).

Nevertheless, it should not be overlooked that the potential of the organisation could be a fatal cause of accidents. As KMST already uses HFACS framework as an accident investigation tool, it is estimated that it is fully aware of the importance of human factors and latent conditions underlying organisational system. The fact that there is the contributory factor which is not included under the Maritime HFACS category (organisational procedure) suggests the possibility that more latent factors may be found. It is necessary to clarify what is the root cause of the accident through the multiple investigations including the education-training of the seafarers, the working process, the organisational culture, and not only the fragmentary cause of the accident.

6. Conclusions

6.1. Conclusions

Although the internal and external research that human error as a cause of accident occupies over 80% of marine accident, the object or application of human error in Korea maritime field is not sufficient. While the maritime technology has progressed evidently in material aspects of navigational hardware equipment such as Automatic Identification System (AIS), Automatic Radar Plotting Aid (ARPA), Electronic Chart Display and Information System (ECDIS), and E-navigation system, a study for advancements of the seafarers' software aspect is the slow lane, comparing with the technological development. Although the sinking accident of *Sewol* ferry on the Korean coast gave a tremendous shock to our society and made the necessity of studying human elements more urgently, much research is still needed in the field of human error causal factor on the safety of the passenger ship in Korea.

Accordingly, the aim of the current study was to determine the contributory factors to the passenger ship accident, and discussed the safety issue related to the passenger ship and the depth of information in the investigation reports. For the purpose, this paper presented the review of 30 accident investigation reports in order to examine the human error causal factors contributing to the passenger ship accident in Korean domestic water. The customized HFACS framework to the maritime accident was adopted and used to analyse the causal factors described in the accident reports.

As a result, this study successfully demonstrates the validity of HFACS, that is, the analysis of human factors for the cause of marine accidents and the retrospective analysis of existing accidents. The adopted Maritime HFACS framework used in this study was able to identify 96 human error causal factors on three different level:

organisational influences, precondition of unsafe acts, and *unsafe acts*. The relational analysis of distributed factors between levels facilitated to understand the pattern of accident type.

As a predominant result, the violation of crew, specifically those related to the maintenance negligence and violation of navigation law, was found that it had the greatest impact on the passenger ship accidents. As for the onboard latent failures, onboard organisation, personnel readiness, physical environment, technological factors, and cognitive factors affected the unsafe acts. At the organisational level, the factor of resource management and unsafe supervision exercised an influence on the lower level.

The key findings in this study make available a new understanding of organisational procedure. The addition of the category of organisational procedure may provide further various aspect to the organisational influences. Also, this study confirmed that even though different accidents were caused by the same active failure, the latent condition affecting the active cause identified differently. Linked to this, the prevention plan against all potential failures should be prepared in advance to hinder even a single accident rather than a reduction in accident.

Including this research, many of the existing studies discussed in this paper presents the lowest frequent findings of organisational failures, comparing with the level of active failures. This study did not reveal the specific reason for the lack of organisational factors, but it is considered that the acquisition of data is difficult due to the special environment of the ocean or the accident investigation focuses more on the estimation of liability for violation of laws than on the identification of causes of accidents.

The contemporary marine safety issue requires discovering the latent failure to approach into the unobserved but fatal cause. Although identifying potential factors is necessary for the investigators to make tremendous efforts and sincerity, it is an essential process to eliminate the repetition of another accident risk. In order to ensure the marine safety, it is necessary to thoroughly and systematically carry out the investigation of all details of human factors from seafarers' navigation skill at every accident. By using the data analysis from the higher quality of investigation reports, we are able to establish the effective strategy for the marine safety and reduce the repetitive mistakes.

6.2 Limitations and future research

This study has limitations and pragmatic performance as well. This paper shows the way to advanced study for the safety issues of marine accident, particularly to the passenger ship.

This dissertation has the objective of factor analysis for the identification of active and latent cause of passenger ship accidents, but the study is limited by the lack of information on the organisational latent conditions in the investigation reports. The development of organisational elements, along with the addition of organisational procedure code, is a more challenging task for investigators.

Secondly, this study is limited to passenger ship only, but by expanding the research area with various types of vessels, it would be possible to improve the overall quality of ship’s safety by finding measures to prevent human error that may be present in the entire domestic ship.

A third limitation is the bias of the author. Even if the contribution factors are objectively analysed based on the contents of the report only and classified according to the category of HFACS, the results cannot help but reflect the opinions expressed by the author.

