A basic study on standardization of fire-fighting drill scenarios on board

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ABSTRACT

Fire-fighting drill is conducted by the crew assuming that fire is occurred on board; in most cases, engine room drill is carried out due to high possibility of fire occurrence. In general, fire-fighters attempt to extinguish the fire and if fail, the fixed fire extinguishing system is operated. In this connection, fire drill scenario is very important not only for improving crew’s fire-fighting competency but also for fire-fighters’ safety. During the drill, captain should decide fire-fighters’ entry and withdrawal. However, in most vessels, the time to withdraw from the fire scene is not indicated, but the decisions are left to the fire-fighters based on the air bottle’s low pressure alarm. In this study, for a basic study on standardization of fire-fighting drill scenarios, by the experiments on the training ship with apprentice officers and analysis of ship’s drawings, the time required for crew assembling, the arrival time to fire scene, the time to wear fire-fighter’s outfit, the moving time of fire-fighters in fire scene depending on the flat ground or the stairs, and the water pressure in fire hose were considered. Moreover, the allowable time for fire-fighting work was estimated by analysis of working time limitation based on the air consumption of the self-contained breathing apparatus. As a result, basic model standard fire-fighting drill scenario was developed showing the action guideline according to the time elapsed. The model standard scenario can be modified by each ship’s circumstance, and this will be a great assistance to ensure the safety of fire-fighters and ship.

Introduction

Ship fire accidents at sea cause huge physical and personal damage. In particular, if the fire cannot be suppressed at the early stage, it directly linked to a large human casualty, and the amount of damage also be increased astronomically. You and Chung (2015) analyzed that astronomical property losses were recorded in the event of a sinking due to a fire of a large cargo ship in comparison with a small fishing boat or a barge. Such a large-scale fire accident on a ship causes not only enormous physical damage but also human disaster.

In response to the occurrence of ship’s fire, crew members conduct periodic fire-fighting drill. This is in accordance with the International Convention for the Safety of Life at Sea (hereinafter referred to as SOLAS) Reg. III/19.3, that fire drill should be carried out like actual emergency situation and that all crew members should participate in fire drill once a month. In addition, the International Safety Management Code (hereinafter referred to as the ISM Code) requires scenarios of fire-fighting drill for each vessel. Accordingly, the Port State Control Officer (hereinafter referred to as the PSCO) in each country requests fire-fighting drill to check the status of implementation of SOLAS and ISM Code during PSC inspection. (Ha 2016)

Ship’s engine room and accommodation area are the most vulnerable area to fire due to the heat, gas, misuse of electricity or cigarette, and etc.

Therefore, PSCOs request fire-fighting drill for these areas. During the fire drill, the crew should show and prove their proficiency based on the scenario set up by the company.

In the study of Han, Cho, and Park (2006), the evacuation times were estimated by simulation and the effluent coefficients were obtained. As a result, it is pointed out that the risk of human life in the engine room fire is about four times higher than that in the public rooms and that systematic evacuation drill is necessary according to the scenarios.

In the engine room fire-fighting drill, it is a general process to try water-extinguish by crew as fire-fighters first, subsequently the fixed fire extinguishing system is operated when the fire suppression by water-extinguish is not possible.

When fire-fighting work is conducted by the crew, the responsible officer or engineer in charge of the fire scene and the captain on the bridge should pay attention to the time elapsed since the fire-fighters enter the fire scene. This is because fire-fighters can be restricted to stay at the fire scene by air consumption of self-contained breathing apparatus of fire-fighter’s outfits. However, almost all of the scenarios that are being used in most vessels do not have indication of retrieval time of fire-fighters based on the assumed air consumption, but the decision of retrieval is left to the fire-fighters in the fire scene. In addition, from the
viewpoint of the captain who commands fire-fighting drill, there is no guidance on when fire-fighters should be withdrawn.

