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Recent development of the fire fighting systems on board ship

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Abstract
This survey review is purposely conducted to evaluate and compare the effectiveness, efficiency, applicability and appropriateness of modern firefighting systems installed on board ships. As a result, the review attempt to ascertain the significance of firefighting systems on ships in terms of their safety, types, structure, principles as well as installations. In this way, the review tries to justify the importance of these systems on board ships.
The design of this survey revolves around three basic elements that incorporate the complete firefighting procedure. These components include: modern technology of firefighting, different types of systems that are used on board ships and people traits in terms of drilling, firefighting training to deal with any incident of fire.
In the previous decade, the globe has experienced massive destructions, harms and injuries resulting from fire incidents on ships. This has triggered and ignited enhanced fabrication and staging of new practices, technologies and inventions aimed at efficiently deal with fire incidents so as to support the safekeeping and reliability on these fire systems on board ships. Equally, through this technological enhancement, the firefighting systems have been designed to facilitate rapid detection capable of differentiating between real smokes or flames indicators in case of a fire event on board ship. In recent times, these technological developments have been viewed as strategies that help ship owners to ensure better protection of the crew's life, ship's inventories as well as minimising on the possible losses that occur as a result of fire events on board ship. Therefore, with the review of the recent or latest methods and technologies for speedy fire detection on ships, the review demonstrates enhancement attributes, features and qualities of these new systems. Additionally, the paper critically evaluates the components of these firefighting systems, as well as looking at their competences, capabilities, benefits and applicability on board ships.

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I. Introduction:

In recent times, the marine environment has witnessed increasing demand to decrease the risks, dangers and hazards caused by fire on board ships. This has resulted into increased innovation, invention and deployment of new and better firefighting strategies to engulf and efficiently harness this destructive effect of fire. In the sea, fire events kindles to catastrophic and devastating consequences such as loss of life, property, creating major mutilations to the ship and its shipment as well as damaging the environment and its ecosystem. Due to this, protection and fire safety has been much attention among ship manufactures and owners.

In the past, fire safety necessities and fundamentals have traditionally been integrated on flammability tests of materials and other ship constituents. This implied that only those materials satisfying the criteria of being less flammable were used in shipbuilding. However, this strategy has witnessed various problems leading to more survey on how to solve the experienced difficulties. In 2001, this survey resulted into ship building focused on designing and configuring fire safety measures and solutions through the development of systems that were entirely dedicated to curbing any incident of fire on board ships. The primary goal and purpose of these systems was to provide and facilitate efficient level of fire safety on board ships (International Maritime Organisation. 2001). This is simply because most of the fire incidences or accidents that happened in the sea transpired because of lack of adequate protection and safety measures or systems to help deal with the threat of shipboard fire. This meant that in case of fire event on the ship, the sea voyage depended on assistance from the on-shore (Maritime Training Advisory Board (U.S.). 1991). Despite this strategy being effective, it comes to appoint when the ship in danger cannot be visible from the land and no communication is possible and therefore persons on board have to cope with the fire incident hence this has led to more tragedy (loss of life and property) as shown in figure1. This therefore has ignited the need for adequate training of the ship crew, installation of firefighting systems and equipment to help harness any fire outbreak even when assistance cannot be offered from onshore (Maritime Training Advisory Board (U.S.). 1991).

Figure 1: *Tragedies of ship fire outbreaks that leads to loss of lives and properties.*

Therefore, technological revolution today has enabled ship designers and manufacturers to develop and configure different systems with varied capabilities to help handle and curb any incident of fire outbreak on board ship. Similarly, modern maritime policies demand that mariners should possess adequate knowledge, skills and awareness on how to deal with fire at various levels such as prevention, control and extinguishment (CIRP, Mitsuishi, Ueda &Kimura, 2008).

1.1 Definition of Fire:

Fire is a fundamental aspect of life that is popular to almost everybody as it plays an important part in the human daily life. This element is utilised on daily basis for various reasons ranging from cooking to heating or warming houses (Jones, 2009). When fire is well managed, controlled and utilised, it serves the human purposes adequately and properly. On the other hand, improper management and uncontrolled use of fire can result into great destruction and damage of property, life and everything that it comes across. From a scientific point of view, fire can be described a chemical process that involves rapid oxidation of a material in the reaction of combustion, releasing heat, light and other reaction products. These elements result into a fire triangle, which is a paradigm, that presents that essential constituent of fire. The fire triangle illustrate that the process of combustion occur when these three critical aspects (i.e. heat, fuel and oxygen) are present in their correct proportions as shown in figure 2. However, today this theory has further been developed to form a new model called a tetrahedron, which provides a new perspective of combustions. In this new theory, it is stated that fire is a chemical chain reaction that occur when the three elements are available in the correct ratios.

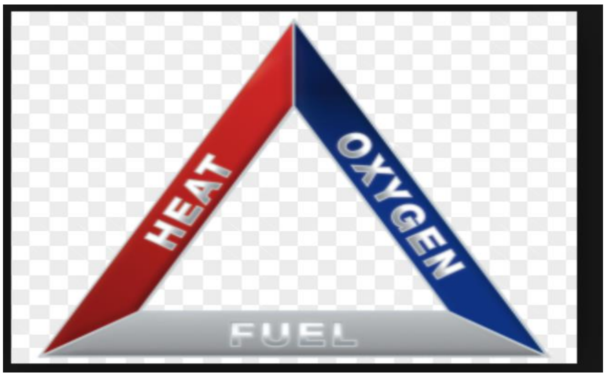

Figure 2: *The process of combustion occurs when the three critical aspects of the fire triangle (heat, fuel and oxygen) are present in their correct proportions.*

1.2 Fire classification:

During the combustion process, the fire flame is the only visible element of this chemical reaction such that when hot enough the gases become ionized to generate plasma. Therefore depending on the substances involved in the chemical reaction and the impurities outside, the color and intensity of the fire are different and unique. As a result of these properties and features of fire, the efficiency of extinguishing agents, methods, techniques and systems vary based on the fuels involved. Therefore while particular systems are effective on fires containing certain fuels, they may not be effective or even become dangerous for use on other types of fires. A good example is the use of a portable fire extinguisher in which as we all understand that water is a good fire extinguishing medium as its efficient and effective when dealing with a deep-seated fire e.g. burning wood or rubbish. In spite of this, this method or technique is less effective when dealing with fire comprising a live electrical panel or switchboard due to the aspect of conductivity of water and the probable shockwave and distress that could be the outcome of using this system of firefighting.

