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Concept Design of Fire Safety Module for SV20 Service in the Korean e-Navigation System

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Abstract : *The Korean e-Navigation system is a Korean approach to correspond with implementation of IMO e-Navigation. It provides five services, among them SV20 service, a ship remote monitoring system that collects and processes sensor information related to fire, navigation, and seakeeping performance safety. The system also detects abnormal conditions such as fires, capsizing, sinking, navigation equipment failure during navigation, and calculates the safety index and determines the emergency level. According to emergency level, it provides appropriate emergency response guidance for the onboard operator. The fire safety module is composed of three sub-modules; each module is the safety index sub-module, the emergency level determination sub-module and emergency response guidance sub-module. In this study, operational concept of the fire safety module in SV20 service is explained, and fire safety assessment factors are estimated, to calculate the fire safety index. Fire assessment factors included 'Fire detector position factor,' 'Smoke diffusion rate factor,' and 'Fire-fighting facilities factor.'*

Key words : *Ship Fire, Remote Monitoring, Fire Safety Assessment Factors, Fire Safety Module, Korean e-Navigation System*

1. Introduction

According to the statistics of domestic marine accidents causes, human factors such as operating errors are implicated in 79% of all marine accidents that occurred from 2013 to 2017(KMST, 2017). And more than 1093 maritime accidents have occurred each year and 2,346 people have been dead or injured in the recent five years. Also, 485 fires and explosions occurred on board ship, and most of the accidents were caused by human errors such as lack of safety awareness(KMST, 2017; You and Chung, 2015). Especially, among the types of ship accidents (collision, contact, standing, fire explosion, flood, etc.), fire and explosion are classified into main priority factors requiring decision making of the ship and passenger evacuation(Youn et al., 2018). For this reason, to prevent marine accidents caused by human error in case of a disaster such as a ship fire and explosion, capsize, etc. It is necessary to introduce a decision support system of the navigator through providing real-time marine safety information. Concerning this, IMO(International Maritime Organization), presented the e-Navigation concept that is related services for safety and security at sea to prevent marine accidents caused by human factors and improve the maritime safety. In more detail, e-navigation expects to prevent the accidents in advance by monitoring a ship, informing the vessel of more safety information, and warning of risk situations through sixteen Maritime Service Portfolio (MSPs)(IMO, 2008a; IMO, 2013; IMO, 2014).

In order to lead international technical standard for maritime safety by the implement of IMO's e-Navigation concept, the Ministry of Oceans and Fisheries(MOF) established the strategic implementation plan for Korean e-Navigation. The main services of Korean e-Navigation are classified into five services, each of which includes 1) SV10 service: navigation monitoring & assistance service, 2) SV20 service: ship-borne system monitoring service, 3) SV30 service: safe & optimal route planning service, 4) SV40 service : real-time electronic navigational chart distribution & streaming service, 5) SV50 service: pilot/ tugs assistance service, 6) SV60 service: maritime environment and safety information service(SMART Navigation, 2017, Yoo et al., 2017).

Among these services, the SV20 service of Korean

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e-Navigation automatically recognizes abnormal conditions in the passenger ships within Korean flag and other vessels requesting the service from the onboard system and provides them with information on their status, emergency level, and emergency response guidance.

The purpose of this study is to explain the overall operation concept of the fire safety module in the SV20 service. It also aims to review existing fire safety assessment methods and to suggest fire safety assessment factors for fire safety module operation. Thus, this research can be considered as a concept design when developing a fire safety module.

2. A new approach to response to ship fires

2.1 Proposal for fire emergency response system

In the Korean e-Navigation system, SV20 service which is the onboard remote monitoring service collects and processes the status of sensor data (fire, flooding, capsize, navigational equipment, etc.) of the ship to identify the hazardous events. And this service provides the emergency response guidance to the vessel where the accident occurred to ensure promptly and efficiently respond to the emergency situation. The service modules offered in the SV20 service are fire safety module, seakeeping performance safety module and navigation safety module. In this study, it is focused on the fire safety module in the SV20 service.