In this study, fire-fighters working time limitation was analyzed by the air consumption of the self-contained breathing apparatus, and recommend the retreat time of fire-fighters from fire scene and give indication to start operating the fixed fire extinguishing system.

**Status of fire-fighting drill and related regulations**

**Statistics of engine room fire**

Table 1 shows domestic fire accidents on ships for all types of vessels and are classified according to the occurrence location by the Korea Maritime Safety Tribunal’s judgment for 6 years from 2013, and the rate of the engine room fire occurrence is the highest at about 61%\(^1\). According to the statistics, it is evident that the engine room is the most probable place of fire, and this is the reason why the PSCOs mostly request fire-fighting drill in engine room.

**Previous research related to ship’s fire**

A study on the case analysis of ship fire accidents analyzed that the incidence of fire in the engine room has the highest fire occurrence rate, and the engine fire spreads to the entire space because the engine room is one space and in spite of even local fire, it can spread to the entire space of the engine room (Kim et al. 2002).

National Fire Service Academy (hereinafter referred to as NFSA) explained that the air consumption per minute of human is as follows: 30–40 L/minutes during the average work, 50–60 L/minutes during heavy work, and 80 L/minutes during very intense work (NFSA, 2017).

According to the instructions of the self-contained breathing apparatus that is being used in the actual ship, it can be used for about 30 minutes when used at a volume of 30–40 L/minutes, and the available time may be significantly different depending on the physical condition and working environment.

Lee et al. (2016) conducted a study to perform treadmill exercise by experimental subjects who wear various working equipment and clothes. They found out that the rating of perceived exertion after 20 minutes of running at a speed of 6 km/h that is at a little fast pace with ordinary clothes was a bit tough level, with fire-fighter’s outfits and general personal protective equipment was a tough level, and with the self-contained breathing apparatus was a very hard level.

**Regulations of fire-fighting drill and the storage location of fire-fighting equipment**

Fire-fighting drill should be conducted as if it is real emergency situation according to SOLAS Reg. III/19.3.1, and SOLAS Reg. III/19.3.2 stipulate that fire-fighting drills should be conducted at intervals not exceeding 1 month (IMO, 2017a).

According to SOLAS Reg. II-2/10.10, general cargo ships shall carry at least two fire-fighter’s outfits, and the fire-fighter’s outfits shall be kept ready for use in an easily accessible location that is permanently and clearly marked and, where more than one fire-fighter’s outfit is carried, they shall be stored in widely separated positions. According to the International Code for Fire Safety Systems (hereinafter referred to as the FSS Code), the fire-fighter’s outfit shall consist of a set of personal equipment and a breathing apparatus. Breathing apparatus shall be a self-contained compressed air-operated breathing apparatus for which the volume of air contained in the cylinders shall be at least 1,200 L, or other self-contained breathing apparatus that shall be capable of functioning for at least 30 minutes, and also personal equipment shall consist of fire-proof clothes, boots, helmet, electric safety lamp, axe, and so on. Additionally, the lifeline shall be capable of being attached by means of a snap-hook to the harness of the apparatus or to a separate belt to prevent the breathing apparatus becoming detached when the lifeline is operated (IMO, 2017b). As described earlier, SOLAS and related codes do not provide specific contents of fire-fighting drill and time required.

**Current ship’s fire-fighting drill**

Table 2 shows brief description about the engine room fire-fighting scenarios generally used on a ship.

The fire hoses located at the outside the accommodation are mainly used for fire-fighting purpose, and no pressure is applied when drill. This is because the engine room machineries should not be sprayed by

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1. Verdict of fire accident by Korea Maritime Safety Tribunal(2018), https://www.kmst.go.kr/kmst/verdict/writtenVerdict/selectWrittenVerdict.do.
the pressurized fire hoses during the drill. Then, to access to the fire scene two fire-fighters should pass through the doors and climb or descend the stairways that give a lot of difficulties to handle fire hoses due to the door sill, turning corner, and so on.