Finally, only HFACS tool was used in this study to identify the predominant causal factors. Further analysis through comparison with other systemic analytical tools, e.g. Accimap (Rasmussen, 1997), FRAM (Hollnagel, 2012), is required for the practical objective.

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Appendix A

List of selected investigation reports into passenger ship accident

No.	Date	Ship Name	Age	GT	Category of Accident	Accident location	Damage for Ship	Casualty
1	18-2-14	SHINANFERRY NO.2	4	400	Machinery damage/failure	Haenam-gun, Hwawon-myeon	Steering gear damage	
2	21-5-14	DAEHUNG	3	424	Machinery damage/failure	Sinangun, Palgeummyeon	Steering gear damage	
3	16-11-15	JOYANGFERRY NO.2	20	196	Machinery damage/failure	Mokpo port	Steering gear damage	
4	24-3-15	GUMOHGOSOKFERRY	12	255	Machinery damage/failure	Yeosu, Nammyeon	No damage	
5	23-5-14	PARADAIS	20	309	Machinery damage/failure	Sinangun, Anjwamyeon	Main Engine damage	
6	11-8-15	PANSTARDREAM	18	9,759	Machinery damage/failure	Busan port	Main Engine damage	
7	03-9-15	CSTAR 3	17	550	Machinery damage/failure	Gangleung port	Main Engine damage	
8	20-5-15	CSTAR 1	6	388	Machinery damage/failure	Sadong port	Seawater Pump damage	
9	26-2-15	SAMBO NO.12	7	393	Machinery damage/failure	Eolyujeong port	Water Tank Explosion	
10	05-5-15	SUNFLOWER	20	2,394	Machinery damage/failure	Ulleungdo	Main Engine damage	
11	11-12-14	SEODONGGOSOKFERRY NO.1	17	333	Machinery damage/failure	Tongyeong, Yeonghwado	Steering gear damage	
12	01-3-15	JULIAAQUA	20	228	Machinery damage/failure	Yeosu	Fuel Oil Filter damage	
13	15-6-14	SINHAE NO.9	17	154	Machinery damage/failure	Yeonggwanggun, Gyema port	Main Engine damage	
14	10-5-14	KOREANA	17	226	Machinery damage/failure	Incheon, Palmido	Main Engine damage	
15	04-5-14	SEAHOPE	23	299	Machinery damage/failure	Ongjingun, Daechungmyeon	Main Engine damage	
16	02-5-14	DOLPHIN	18	310	Machinery damage/failure	Ulleunggun, Dokdo	Main Engine damage	
17	15-12-15	SHINANFERRY NO.5	2	353	Grounding	Shinangun, Jangsanmyeon	Rudder/Propeller damage	
18	23-9-15	GUMOHFERRY NO.3	22	137	Grounding	Goheunggun, Jijukdo	Bottom scratches	
19	17-8-14	CHEONSA CARFERRY	10	279	Grounding	Shinangun, Hyojido	Propeller damage	
20	23-6-15	HANILREDPEARL	20	2,862	Grounding	Jeju, Shinyang port	Bottom dent	
21	30-5-15	NEW NAMHAEQUEEN	21	477	Flooding	Mokpo port	Lubricant, Bilge leakage	
22	21-3-14	DDANGKKUT	14	225	Flooding	Wando, Sanyangjin Pier	Engine room Flooding	
23	20-10-15	MOSULPO NO.2	1	156	Contact(eg. bridge, pier)	Seogwipo, Mosul port	Handrail damage	
24	25-10-15	QUEENSTAR NO.2	2	364	Contact(eg. bridge, pier)	Jeju Sangchujado	Hull warp	
25	10-12-14	NAMHAEGOSOKCARFERRY NO.7	23	3,780	Contact(eg. bridge, pier)	Gohunggun, Nokdong New port	Bow Ramp damage	11p injury
26	26-10-14	NAMHAEGOSOKCARFERRY NO.7	23	3,780	Collision(F/V SINGSING)	Gohunggun, Sologhwado	No damage	6p injury
27	19-8-14	HANRYUFERRY	21	178	Collision(F/V NO.808 TAEYANG)	Yeosu, Dolsan 1st Bridge	Hull dent	
28	17-1-15	SEOKYUNG ISLAND	22	5,223	Collision(O/T MANSUNG)	Busan port	Hull scratches	1p drowning, 1p injury
29	19-7-14	RAINBOW	18	228	Collision(F/V GUKILHO)	Incheon, Ongjingun	Bow dent	8p wounds
30	28-3-14	DEMOCRACY NO.5	20	396	Collision(F/V ENSUK NO.5)	Incheon, Ongjingun	Pitting	