Fig. 1 shows the operational concept of the fire safety module for SV20 service. It monitors and gathers the alarm data related to the shipboard fire from the ship area such as accommodation spaces, machinery spaces, service spaces, etc. If an alarm detected due to fire on the ship, fire safety module calculates the fire safety index and determines the emergency level according to the fire severity. And to support the emergency response, it provides information on fire-fighting facilities and emergency response guidance based on the alarm position where the fire alarm activated and the emergency level.

Fig. 2 shows the operating procedures of the fire safety module in SV20 service. The onboard system real-time collects the sensor data associated with ship fire such as fire detectors. The sensor data for implementing the fire safety module includes the alarm operation status, the alarm operation time, and the location ID where the fire occurred, and the sensor list is shown in Table 1. The collected data is saving after the data processing and displayed to the onboard service user. And the onboard system analyzes the collected data to calculate the fire safety index of the ship where the fire occurs and determines the emergency level. The onboard e-Navigation system generates the emergency response guidance based on the emergency level and provides guidance to the onboard user. The shore system receives the sensor data from the onboard system and processes the data in the same way as the ship server and provides the results to the shore e-Navigation center. The e-Navigation center on land can monitor and support the incident of a vessel.

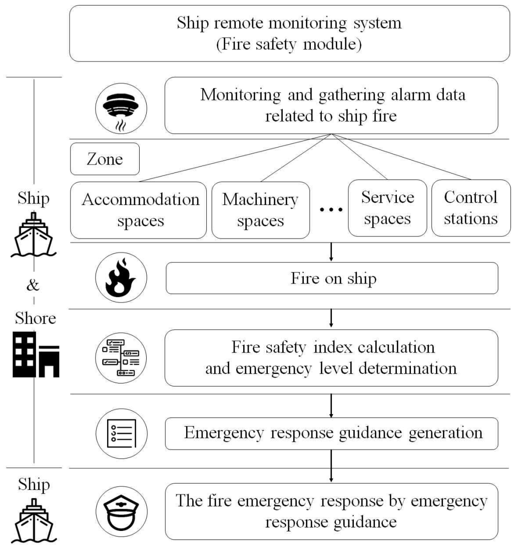

Fig. 1 Operational concept for SV20 service(Fire safety module)

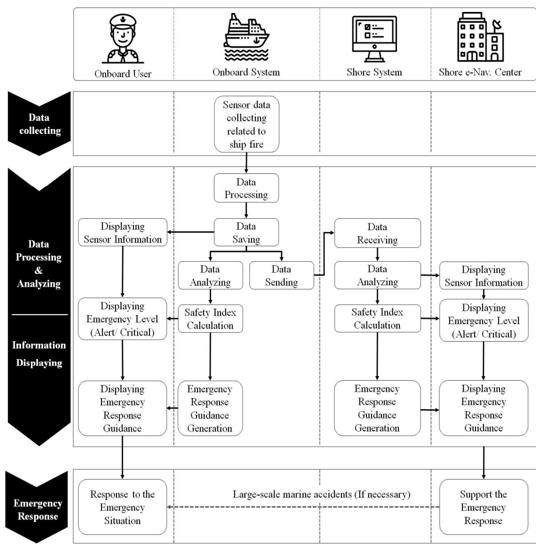

Fig. 2 Operating procedures of SV20 service (Fire safety module)

Table 1 Sensor list of fire safety module

No.	Sensor list	Description
1	Smoke detector	Alarm operation status,
2	Heat detector	Alarm operation time,
3	Flame detector	Alarm position ID

2.2 Review of conventional Formal Safety Assessment (Fire risk model)

The fire safety module calculates the fire safety index as per the fire sensor information to determine the emergency response level. Therefore, to calculate the fire safety index, it is necessary to analyze the concept of factors affecting fire safety. In this study, based on review related to existing ship fire safety assessment, the concept of fire safety assessment factors was investigated.