Therefore, bearing in mind the various forms of fires resulting from various fuels involved the varied agents and mechanisms of extinguishing as well as the different systems utilised in effectively and efficiently put-off each type of fire; it is essential to classify each type of fire based on the kind of system(s) that can effectively extinguish the fire menace. This is primarily aimed at enabling easy, convenient and proper selection of the kind of systems, techniques, methods or agents that can effectively deal and curb each type of fire. In regard to this, fire is categorised into four different types or classes that are denoted by letter “A” to “D”.

This classification is dictated by the fuels involved in each type of fire and each class is comprised of substances with related combustion properties and hence requiring similar extinguishing systems and methods. For on board ships, the knowledge and awareness of these classes is significant in order to adequately facilitate firefighting operations as well as understanding the blazing or flaming attributes of materials that may be found on the ship. The table below summarises the different classes or types of fire and the type of fuels involved in each type.

Classes or types of fire	***Types of materials or fuels involved***
A	Wood, paper, cloth, trash and other common materials
B	Gasoline, oil, paint and other combustible liquids
C	Encompasses fire resulting from live electrical equipment with no harm to the user.
D	Involves flammable metals and metal alloys
K	Cooking agents (vegetable and animal oils and fats)

Table 1:*Summary of the different types of fire and fuels involved in each type.*

1.3 Fire protection:

Adequate and efficient knowledge and awareness of the various types of fires enable any crew to effectively combat any incidence of fire on board ship. This is because through the awareness the crews understand how to curb fire at its various stages by applying appropriate portable or non-portable firefighting mechanisms and systems fitted and configured on the ship (Stavitskiĭ, 1983). The firefighting method or system implemented depend on the level at which the fire is and the location of the fire on the ship.

In general, firefighting on board ships is the responsibility of everyone on the ship whether you have the skill and knowledge on the type fire and how to use the firefighting systems on the ship or not. Similarly, it is important to notify the passages or crew of the various locations where these systems are fitted on the ship and directing how to respond in case of fire on board (Cote& Bugbee, 1988). This necessary to avoid fire damages, injuries, losses of life and property.

1.4 Problem statement:

In the modern marine environment, the number of tragedy resulting from fire occurrence have significantly reduced due to the continued development of firefighting systems that have enabled easy detection, and communication of any fire event on board ships. The efficiency of these systems, techniques and methods has believed to be based on use of computers that have enabled proper monitoring and control of the sea voyage activities and operations. It is therefore for these extended technological innovations that this review seeks to uncover and comprehend the effectiveness of modern firefighting systems on board ships compared to the traditional mechanisms of firefighting. The review will also seek to evaluate if this rapid technology development can help design and establish a computer interfaced and driven strategy that can be configured to the various systems in order to facilitate immediate response once any kind of fire is sensed or detected at any location on the ship.

II. Project Aim, Objectives and Justification:

2.1 Aim:
The aim of this literature review is to evaluate how recent technological development has effectively transformed firefighting systems and mechanisms on board ship thus reducing sea tragedies.

2.2 Objectives:
1. Compare recent and ancient firefighting systems in terms of advantages and limitations.
2. Establish the coordination and collaboration that occur among the three elements (i.e. technology (recent types), systems (different types used on board ships), and people (drilling, firefighting training)) of firefighting strategies.
3. Establish the development trend in the ship industry as recommended by the International Maritime Organisation (IMO).

2.3 Justification of the review:
Firefighting systems is perhaps the most critical component on board ship since it is aimed at defending human life, protecting loss of property as well as shielding environmental destruction as a result of fire. Therefore to effectively tackle any fire incident on board ships, the destruction management crew and any other individual on the ship must not only be familiar with the basic firefighting equipment but as well have the knowledge of complex firefighting systems on board. Therefore understanding the various properties and features of different types of fires will help the crew to select the most appropriate tactics and adopt suitable firefighting systems and equipment to attack and extinguish the fire event on board ship.

As a result, there need for on board crew to understand how recent firefighting systems are applied and utilised in combating fire on board ship. Despite being expensive to install and maintain, modern firefighting systems have proved effective thus considerably decreasing marine tragedies. However, some of these systems require manual operations which great challenge for the on board crew. All these aspects are vital and important areas of focus in this review.

III. Methods:

Literature search was conducted in an iterative manner during October 2015 to May 2016 using the search engines IMO, Google scholar, university of Strathclyde library search (SUPrimo), and ProQuest databases. Search terms were “firefighting systems”, “onboard ships”, “fire-detecting tools”, “ship fire system”, “recent technologies”, “marine fire systems”, and “firefighting training”. No specific key words were required as inclusion criteria; a relatively small number of studies exist on the topic, so a “bottom-up” search strategy was required. The reference lists of each article were reviewed in detail to find additional articles.