Fire-proof clothes, helmets, gloves, and self-contained breathing apparatus of fire-fighter’s outfit also give difficulties to the activities of fire-fighters; in addition, lanterns, axes, and two-way portable radios that fire-fighters must bring are a significant obstacle to fire-fighters.

During the drill, it is very important to check and record the time of entry and withdrawal of the fire-fighters and the pressure of the self-contained breathing apparatus, because chief officer or captain on the bridge should know how long the fire-fighters are staying at the fire scene and they can estimate the level of spread of fire considering the elapsed time of total drill. This can give information for the judgement of the captain to stop fire-fighting work of crew members and to decide the time to operate fixed fire extinguishing system. However, current scenarios used on ship do not provide such guidelines.

In this study, assuming that the fire-fighting drill is in actual condition, it was confirmed by experiments that crew assembly time, time to wear fire-fighter’s outfit, travel time, fire-fighters’ fatigue, and progress speed when climbing or descending the stairs; as a result, basic data that can calculate the fire scene access time and allowed time to stay in fire scene for fire-fighters shall be provided.

**Limitations of fire-fighting scenario**

As a result of analyzing the scenarios of three major shipping companies in Korea, merely the time of entry and withdrawal of fire-fighters are recorded and the fire-fighters themselves are instructed to check the pressure gauge of the self-contained breathing apparatus and withdraw before the low-pressure alarm sounds. There is no procedure for confirming the time of fire-fighters withdrawal by the captain of the bridge or chief officer at the outside the engine room. Table 3 shows specification of fire-fighting scenarios of three Korean shipping companies.

As shown in the fire-fighting drill scenarios used in the ships, only the action manual until the moment of entry into the fire scene is presented, but detailed scenarios are not presented after the fire-fighters have entered to the fire scene; in addition, there is no clear guidance about time of fire-fighters withdrawal and fixed fire extinguishing system operation.

### Table 3. Specification of fire-fighting drill of shipping companies.

| Sort. | No. of vessels | Type of vessels | Remark |
|-------|----------------|-----------------|--------|
| "A"  | 50             | Bulk, LNG       | Commonly, there are no detailed scenarios like the procedure to check the condition and withdrawal time of fire-fighters in the fire scene after the entry into the engine room |
| "B"  | 115            | CNTR, Bulk, LNG |        |
| "C"  | 54             | PCTC, Bulk, Tanker | |

**Experiment of the time required for each step of fire-fighting drill**

For analysis of the time required for each step of fire-fighting drill, the time required for gathering at the muster station, for wearing fire-fighter’s outfit and for traveling in the engine room to approach the bottom of the engine room where the fire broke out were checked through experiments on a 6,000 ton class vessel.

These experiments were carried out with the ship on the berth and no inclination, and it was proceeded with sufficient illuminance and visibility for the safety of the involved personnel.

**Experiment of the time required for gathering at the muster station**

In the fire-fighting drill scenarios used by most ships, crew members are firstly gathered at a muster station immediately after they hear fire alarm to take a roll call, and then they perform their duties.

There are two ways for mustering at the muster station, one is that the crew collects their fire-fighting equipment on the way to assemble at the muster station and the other is that the fire-fighting equipment is collected after gathering at the muster station.

In this study, the time was measured for both way of gathering at the muster station with a group of eight crew members of the training ship who are familiar with the ship’s construction. The subjects were the apprentice officers who completed the education and training for ship familiarity.

Table 4 shows the time taken to bring fire-fighter’s outfits after gathering to the muster station after fire alarm.

In this experiment that measures the elapsed time by the crew who firstly gathered at the muster station...
Table 4. Travel time to the muster station and time for bringing fire-fighter’s equipment at the fire locker.

| Route       | Cabin → Muster Stn | Muster Stn → F.L | Total |
|-------------|---------------------|------------------|-------|
| Distance (m) | 42                  | 15               | 57    |
| Group 1     | 1’ 8”               | 1’ 28”           | 2’ 36” |
| Group 2     | 1’ 26”              | 1’ 22”           | 2’ 48” |
| Average     | 1’ 17”              | 1’ 25”           | 2’ 42” |

(42 m) recognizing the fire alarm and reassembled at muster station (15 m) after bringing fire-fighter’s equipment at the fire locker, and the average time spent traveling 57 m was 2 minutes and 42 seconds.