Formal Safety Assessment(FSA) is a methodology for assessing the risks relating to maritime safety and evaluating the cost-benefit to assist in the decision making process. The guidelines for FSA were first adopted in 2002 and had also been updated in 2007. The underlying philosophy of FSA is that it "can be used as a tool to facilitate a transparent decision-making process. In addition, it provides a means of being proactive, enabling potential hazards to be considered before a serious accident occurs" (IMO, 2002; IMO, 2007). According to the guidelines of FSA that comprise five interrelated steps: Step (1)-Identification of hazard, Step (2)-Risk analysis, Step (3)-Risk control options, Step (4)-Cost-benefit assessment and Step (5)-Recommendations for decision-making.

A high-level FSA application on cruise ships has been performed and submitted by Denmark. FSA studies identified the high-level risk models that are referred to as accident types such as collision, grounding, contact, other flooding and fire/explosion. Among the risk models, this study contains a consequence assessment factors of the fire and explosion scenarios(IMO, 2008b).

Fig. 3 shows the fire and explosion scenarios of cruise ships which categorized into the following main area: the development and severity of the fire, the time for detection and suppression and the density of the people in the fire areas. The possible relevant scenarios of the fire and probability distribution of each scenario are established by results from earlier work on cruise ship fire. And Lloyds Register Fairplay (LRFP) accidents database has been used as a source to determined the accidents frequencies and fatalities. To calculate fire and explosion per ship year is to divide the number of accidents recorded in a given period by the number of ship years accumulated for that period of risk reduction methods.

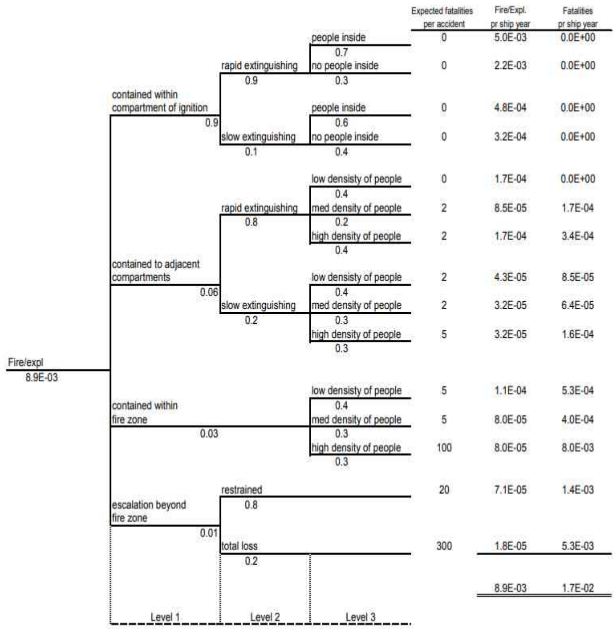

Fig. 3 Fire and explosion scenarios of cruise ships (IMO, 2008b)

However, the current formal safety assessment will only evaluate the fire safety of ships and consider the feasibility of risk reduction methods. Therefore, the practical system and method are needed to cope with the fire in the case of ship fire. In this study applied the concept of fire safety module of SV20 service which is a new approach to cope with ship fires.

For the operation of the fire safety module, fire safety assessment factors were constructed by referring to the FSA-Cruises document. As shown in Fig. 3, when analyzing the fire risk on board, it is essential to consider the zone where the fire occurred, the extent to which the fire has spread, the initial discovery and extinguishing of the fire, and the density of the people in the fire zone. Fire safety assessment factor is divided into three categories. First, the fire detector activation position factor which identify the fire area and the density of the people in the fire zone. Second, the smoke diffusion factor which recognize the fire spread and suppression status based on the activation time of the smoke detector. Third, the fire-fighting facilities factor which assessed the possibility of the fire extinguishing as per the fire detector activation position.