IV. Results and Discussion:

4.1 Traditional systems:
Conventionally, fire containment strategies, techniques, procedures and systems have always relied on water with the most popular mechanism being the sprinkler systems. Based on this, water has been extensively been utilised to control and harness various types of fire events (Cote, 2003). However, water is not ideal for fire associated with live electrical equipment, fires of combustible liquids as well as other fire hazards that aggressively retort with water causing more danger to life and property. For instance, covered fires in electrical equipment such as computer cupboards, switch and router cabinets and server rooms; cannot be put off using water because it will react to electric chargers which can cause adverse effects to people, property and environment. Similarly, the use of water on this type of electrical appliances destroys them completely making them to malfunction or render them obsolete and never to be used again (Dinaburg&Gottuk, 2012).

Besides water-based systems, dry chemical systems were also widely used to effectively control fires resulting from flammable liquids such as spray fires. Likewise, these systems contributed less in dealing with such types of fires. The mechanism of these systems is to deliver little freezing effect, which was inefficient particularly when the powder has settled. Under this category of firefighting systems, various forms of powders were used in dealing with this type of fires. Thus dehydrated chemical powders popularly employed were mono-ammonium phosphate, potassium and sodium carbonate or bicarbonate. However, these powder systems are not recommended for deployment in public or engaged spaces as they exhibit an environmental destruction, which can also be adverse to the well being of human life.

Furthermore, carbon dioxide systems have also been greatly employed in dealing with fire for many years and it’s still a common strategy used to handle fire incidences today. Despite its popularity in firefighting, carbon dioxide cause suffocation based on the level of concentration mandatory to extinguish fire. As a result, this mechanism should be considered and recognised as toxic to the ship crew and therefore carbon dioxide full flooding models cannot be automatically controlled in occupied spaces on the ship. This is simply because effective carbon dioxide is accumulated at high pressure and at very high concentration so as to efficiently perform the role of extinguishing fire. This high concentration of these gases is harmful to human life as it results into unconsciousness and chocking among the ship crew. Additionally, carbon dioxide systems entail bulky and heavy equipment therefore making it difficult to apply during in some cases of fire events.

Equally, adoption and deployment of low and medium expansion foam system was common and appropriate to tackle liquid pool fires. The foam establishes a fence mechanism to cut the supply of oxygen as well as cooling the fuel is a result of oxygen blockage. The foam system is ineffective especially when dealing with spray fires (Dinaburg&Gottuk, 2012). Conversely, fuels such as alcohols may be used to deplete the foam blanket formed to reduce burning process and therefore proper caution should be considered when selecting the foam compound to be used in dealing with various kinds of fires. In addition, the foam chosen should not be used to protect any hazard that can react violently with different types of fires.

Therefore all these traditional firefighting systems helped in tackling fire incidences both offshore and onshore and they accomplished their roles perfectly in particular situations. In spite of this, all these conventional systems of firefighting proved to be less sufficient and ineffective especially on board ships (Cote, 2003). Due to inefficiencies and ineffectiveness of these traditional firefighting systems, technology has triggered the development of modern highly effective and efficient firefighting systems that have really impacted the marine environment.

4.2 Modern development in firefighting systems:

Today, there is increased development in the creativity of firefighting systems installed and configured on board ships. This is aimed at responding to the various types of fire accidents that may occur on the ship so as to minimise loss of life and property on board (Institute of Marine Engineers. 1994). Some of these design development are as follows based on the description of earlier scholars.

4.2.1 Firefighting systems based on modern technology:

Prior studies shows that much has been done in the design of various types of fire detection sensors but little has illustrated how automation can be integrated and configured in this systems. This is illustrated through a review by Angus (2002) who showed the design of an intellectual fire siren system, which utilised heat, smoke and infrared sensors to detect and signal the occurrence of fire. The primary goal of this was to minimise the irritation generated by smoke sensors, which was common in various areas on board ship. Similarly, Jimmy (2004) developed a safety system that was based on heat, smoke and motion sensors such that the detection of these three elements could activate an alarm bell that signaled everybody on board. Gabriel et al. (2009) staged a panel portrayal for fire safety designed with modern compound materials based on basalt fibers. The review demonstrated that these materials offered low wall temperature and better residual power, which checked fire disaster. Likewise, Dongil & Lee (2009) showed an appearance handling procedure for automatic real time flame and smoke detection in a tunnel setting. In this design color and motion data was utilised to reduce incorrect or wrong detections in this environment hence facilitating enabling accurate recognition of the exact position of the fire event in this tunnel environment. As evident, majority of these studies focused more on fire sensing and detection with little attention being directed to the automation stimulus of these firefighting systems. A survey report conducted on fire protection depicted that most of the fire sprinkler systems relied on manual operated pumps to effectively execute and accomplish its role in firefighting (David et al., 2005). This survey demonstrated the difficulty of such systems on board ships making cumbersome to control fire in case of its outbreak on the ship.

On the other hand, few recently developed systems used in firefighting have evidenced the element of automation in which there is extensive use of heat sensitive glass bulb fitted on the outlet holding a liquid which inflates and fractures when ambient temperature is surpassed hence discharging fire extinguishing agents such as gas and water (Craighead, 1996).

4.2.2 Computer based systems:

The advent of technology has made it easier to control and manage firefighting systems hence making firefighting operations and activities convenient on board ships. For instance, Carlton & Rafic (2004) developed a response control system that monitored and regulated temperature of a process at various desired set point thus influencing action initiation to counter the incident when it is still in its early stages. Lee (1996) built on the already present smoke alarm circuitry idea to create a fire indicator that relied on sensing and detecting the presence of smoke. This detector was configured and interfaced on a computer system which facilitated control that enabled communication of fire related information as an SMS to the responsible individuals so that instantaneous human response could be initiated. This is an indication that survey is attempting to establish a more effective system that is automatic such that it can sense, detect and initiate mechanisms to extinguish the

fire while notifying the relevant ship crew view message notification. It is anticipated that development of such firefighting systems will adequately address this critical challenges during fire outbreak on the ship.
Overall, to fully meet the need to for proper firefighting systems to replace the traditional systems, technology has greatly supported recent development of suitable fire repression systems. Based on the ideology of technology, the review critically looks at some of the recently developed and widely used firefighting systems that have proved efficiency and effectiveness in dealing with fire events on board ships (Das, 2014).