Ha (2016) analyzed that when a fire alarm is issued in ship, it is more common that the designated crew brings the fire-fighter’s outfits on the way to the muster station. Accordingly, the experiment was conducted in such a way that subjects collect their fire-fighting equipment at the fire locker on the way to the muster station after hearing the fire alarm in the cabin on the main deck. The results are shown in Table 5.

The total cross-sectional distance in the drawing of the experiment is 52 m, and the object to be tested is the same as the previous experiment. The crew member who recognized the emergency fire alarm in the cabin on the main deck took 2 minutes and 16 seconds to move 52 m to arrive at the muster station with the fire-fighter’s outfits at the fire locker, and the moving speed is 0.38 m/s.

Experiment of time spent wearing fire-fighter’s outfit

Table 6 shows the result of time measurement when four groups of crew members that consist of a pair of crew wear fire-fighter’s outfits including fire-proof clothes and self-contained breathing apparatus. The experiment consisted of apprentice officers in their early 20s, and especially group 1 is made up by female and the rest of male. The average is 3 minutes and 17 seconds.

Table 5. Travel time to the muster station with fire-fighter’s equipment.

| Route          | Cabin → Fire Locker → Muster Station |
|----------------|--------------------------------------|
| Distance (m)   | 52                                   |
| Category       | Group 1                              |
|                | Group 2                              |
| Time           | 2’ 16”                               |
|                | 2’ 16”                               |
| Average        | 2’ 16”                               |

Table 6. Time for wearing fire-fighter’s outfit.

| Category | Group 1 | Group 2 | Group 3 | Group 4 |
|----------|---------|---------|---------|---------|
| 1st      | 4’ 50”  | 3’ 35”  | 2’ 33”  | 2’ 23”  |
| 2nd      | 3’ 26”  | 3’ 11”  | 3’ 13”  | 3’ 05”  |
| Average  | 4’ 08”  | 3’ 23”  | 2’ 53”  | 2’ 44”  |
| Total    | 3’ 17”  |         |         |         |

Ha (2016) showed an average of 3 minutes and 14 seconds in the same experiment with another subject.

Experiment of the time spent of fire-fighters on flat ground

The travel time from the muster station to the entrance of the fire scene on the ship was measured, the distance was 16 m by a couple of the crew members with fire-fighter’s outfits, and they moved and fell into step each other. Figure 1 shows the route where the participating fire-fighters move.

Table 7 shows the results of the time required to travel for four fire-fighters consisting of a set of two persons.

In this experiment, which moves 16 m in plane distance on the ship, the average time required for the four groups that each group is consisting of two persons was 41.3 seconds. In other words, it can be seen that a pair of fire-fighters who wear a fire-fighter’s outfits move at an average speed of 0.39 m/s.

Experiment of stair-climbing time with fire-fighter’s outfit

Fire-fighters must use the slant ladder several times to get down to the fire scene in the engine room from the entrance of engine room. When fire-fighting drill, it is unusual to apply the pressure to the fire hose, but in case of actual fire situation fire-fighters should use pressurized fire hose, the time required to move up and down using a staircase was measured with pressurized fire hose by a pair of crew wearing fire-fighter’s outfits. The cross sectional distance of the stairs is 5 m. Table 8 shows the experimental results for climbing and descending stairs with unpressurized status of fire hose. According to the results, it is 0.16 m/s when climbing the stairs, and 0.20 m/s when descending.

Table 9 shows the results of measuring the time taken for climbing a stairway of 2.2 m under pressure applied condition in the fire hose.