2.3 Suggestion module for fire emergency response system

The fire safety module is composed of three sub-modules. First, the safety index sub-module estimates the risk based on the fire safety assessment factors regarding the ship fire. Second, the emergency level determination sub-module determines the emergency level according to the safety index. And Finally, emergency response guidance sub-module generates response guidance by emergency level and location where the fire occurred.

2.3.1 Fire safety index sub-module

In case of a shipboard fire, the emergency response level is determined based on the fire safety index which is calculated by factors that can be obtained from the fire detector information. Fire safety index is weighted of the risk values of each factor and sub-factor, and the risk index is calculated from the equation (1). The assessed fire safety index value is expressed as emergency response levels through the normalization process.

$$FSI = \sum_{i=1}^{N} w_i x_i \qquad (1)$$

where, FSI is the risk index expressing the fire safety, N is the number of fire safety assessment main-factor and sub-factor, w is the weight for fire safety assessment main-factor, x is the weight for one of the fire safety assessment sub-factors. The sum of the weight value of main-factor and sub-factor corresponding to the main factor is equal to one. And Table 2 shows the details of main-factor and sub-factor of *FSI*.

Table 2 The details of main-factor and sub-factor of *FSI*

Main-factor (w_i)	Sub-factor (x_j)
Fire detector activation position (Zone)	Machinery spaces
	Accommodation spaces
	...
Fire detector activation position (Deck)	Nav. Bri Deck
	A Deck
	...
Smoke diffusion	Ultrafast
	Fast
	...
Fire-fighting facilities	Portable fire extinguisher
	...

2.3.2 Emergency level determination sub-module

The emergency level determination sub-module is a module that determines the emergency level for the taking into account whether or not the initial fire is extinguished in case of ship fire. According to the Ministry of Oceans and Fisheries(MOF), the emergency level is divided into attention, warning, alert, and critical following the risk severity of marine accidents in the ship(KOMF, 2014). However, the fire safety module is based on the ship sensor information, so if the fire alarm is activated, it is an urgent situation. Thus, the fire safety module starts from the alert level. And it goes up to critical level according to the calculation value of fire safety index. Fig.4 shows flow chart of the fire safety module which contains emergency level determination sub-module.

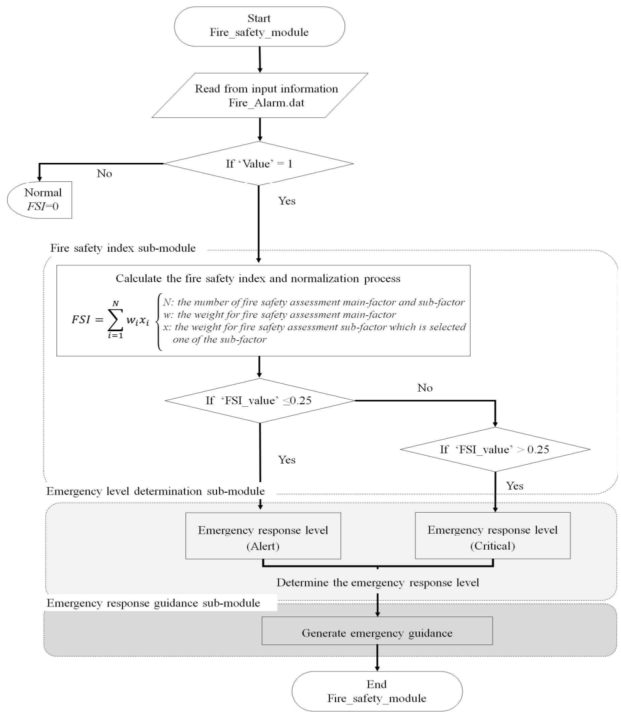

Fig. 4 The flow chart of the fire safety module

2.3.3 Emergency response guidance sub-module

Any ship should have a muster list and emergency instructions according to SOLAS Reg. 37(SOLAS, 2017). In the event of a fire alarm activates, an immediate and accurate response is a key factor in fire suppression. If crew members manage it incorrectly, the whole response will not be successful. Furthermore, if crew members take so much time to find the fire equipment the next step will also be delayed. Therefore, the emergency response guidance sub-module of SV20 service is a module for providing the information on the emergency response guidance and fire facilities to the ship operator according to the emergency level and ship area. Fig. 5 shows the concept of emergency response guidance in case of galley fire according to the emergency level.