4.3 Different types of systems:
4.3.1 Gaseous systems:
Recently development of modern gaseous firefighting system utilises jets, pipes and pressurised cylinders to disseminate the gas at a very high speed when dealing with fire on the ship as shown in figure 3.

Figure 3: *Gaseous systems onboard ships.*

Based on this, the crew should factor that the area being targeted can withstand the pressure of the gas without failure to which may lead the destruction to the part or section under concern. In this group of firefighting systems, two kinds of gaseous agents are greatly employed when dealing with different types of fires on the ship (NFPA, 2001). These agents are inert gas agents and halocarbon agents.

4.3.1.1 Inert gas agents:
In firefighting, the principle working mechanism of this system is to deplete oxygen supply in the combustion process and hence extinguishing fire. Among the basic inert gases that facilitate this include nitrogen, argon and helium, which are pure and naturally occurs in the atmosphere. The suitability of inert gas agents is based on the fact that they hold zero ODP and do not have global warming capability. Another positive about these gases in fire extinguishing process is that they are not exposed to thermal corrosion and therefore they do not form any combustion by-products that can be harmful to the surrounding (Nolan, 2010).
Using these gases, the fire controller aim at infusing adequate amount of gas to the fire site at high pressure to lower the level of oxygen content in order to stop the burning process and ensure it can no longer be sustained. From a scientific point of view, to sufficiently achieve a protection factor when handling fire, the system concentrate on the objective of decreasing oxygen rate to about 12.5% by ensuring the concentration of these gases (inert gases) at the fire site is 50%.
Today, three inert gas systems have been designed and popularly used to suppress fire incidences on board ships. These systems are;
1. Aragonite (IG-55) method (comprised of 50% nitrogen and 50% argon)
2. Inergen (IG-541) method (composed of 52% nitrogen, 40% argon and 8% carbon dioxide)
3. Argon (IG-01) method (formed by 100% argon)

Under the influence of technology, these three systems employ the same firefighting principle performance with only the Inergen method inducing high breathing rate due to the addition of carbon dioxide as one of its component material. This helps the crew dealing with fire on board to operate unaffected due to the effect of oxygen exhaustion for longer periods while dealing with fire events (Nolan, 2010). However, care should be considered when using these gases as the breathing of ignition products can have harmful effect to the ship crew and environment as a whole. Additionally, these gases are not liquefied and thus are stored at extremely high pressure hence need high pressure storage cylinders which may be costly as well as having repercussion for space and weight on the ship.

4.3.1.2 Halocarbons agents:

Halocarbons are extended development of halon. This development is based on molecular constitutes which are enhanced to minimise or eradicate the chlorine and bromide atoms that cause ozone destruction. These agents employ the cooling mechanism to fight and extinguish fire. The most popular halocarbon chemicals vary in terms of their basic properties, environmental influence, and toxicity as well as fire containment competence factors. A cup burner experimental technique is mainly used to assess fire suppression capability of different halocarbon agents in which the cup burner flame, which is the concentration of the agent, is used to extinguish fire in the process of firefighting (American Institute of Chemical Engineers. 2005). However, despite the type of fuel involved in the fire, halocarbon agents are highly efficient in fire extinguishing compared to the halon.

On the other hand, for firefighting two elements have to be considered when using these agents. The first element is the harmfulness of the agent itself and secondly is the toxicity of the chemical reaction output during burning process. These two aspects of these fire suppression methods determine the environmental impact on the ship. This is because breathing of halocarbons and hydrocarbons has an influence to the heart's normal functioning resulting from sensitive to raised adrenaline levels which can cause cardiac arrhythmia as well as potential heart attack (Moore, Dierdorf & Skaggs, 1993). Technological survey has evidently established that various halocarbon chemical (such as FM-200 (HFC 227ea), FE-13 (HFC-23), NAF S-III (HCFC blend), and CEA-410 (FC-3-1-10)) have similar properties and are clean to be used in public occupied spaces e.g. on board ships.

To evaluate the exact mechanism of fire suppression using halocarbons, intermediate and full-scale firefighting experiments were conducted by University of New Mexico Engineering Research Institute (NMERI). In the intermediate examination, encompassed evaluation of the four halocarbons with various types of fires (Lataille, 2003). The outcome of these tests showed relatively similar fire suppression performance among the four-halocarbon agents. The experiment also uncovered that the concentration of the acid gas products resulting from the process relied on the time taken to extinguish the fire as well as the size of fire. In other similar experiments conducted by the US Naval Research Laboratory (NRL), it was founded that raising the agent concentrations obviously resulted rapid extinguishment of within a short duration. In support of these results, other tests were conducted aboard the Ex-USS SHADWELL in Mobile Bay, Alabama and result indicated successful containment of the various kinds of fire within a time frame of 28 seconds. This illustrated that fire extinguishment time reduced with increase in the concentration of the agent (Hansen, Richards, Back & Moore, 1994). It was also established that large fire were easy and faster to put off compared to small ones.

Generally based on these and many other experiment conducted to evaluate halocarbons performance capability in fire suppression, it was uncovered that halocarbon agents extinguishes different types of fires at their design concentrations. However, this is largely dictated by the agent type and intensity, fire type and size, and release and containment durations. Likewise on the negative side, use of halocarbon agents cause long-term influence to global warming if released into the air. This is due to their ability to prevail in the atmosphere for long periods.