In the experiment, which was divided into three groups, the hose under the water pressure was not bent well and the weight of the hose became too heavy as the fire-fighters proceeded, so it was impossible to raise the fire hose themselves, so neither of the three experimental groups could even attempt to enter the second step of stairs. The average moving speed when climbing the stairs was 0.035 m/s. Table 10 shows the time required for the fire-fighters divided into groups of two crews to go down two stairs of 2.2 m in cross-section continuously.

In the experiment of measuring the time taken to descend, it was found at 0.042 m/s of speed that was a little bit faster than when it went up. However, when descending two stairs, the time taken to pull down and
arrange the fire hose between each stair was included on an average of 23 seconds. Excluding this time, the descending speed of the stairs is significantly reduced to 0.029 m/s. However, all three groups could not enter the third step because it was impossible to arrange heavy pressurized fire hose. Especially, life line and fire hoses were tangled around each other. The subjects of experiments were physically difficult because of poor visibility of the helmet and inconvenience of gloves.

### Analysis of the time required for each stage of fire-fighting drill

In this chapter, a model standard scenario is developed for each step of fire drill for 35,000 DWT bulk carrier based on the experimental results of Chapter 3.

According to the fire control and safety plan of the target vessel, one fire-fighter’s outfit was kept in the fire control station (FCS) and the other was stored in the bridge, and each distance to muster station is shown in Table 12.

**Figure 2.** Moving route with fire-fighter’s outfit.

### Time analysis for gathering at muster station after fire alarm

The estimated travel time was calculated through the derived cross-sectional distance, which is shown in the formula (1).
where $T_m$: traveled time of crew (s)
$S_d$: traveled distance on drawing (m)
$V_e$: experimentally calculated travel speed (m/s)

Based on the storage place located farther from the muster station between two fire-fighter’s outfit storages, it can be seen that it takes about 1 minute and 7 seconds according to gathering speed of 0.38m/s. Of course, if the crew was in the cabin or some other place at the time the emergency fire alarm was issued, it may take more time.

**Analysis of the time required to travel through the stairs from the engine room entrance**

As a result of the examination of the 35,000 DWT bulk carrier drawings, the engine room was confirmed to have three decks and four stairs to the lowest deck, and the required time was calculated by applying the moving speed of the previous experiment to the length of the flat ground and the stairs. The results are shown in Table 13.

According to the results of the analysis of the drawings, it took 2 minutes and 12 seconds to add the moving time 10 seconds on flat ground per a stair and 2 minutes 2 seconds for descending stair. It took 4 minutes and 24 seconds to get down the stairs because it is possible to descend maximum 2 stairs.

**Analysis of time for decision making by stage of ship fire-fighting drill**

The possibility of fire suppression by water-extinguish of the crew in case of an engine room fire should measure the time that fire-fighters can actually spray water after reaching the fire scene. At this time, it is necessary to examine the available time of the air bottle of the self-contained breathing apparatus used by the wearer of the fire-fighter’s outfit. To calculate the time allowed for fire-fighting work at the site where fire occurred arithmetically, it is necessary to find out the time excluding the time required for the fire-fighters to move from the time allowed by the capacity of the self-contained breathing apparatus worn by the fire-fighters, and it can be expressed as the following formula (2).

$$T_E = a_r - (T_w + T_d + S_a)$$

where $T_E$: time available for fire-fighting work

| Table 12. Distance to muster station from each area. |
|-----------------------------------------------|
| Category | FCS – Muster Station (M) | FL – Muster Station (M) |
| 35,000 DWT Bulk Carrier | 21.6 | 25.4 |

| Table 13. Moving distance and time of target vessel. |
|-----------------------------------------------|
| Vessel Info. | Distance (m) | Time (sec.) |
|---------------- |------------- |-------------|
| 35,000 DWT Bulk Carrier | 11.4 | 10.6 | 29.2 | 365.5 | 3 |

Figure 2. Stair test with pressurized fire hose.
α: breathable time of SCBA air bottle (21 m 49 s)