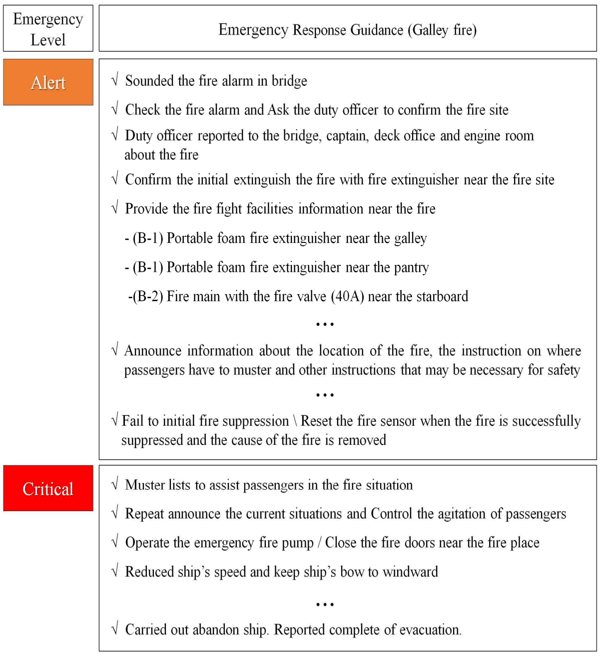

Fig. 5 The concept of emergency response guidance in case of galley fire according to emergency level

3. Case study on fire safety assessment factors for fire safety module

3.1 Overview of the target ship

In the Korean e-Navigation service, the target service ship is passenger ship. However, before studying passenger ships, this study organized fire assessment elements for training ship of H University. The training ship was built in 1993 to provide students with maritime studies and have on-board experiences in the environment of the sea. Fig. 6 and Table 3 show appearance and specifications of the training ship.

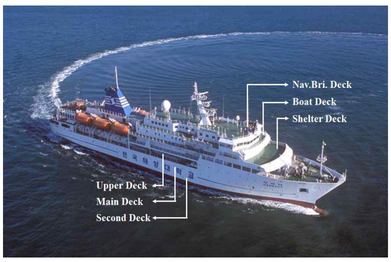

Fig. 6 External appearance of the training ship

Table 3 Overview of the training ship

Length	117.20m	Width	17.80m
Gross Ton	6,686GT	DLWL	5.9m
People	Total 246 (Crew 42, Trainee 204)		
Speed	Max.19, Av. 17.5 kts		

3.2 Classification of fire safety assessment factors

3.2.1 Fire detector activation position factor

Depending on the zone and deck where the fire alarm activated, fire risk and the possibility of fatalities are different in the event of the fire. So SOLAS Chapter Ⅱ-2/ Regulation 9.2 regulates to divide the zone according to fire hazard(SOLAS, 2000). Fig. 7 shows the zone and deck of the training ship. And as shown in Table 4, the factor and sub factor was constructed based on the zone and deck of the training ship.