4.3.2 Water mist system:

Water has for a long time been used and perceived as an effective fire suppression agent. This is due to its high capacity of heating and vaporisation, which enable it to absorb a considerable magnitude of heat from flames and fuels thus effectively extinguishing fires of various forms. However, technology has enabled modification of these mechanisms of water suppression to design what is today referred to as water mist. The term water mist describes thin water showers or jets in which 99% of the quantity of these sprays formed of drops whose diameter is less than 1000 microns as shown in figure 4.

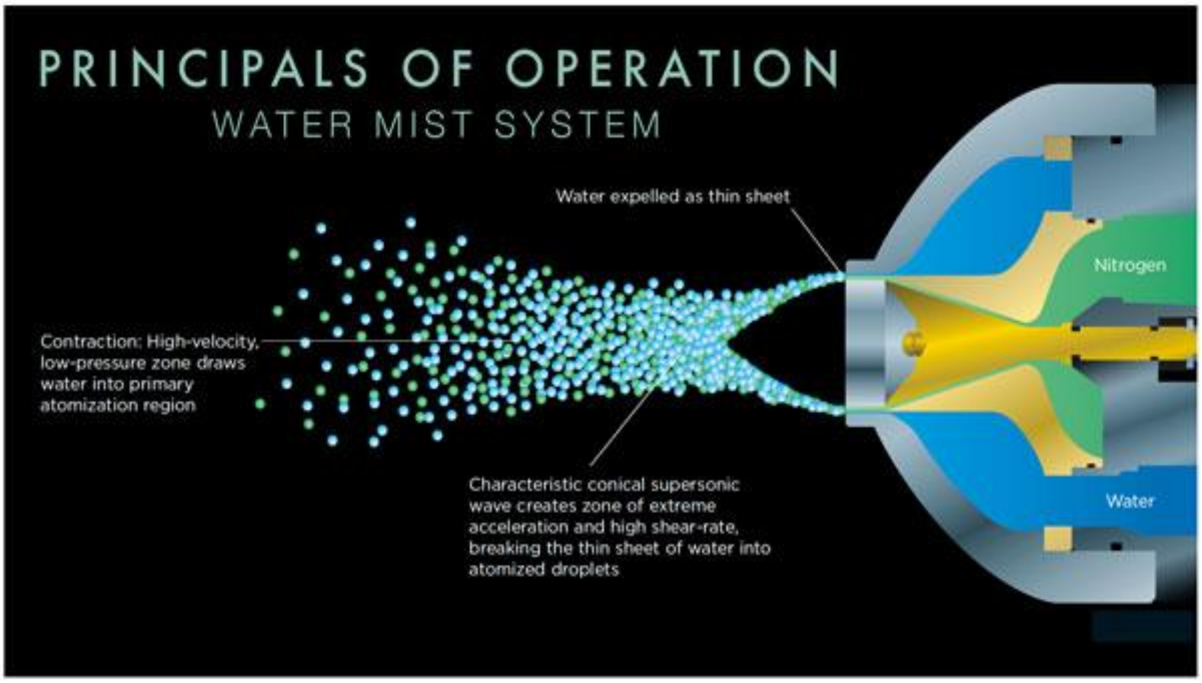

Figure 4: *Water mist systems sprays thin water showers or jets in which 99% of the quantity of these sprays formed of drops whose diameter is less than 1000 microns.*

The emergence of water mist system in firefighting is traced back in mid-1950s and it is believed to have come as a solution or replacement of the gaseous systems, which had toxicity issues to the environment (Shelley, Cole & Markley, 2007). This is because water is not toxic, it is freely accessible, and it is cost effective compared to most of the chemicals or untested mixtures deployed in the gaseous systems. Additionally, water mist offers efficient cooling of fuel, flames or fire and potentially inhibiting re-ignition of any kind, which for gaseous agents it is a common practice. As a result of its effective cooling and low cleanup duration, water mist technique can effectively work in public presence or occupied space without creating any harm. Similarly, water mist are advantageous over traditional water sprinklers in various ways such as decreased rate of water flow thus minimal water loss or damage to sensitive equipment and occupancies. In addition, these low rates of water flow have benefits in terms of space and weight of water supply. Other than this, water mist facilitates proper control of flammable liquid fires that conventional sprinklers could not due to dashing and leakage of fuel. Extensive and intensive research has been conducted on water mist system in effort to establish its fire extinguishing mechanisms as well as the maximum droplet parameter that satisfy efficient fire suppression on board ships.

In firefighting, fire suppression using water mist system is primarily a practical mechanism and does not involve any kind of chemical. Previous research revealed that fire cooling and oxygen disarticulation were the most popular strategies utilised in water mist fire containment. On the same note, recent studies propose the existence of further mechanisms in water mist fire control system. Among these extra mechanisms is the radiation attenuation (weakening or reduction) that is offered by water mist and can cease the fire from broadcasting and scattering to un- inflamed fuel surface as well as minimising dehydration rate at the fuel surface on board ships. A study conducted by NRC (National Research Council of Canada) established that water mist decreased radiant heat by 70%. Other firefighting mechanisms provided by water mist system include dilution of flammable vapor as well as direct impact wetting and cooling of combustibles.

Water mist features including drop size circulation, fluidity mass and spray force possess a straightforward impression on its effectiveness in firefighting. This is because for it to achieve efficiency in fire suppression, water mist system has to produce and disseminate optimum sized water particles (droplets) at an adequate concentration and force on the fire. These droplets rely on the possible size of fire, characteristic of burning materials as well as the extent of hindrance.