Tα: time required to move the flat ground (20 s)

Tδ: time required to use the stairs (4 m 4 s)

Sα: time required for withdrawal (5 m)

Fire-fighters will perform heavy work during actual fire (Lee et al. 2016). Therefore, 50–60 L of air per minute will be consumed. If you expect the fire-fighters to consume 55 L of air per minute at a capacity of 1,200 L in accordance with the regulation of SOLAS, the breathable time of the air bottle α/ will be 21 minutes and 49 seconds. By subtracting the sum of the time for the fire-fighters’ move to this value, the time allowed for the computational fire-fighting operation can be determined. That is, you can subtract the time for the audible alarm to escape Sα, except for the time it takes for the fire-fighters to move on the flat ground Tα and the time it takes to descend the stairs Tδ. In other words, Tδ is calculated as 12 minutes and 25 seconds.

**Suggestion of model standard scenario for ship fire response**

Table 14 shows the model standard scenario for engine room fire. This standard scenario advises that 4 minutes and 24 seconds shall not pass until the fire-fighters wear the fire-fighter’s outfits at the muster station and enter the engine room, and the stay time in the room where the fire occurred should not exceed 21 minutes 49 seconds, and fire-fighting operation except for the moving time in the engine room should be carried out within 12 minutes and 25 seconds, and finally the captain must order the fire-fighters to withdraw within 16 minutes and 49 seconds. It shows that fire-fighters behave according to time pass and fire-fighting work should be done within the given time in the model standard scenario. Moreover, the model standard scenarios can be modified according to the circumstances of each vessel.

**Conclusion**

The purpose of fire-fighting drill is to carry out fire-fighting work as trained when actual fire occurs. However, it is doubtful whether the fire-fighting drill can be performed well as trained. As shown in this study, when the water pressure is applied to the fire hose, it becomes difficult for fire-fighters to handle fire hoses to reach to the fire scene. In addition, the elapsed time from fire alarm to ready fire work at the fire scene is very important considering the speed of fire spread. It is also important to consider the fire-fighter’s safety. Once the fire-fighter is inside the engine room or other fire scene, the rate of air consumption is very high due to the hard work. Therefore, it is necessary for the captain or chief officer to have basic information for retrieval time of fire-fighters inside the fire scene.

In this study, a basic experiment was performed to calculate the time of each stage of the fire drill after the fire alarm. As a result, a standard fire-fighting drill scenario based on the air consumption of the air bottle of the self-contained breathing apparatus was presented by applying the results of the drawing review of the 35,000 DWT bulk carrier. This model standard scenario is divided into two parts, before and after entering the fire scene.

Moreover, it will help to ensure the safety of the fire-fighters and indicate the role of the captain and chief officer more clearly by providing the guideline based on the situation and elapsed time of each step of fire-fighting drill.

**Table 14. Model standard fire-fighting scenario.**

| Time Elapsed | Circumstance and Behavior |
|--------------|---------------------------|
| Total Before/After Entry | |
| <Before entry to the scene> | |
| 0' 00" | - |
| 1' 07" | - |
| 4' 24" | - |
| <After entry to the scene> | |
| 4' 24" | 0' 00" |
| 6' 36" | 2' 12" |
| 8' 48" | 4' 24" |
| 15' 00" | 10' 36" |
| 21' 13" | 16' 49" |
| 26' 13" | 21' 49" |
| 26' 13"+ | |

※ FFO/Str: Fire-fighter’s outfit storage
M/Strn: muster station
This model standard scenario would be used vessel if the time required for each stage of fire-fighting drill is properly modified depending on the structure and situation of each vessel.

It is considered that fire-fighting work by crew has many difficulties due to the characteristics of the fire, ship’s structure, inconvenient fire-fighters outfit, crew competency, and etc.

In the next study, the guideline for the use of internal fire hoses and other fire-fighting appliances such as foam applicator, 45 L movable foam, local fixed spray system and etc.

Disclosure statement

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