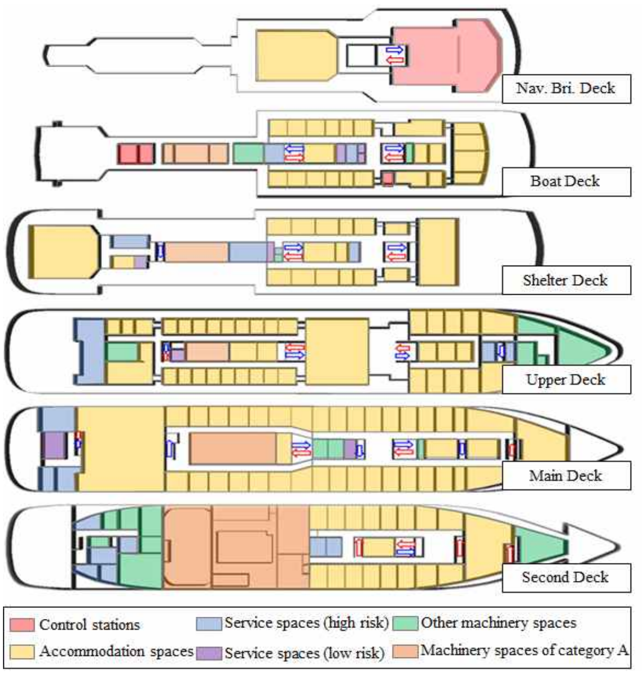

Fig. 7 The zone and deck of the training ship

Table 4 The zone and deck factor of the training ship

Main-Factor	Sub-factor	
Fire detector activation position	Zone	Control stations
		Accommodation spaces
		Machinery spaces of category A
		Other machinery spaces
		Service spaces (high risk)
		Service spaces (low risk)

Fire detector activation position	Deck	Nav. Bri Deck
		Boat Deck
		Shelter Deck
		Upper Deck
		Main Deck
		Second Deck

3.2.2 Smoke diffusion factor

The smoke diffusion factor that can be identify the fire spread and suppression status based on the activation time of the smoke detector. The smoke diffusion rate is determined by the fire growth model. Fig. 8 shows the fire growth model which is divided into 'Slow,' 'Medium,' 'Fast' and 'Ultrafast' according to time characteristics of fire growth. And as shown in equation (2), the heat release rate is proportional to the square of time(NFPA 92B, 2005). Even though the fire size is the same, the rate of smoke diffusion is far different according to the fire growth model.

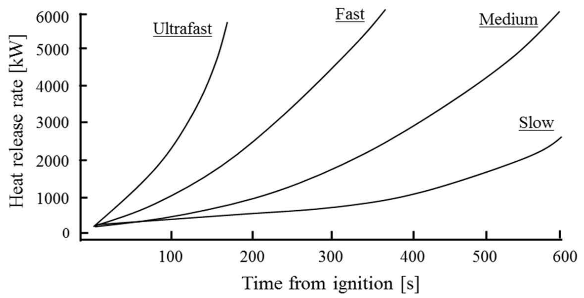

Fig. 8 Time squared heat release rate curve

The t-squared parabolic growth equation

$$Q = \alpha t^2 \qquad (2)$$

where, Q represents the heat release rate [kW], α represents the fire growth coefficient [kW/S^2] and t represents the time [s].

To set the 'Smoke diffusion' factor, fire simulation was performed by applying the fire growth model, using Fire Dynamic Simulator(FDS) 6.0.1. FDS is a highly reliable fire dynamics computational fluid dynamic (CFD) program, which was developed by the National Institute of Standards and Technology (NIST) and widely used in fire analysis. (Hu et al., 2003; McGrattan et al., 2014; Wahlqvist and Hees, 2013). The fire simulation objected the corridor of the main deck, and smoke detectors are arranged based on the basis of the training ship floor plan. The heat release rate is the same as 1000 [kW/m^2] and the fire growth rate is different. Fig. 9 shows the fire simulation modeling and position of smoke detector.

As a result of the fire simulation, there was a difference in the activation time of the smoke detector according to the fire growth rate. Table 5 shows the position and activation time of smoke detectors. As shown in results, when the fire growth rate is 'Ultrafast,' the smoke detector operates at 153 seconds at position ⑩. However, when the rate of fire growth was 'Slow,' 'Medium' and 'Fast,' smoke detectors were not activated.