Various water mist mechanisms have been developed in recent years to help in on board firefighting. Some of the designed strategies practice the utilisation of high or intermediate pressure water ejected through cavities of outlets to generate and splash water mists while other utilise twin fluid outlets (water and air). These water based fire suppression systems have illustrated significant advantages on board ships such as the best fire containment capability, no atmospheric impact resulting from toxicity or chemical emissions into the air. Due to this, water mist fire suppression has been adopted and implemented in a wide range of actual situation on board ships. In an application of firefighting in shipboard, water mist was proven to be effective and had the prospective for efficient fire suppression. This is illustrated by various studies conducted by the NCR, which verified that water mist could effectively extinguish large fires using small amounts of water. In addition, it is established that water mist can effectively suppress fire even when natural ventilation such as doors and windows are open which in contrast when using gaseous agents. This system also speedily reduced the environment temperatures allowing free accessibility to the fire location (National Research Council (U.S.). 1975).

Another element that has presented water mist as a potential halon replacement is the protection of electrical and electronic equipment. A study investigating the viability of water mist system in firefighting in electronic fires confirmed that it was effective in fire containment with no short circuiting as well as causing other damages on the electrical items, object or equipment (Hills, Simpson & Smith, 1993). Research studies have presented the potential advantage of water mist stating that its negative influence on electronic equipment cannot be compared to the damage resulting from thermal corrosion products of the gaseous agents. Kim & Su, (1999) established that the application of halocarbon gaseous agents on smoldering electrical fire could cause corrosion resulting into highly harmful gases.

A latest study conducted by NRC (National Research Council) verified that firefighting performance of water mist could be enhanced by adopting and implementing cycling discharge pattern. This is because cycling discharge increases and improves extinguishing performance. Similarly, the use of cycling discharge further reduced the volume of water used to extinguish the fire besides decreasing the time taken to put off the fire. Additionally, the use of cycling discharge generates large volumes of water vapor, which promote the rate of oxygen depletion hence championing the process of fire extinguishment on board ships.

4.3.3 Compressed air foam systems:

For decades, firefighting has also witnessed the use of compressed air foam as an effective fire compression system especially in chemical and petroleum industries. Compressed air foam is produced by combining the following three elements: water, air and foam making agent. The procedure of making this foam involves mixing of the foam agent with water to create a foam solution. The generated solution is subjected to air through an appropriate aerating mechanism to produce the air bubbles. The suitable foam intensity is achieved when proper proportions of the three components are used as shown in figure 5.

Figure 5: *Compressed air foam is an effective fire compression system especially in chemical and petroleum industries.*

The most common foam concentrates used in the production of this air foam are 3% and 6% of the concentrates used in making the foam solution. For example, when a 3% concentrate is used, this means 3 parts of the concentrate has to be combined with 97 parts of water to generate 100 parts of foam solution and the same applies for 6% concentrate. The foam product in the process is compressed to form air-foam, which is then sprayed to the fire using fixed pipe foam systems. However, traditional foam systems are unstable and inconsistent hence its expansion ratios are not high as would be desired to effectively suppress fire incidence on board ship.

Contrary, if this solution is compressed using suitable aeration equipment the outcome product is a compressed air-foam that has superior quality and considerable injection velocity. This high momentum of the fire suppression agent is determined by the integration velocity of the foam solution and air. This firefighting technique has several advantages; (i) the high and increased momentum of the foam facilitate easy and faster penetration into fire clouds reaching the bottom base of the fire; (ii) has the best stability in line with the drainage compared to that of aspirated foams. This is because it is illustrated by a thin spreading of bubble sizes.

Efforts to incorporate compressed air form into fixed installation on ships still faces challenges as a result of two vital procedural strains: (1) conventional sprinkler-type nozzles do not support dissemination of compressed air foam without disassembling it and (2) the foam produced disintegrates in static piping. However, in recent times NRC (National Research Council) through extended research has established how to overcome these problems within the fixed pipe environment by developing how to manufacture Class A and B compressed air-foam. The capability has been based on the innovation and invention of foam distribution nozzle (Crampton, Kim & Richardson, 1999). The foam fragmentation that inhibited the design of this innovation previously was downplayed through critical engineering design of the nozzle and piping system.

In firefighting, the foam system generates compressed air foam made up of thin and similar sized bubbles, which are sprayed through the nozzle without interfering with its properties. The foam sprayed establishes a foam blanket on the surface of the faming liquid or area hence blocking flammable vapors from escaping the surface while preventing oxygen from reaching the fuel. The outcome of this process is effective extinguishment of fire because this foam smothers the fire. Similarly, the water content in the foam produces a cooling effect hence enabling the foam to lower the temperatures of the environment thus reducing fire spread due to radiation effect.

A number of studies have been conducted in attempt to determine the performance of compressed air form systems in firefighting (Kim &Dlugogorski, 1997). The overall evaluation outcome of all these studies showed that compressed air foam systems revealed superior performance in extinguishing fire particularly liquid fuel and wood crib fires using little volumes of water. Moreover, compressed air foam require minimal amount of foam concentrate to deliver efficient fire suppression compared to systems that are based on air-aspirated nozzles. In another research study conducted by NRC (National Research Council), it was found that fixed pipe compressed air foam systems have better accomplishment than the aspirated methods (Kim &Dlugogorski, 1997). In addition, the study established that the foam spread easily to cover the fire surface with efficient cohesive capability to effectively develop and sustain a vapor tight blanket that preserve enough moisture (water) to provide a long lasting seal as speedy loss of water result into the foam drying out and wither due to the high temperatures of the fire. Likewise the foam is weightless to facilitate easy floating on the flammable liquid or surfaces besides resisting blowing winds. The following physical properties of the compressed air foam enable the achievement of all these during fire suppression process particularly on ships.