Appendix B

Latent causal factor code of Maritime HFACS

(Translated)

	Latent Conditions	Code	Category
OUTSIDE FACTOR	Physical Environment	a.1	Weather
		a.2	Vessel over-traffic
		a.3	VTS failures
		a.4	Obstacle
		a.5	Inappropriate navigation aid
		a.6	Poor navigation aid
		a.7	Inappropriate Notice to Mariner
		a.8	Mismanagement of waterway
		a.9	Inappropriate port facilities
		a.10	Shallow water
		a.11	Narrow waterway
		a.12	Strong current
		a.13	Frozen condition
		a.14	Drift ice area
		a.15	Pilot failures
		a.16	Etc.
	Ruel & Regulations	b.1	Local special navigation regulations
		b.2	Int'l regulations & Codes
		b.3	Flag State regulations
		b.4	Port State regulations
		b.5	Others

PERSONNEL FACTOR	Cognitive Factor	c.1	Complacency
		c.2	Mental fatigue
		c.3	Nerves
		c.4	Haste, Flustration
		c.5	Distration
		c.6	Negative affectivity
		c.7	High-self confidence
		c.8	Low-self confidence
		c.9	Low work satisfaction
		c.10	Immoderate reliance on automated system
		c.11	Personality
		c.12	Mental disease
		c.13	Others
	Physiological Factor	d.1	Physical fatigue
		d.2	Physical disease
		d.3	Alcohol, Drugs
		d.4	Sight or hearing disability
		d.5	Body condition

		d.6	Motor ability
		d.7	Age, Sex
		d.8	Others
	Personnel Readiness	e.1	Inadequate qualification (physical, aptitude, etc.)
		e.2	Lack of knowledge
		e.3	Misknowledge
		e.4	Lack of skills
		e.5	Estimate of the situation inability
		e.6	Erroneous assumption, prediction, prejudice
		e.7	Inappropriate habit
		e.8	Previous accident experience
		e.9	Others

ONBOARD FACTOR	Organisation	f.1	Inappropriate custom regulation
		f.2	Organisational pressure (workload, workhour)
		f.3	Inaccurate responsibility & duty
		f.4	Aberrant communication
		f.5	Improper duty handover
		f.6	Inappropriate placement of human resources
		f.7	Chilling effect of seafarers
		f.8	Seafarers interaction
		f.9	Leadership problem (superior supervision)
		f.10	Immoderate authoritarianism
		f.11	Lack of authority
		f.12	Inappropriate procedure, regulations, instructions
		f.13	Education-training onboard
		f.14	Staffing of seafarers (nationality, qualification)
		f.15	Others
	Technological Factor	g.1	Ship design
		g.2	Equipment & tool (utility, reliability)
		g.3	Maintenance check-up
		g.4	Cargo property
		g.5	Cargo handling management
		g.6	Draft (loadage, overload)
		g.7	Kinds of ship certification
		g.8	Others
	Workplace Factor	h.1	Lighting
		h.2	Noise
		h.3	Temperature, humidity
		h.4	Vibration
		h.5	Cleanliness
		h.6	Atmosphere (stench, fumes, gases)
		h.7	Ergonomic design of work place
		h.8	Work characteristics
		h.9	Influence by others in workplace

		h.10	Absence or misarrangement of equipment
		h.11	Automation level of ship
		h.12	Diet suitability
		h.13	Others

ORGANISATIONAL INFLUENCES	Management/ Supervision	i.1	Boarding inappropriate seafarers
		i.2	Insufficient management of eligibility of seafarers
		i.3	Education-training absence
		i.4	Education-training deficiency
		i.5	Inappropriate education-training contents
		i.6	Inappropriate education-training procedure
		i.7	Insufficient assessment or development of education-training
		i.8	Mismanagement of equipment & supplies
		i.9	Others
	Operation	j.1	Operation tempo
		j.2	Inappropriate operating system
		j.3	Inappropriate ship operation plan
		j.4	Absence of safety culture
		j.5	Management environment (economic, political, legal, social condition, etc.)
		j.6	Budge problem
		j.7	Inappropriate reward and punishment system
		j.8	Poor working condition (vacation, shift system)
		j.9	Hiring policy
		j.10	Accident emergency countermeasures
		j.11	Others
	Violation	k.1	Boarding unqualified seafarers
		k.2	Onboard standards violation
		k.3	Violate behaviour connivance
		k.4	Others