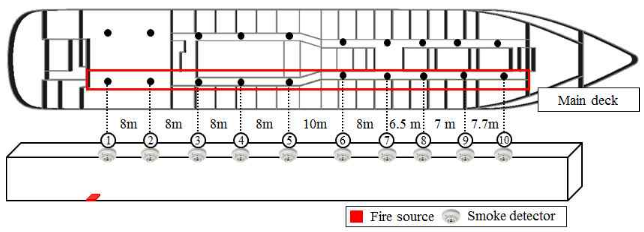

Fig. 9 Smoke detectors position for fire simulation modeling

Table 5 Activation time of smoke detector

Fire growth rate	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Slow	61	100	137	164	193	231	263	290	323	353
Medium	41	75	101	121	141	172	195	215	236	259
Fast	27	54	74	90	105	127	146	161	178	202
Ultrafast	17	40	54	65	78	96	109	124	141	158

Based on the results of the fire simulation, the smoke detector distance interval was divided by the difference between the first smoke detector and the next smoke detector activation time. And as shown in Table 6, the smoke diffusion time factor was constructed according to the fire growth model. However, since this factor is calculated for the training ship, additional verification of other passenger ships is required.

Table 6 The smoke diffusion factor

Main Factor	Sub-factor	
Smoke diffusion	slow	Time[s] > 4.0·dsm[m]
	Medium	3.2·dsm[m]< Time[s] ≤4.0·dsm[m]
	Fast	2.7·dsm[m]< Time[s] ≤3.2·dsm[m]
	Ultrast	Time[s] ≤2.7·dsm[m]

*dsm[m]=Distance between smoke detectors

3.2.3 Fire-fighting facilities factor

In case of shipboard fire, the portable fire extinguisher is mostly used for immediate response to the fire. If the fire becomes more severe, other fire-fighting equipment will be needed to back up the portable fire extinguisher. There are different types of fire-fighting facilities. Depending on the area where the fire occurred, types of fire-fighting facilities are different to extinguish the fire. Therefore the assessment factor was set in accordance with fire-fighting facilities. Table 7 shows the fire-fighting facilities factor.

Table 7 The fire-fighting facilities factor

Main-Factor	Sub-factor
Fire fighting facilities	Portable fire extinguisher
	Wheeled foam fire extinguisher
	Fire hose
	Nozzle for local fire-fighting system
	Nozzle of fixed CO_2 system

4. Conclusion

The purpose of this case study is to explain the fire safety module concept in the SV20 service for Korean e-Navigation system. Also, It aims to propose fire safety assessment factors for fire safety module operation.

The fire safety module of SV20 service is a ship-borne system monitoring service that monitors the abnormal situation caused by the onboard fire during the navigation. It consists of three sub-modules, each module is the safety index sub-module, the emergency level determination sub-module, and emergency response guidance sub-module. The fire safety index sub-modules calculates the fire safety index according to the fire risk. The emergency level determination sub-module is a module for determining the emergency level, which is divided into alert or critical step depending on the fire safety index and whether or not there is an initial suppression. The emergency response guidance sub-module is a module for providing the emergency response guidance. It also includes information on fire-fighting facilities according to the location of the fire sensor and guidance based on the emergency level.

To calculate the fire safety index, fire safety assessment factor should be estimated. In this study organized fire assessment factors for training ship of H University. And it is as followed. First, the ship was classified as a zone and deck according to the fire risk and the possibility of evacuation. Second, as the results of fire simulation, the smoke diffusion rate by the fire growth model was composed of factors. Third, based on the fire extinguishing capability of the area where the fire occurred, assessment factors were formed.

However, In this paper, the target ship has been limited to the training ship. Thus, further studies are needed considering the characteristics of passenger ships and calculating the weighting factor to estimate by the fire safety index. Also to add upon the credibility of fire safety assessment factor, it is necessary for the survey and opinion of the experts on the weight for fire safety assessment factor and sub-factor.

Acknowledgements

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