1. Fuel resistance.
2. Vapor suppression.
3. Heat and radiation resistance.
4. Knockdown speed and flow.

Different techniques are used on board ship when tackling fire using compressed air foam systems. These techniques include:

i. ***Bounce-off procedure***: which involves that use of nozzles and during the practical application the foam should be bounced off an obstacle object such as a wall etc.
ii. ***Bank-in procedure***: here the foam is rolled onto the fire surface by thumping the surface in frontage of the spill to allow the foam to pile in front of the spill. The momentum of the flow sways the foam onto the fire.
iii. ***Rain-down procedure***: in this procedure, the nozzle is guided straightforward and the foam is allowed to penetrate and reach its optimum.

Overall, compressed air foam has demonstrated various advantages in firefighting. Some of the advantages are efficient smothering agent as well as enabling cooling effect during fire suppression process; develops a foam barrier or blanket on the fire surface; ability to hold moisture or water to provide a cool environment and does not require large volumes of water to extinguish fire. On the other hand, these systems have various limitations including being electrically conductive due to moisture or water presence; not recommended for extinguishing combustible metal as well as gaseous related fires.

4.4 Comparison of traditional and modern firefighting systems:

The comparison of the firefighting systems are based on various factors such as processing methods, rating of each system, and development methods as illustrated on the matrix comparison table below(Corbett, 2009).

	Traditional systems	***Modern systems***
Processing methods	➢ Mainly manually operated ➢ Have adverse side effects to the environment ➢ Involves cumbersome, bulky and heavy equipment ➢ Time consuming	➢ Involve automatic operation though there is still aspect of manual operations ➢ Convenient and easy to operate ➢ Less time consuming
System rating	➢ Less effective and efficient due to the manual operation ➢ Uses large quantities of water and	➢ Highly effective and efficient as a result of improved technological development ➢ Highly economical in terms of the quantity of

	chemicals	water and agents used as well as the time taken to extinguish fires
Design and development methods	➢ Incorporate bulky and heavy equipment that makes it difficult to enhance.	➢ Technological based designed making them easy and convenient to use as well as improve their effectiveness and efficiencies. ➢ Recent development is based on computer monitored and operated and being evaluated if a robot can be utilised in firefighting using this strategies

Table 2: *Comparison of traditional and modern firefighting systems*.

From the above comparison of traditional and modern systems, the study narrows down to compare one traditional and one modern firefighting technique as illustrated on the matrix below.

Comparison based on Processing methods and System rating			
		Low pressure flood system	***High pressure water mist***
Fire fighting mechanism	cooling-flames or gases	ineffective	effective
	cooling fuel	effective	effective
	depletion of oxygen	ineffective	effective
	isolating fuel from oxygen	poor	poor
	interrupting the combustion process	fair	effective
primary mitigation measures	mitigation of the influence of covered class A fires	poor	fair
	Containment of uncovered Class A fires	effective	effective
	suppression of class B fires	fair	relatively fair
	Blocking heat radiation	poor	effective
	inhibiting re-ignition by wetting the fire area	effective	fair
Comparison based Design and development methods			
Life safety	fire suppression	relatively effective	effective
	reduction of heat radiation	fairly effective	effective
	prevention of fire spread	fair	effective
	containment of toxic gases down stream	ineffective	effective
Design structure	water distribution	effective (equal)	effective (equal)
	convenience of use	fair	highly effective
	temperature containment	fair	effective

Table 3: *Comparison based on Processing methods and System rating*.

Overall, this comparison analysis has evidently shown that modern design and development of the firefighting systems has championed effective and efficient fire suppression compared to conventional methods. As technological development continues to enhance the capabilities of modern firefighting systems continue to improve and enhance hence enabling adequate and efficient handling of fire incidences on board ships. Therefore as a result fire tragedies in marine environment are well dealt with eliminating property destruction as well as loss of life.

4.5 New industry of ships produced by international maritime organisation (IMO):

With reference to the technological trend that has enabled the design and development of more effective and efficient systems, the international maritime organisation (IMO) has provided guidelines, policies and principles that must be observed by the ship industries particularly manufacturers to ensure the safety, security and efficiency of the human efforts in fighting the menace of fire on board ships. Under these regulations, there is an increasing demand for modern ships to be designed and developed in such a way that minimises the risks and promote the safety and security of life as well as property. This has prompted ship designers and manufacturers to develop and deploy conceptual solution that protect that well being of the crew, passengers and possessions on the ship from incidences particularly fire among others(Papanikolaou & Soares, 2009). As we are aware of fire being the most hazardous event that can result into adverse consequences such as damage to the ship, its systems, cause loss of life and property as well as destructing the marine environment.

Proper measures have to be put in place to help in the effective and efficient tackling of this fire threat. Therefore based on IMO fire safety and protection on the ship is a top priority in the design and development of ships(International Maritime Organisation. 2000). In regard to the protection and safety of human in the sea, IMO through SOLAS convention offer a framework on which manufacturer design ships integrating and configuring various firefighting systems. SOLAS stands the Safety of Life at Sea is an international sea treaty that is responsible of monitoring and controlling building standards of sea equipment, systems, etc. for the protection and safety of the sea users. This has witnessed increased automation of firefighting systems on board ships to ensure increased reliability, safety, security and functionality in case of a fire event(Hurley, 2016). The automation includes fire detection alarm system, smoke detection siren system, computer based fire monitoring systems, etc. the latest of this advanced developments is the innovation and invention by the US Navy of a robot equipped with modern technology and systems to facilitate early detection, origin and respond to the fire incident promptly. Additionally, the use of computer technology has been integrated on the ship technology to enhance security as well as monitoring any fire incident on the ship. This is achieved through the coupling of the new smart multi-sensors that enable the use of video technology (CCTV camera) which have significantly to detect fire events and rapidly respond so as to efficiently contain the fire (United States. 1961).
Based on this, IMO has championed and campaigned for the safety and protection of ship occupancies by emphasising and recommending the following standards to be considered in ship design and development.

4.5.1 Configuration of fire alarm technology:
Due to increased building of extra larger vessels, IMO accentuate on the need for proper installation of fire detection and alarming systems to ensure early and rapid response to curb the fire event before it gets worseas shown in figure 6.

Figure 6: *Fire alarm technology.*

This recommendation by IMO is aimed at establishing protection and safety of the ship during fire emergencies. This technology also includes the integration of fire sensor systems, which permit detection of smoke, flame or fuel at its early stages hence sensitising the concerned crew through sirens, ringing bells as well as computer notification procedures. In general, the configuration of fire alarm technology is purposely targeted at faster and more effective and efficient fire fighting. This promotes initiation of applicable protective measures within a short time using the described advanced technology of firefighting on board ships(Beard, 2005). Through the installation of the alarm technology has helped concerned personnel on board ships to:

1. Automatically identify the origin and location of the fire.
2. Automatic evaluation of the size of the fire and the level of threat.
3. Automatically initiate counteracting response to suppress the fire.
4. Enabling efficient fire suppression methods to be selected and deployed.
5. Facilitate centralised decision making to curb the identified fire incident.

4.5.2 Use of video technology (CCTV camera) in fire and smoke detection:
Recently development in firefighting has witnessed the use of CCTV cameras playing a significant role curbing fire on board ships. The installation of this technology on the ship facilitate proper monitoring and control of the entire ship such that in case of any fire incident it is easy to identify the origin and location of the fire before it spreads to other areas of the ship. This has been fostered by the new technological insights, which have promoted the innovation of highly sophisticated optical sensors, greater processor capability and better electronic reliability enabling automatic optical recognition of fire even in extreme atmosphere.

The CCTV technology provides a vital contribution to the effectiveness of the installed fire alarm systems particularly on board ships. It develops an image, which is reproduced to the control room identifying the area of the incident in real time thus activating the alarm systems in that zone hence enabling adequate rapid response to suppress the fire incident. Coupled with early detection intelligence of fire, smoke and flames in real time, the video technology provides visual sensitivity of fire events on all sections of the ship thus promoting fire protection and safety on board ships(Johns Hopkins University, United States Fire Administration, United States, & Informatics General Corporation. 1976).

Modern technology of ship building design and configure video fire detection, flame images, smoke and fire recognition, monitoring which has improved and enhanced efficiency in fire suppression on ships today. An example of a control room installed with modern systems and technology for monitoring operation and activities on the ship so as to detect any fire incident is shown on the figure below.

Figure 7: *An example of a control room installed with modern systems and technology.*

However, for the effectiveness and efficiency of all these fire, flame and smoke detection systems depend on the choice of the programming algorithm used. As a result, this has ignited more research on which algorithm is more effective in this field thus various algorithms have been developed and are still developed and linked on board using video image hence providing an acceptable monitoring system on the ship. Some of the modern algorithms used for fire detection on board ships include;

i. Wavelet image (video) model based on real time recognition of smoke
ii. Categorisation of flame or fire using pixels based on fuzzy logic and arithmetical patterns of shades.
iii. Intelligent real time fire recognition system relying on video processing
iv. Computer image processing system depend on the real time detections
v. Automatic routine supervision and monitoring of fire incident on board ship using video imaging.

4.5.3 System modeling to minimise fire spreading scenarios on board:

With regard to the type and size of the ship, fire on board can have adverse consequences if allowed to spread. IMO through SOLAS has identified that majority of fire incidences occur in engine room section for cargo ships and in superstructure cabins for passenger ships. Based on this, SOLAS recommend for preventive strategies to stop the spread of fire to other areas of the ship (Institute of Marine Engineers. 1994). As a result, automatic water mist sprinklers are installed and configured in these areas so that incase of fire they are automatically activated proving cooling impact that inhibit the fire from spreading to other areas. Other than this, modeling has also occupied center stage in ship building to ensure that particular operations such as fire zones planning, sensor and detector positioning are being considered. All this is aimed at effectively restraining fire spread on the ship, which is largely dictated by the conditions of the surrounding (humid or dry), the origin of the fire and kind of fuel in the surrounding. The following are some of the modern simulation programs used for displaying of fire spread on board ship:

i. Fire dynamic simulator of fire, fuel or flame.
ii. Fire and smoke simulator.
iii. Merged model of fire and smoke scattering.

4.5.4 Fire prevention organisation and drills:

Effective firefighting on ships does not only entail detection systems and firefighting techniques installed on board ship but also rather include preparedness of concerned personnel and everyone on the ship. This mean that fire prevention begin by focusing on how to stop or eliminate the chances of fire startup on the ship and this commence with appropriate ship design as earlier seen followed by a good and proper organisation of the crew and everyone on board ship. On the ship, good organisation is achieved through appropriately formulated policies that can effectively be carried out by the crew(Bennett, 1964). As such, the most critical area of interest to achieving a good organisation is the human element (in terms of drilling and firefighting training) on board ship. Proper organisation on board ship ensures rapid and efficient initiation of adequate actions by the crew to effectively handle fire incidences on board. It is through this proper planning that safety plans that illustrate lifesaving strategies and equipment are described how to be accessed and used in case of fire.

4.5.5 The human element:

Despite being the main causal of fire accidents on board ships, human element is a fundamental component if effective and efficient prevention, control and suppression of fire events on the ship. As a result, more focus in firefighting is given to ability of the crew. This is rooted on their level of knowledge, skills and expertise on the various aspect of fire such as causes, reduction of fire risks as well as the frequency of fire. This help them to understand the best procedures to be adopted in handling various types of fire on board ships using various firefighting systems, techniques and methods as well as ensuring proper protection and safety of lives and property on the ship. Different practices are adopted and implemented by the crew as an indication of readiness and preparedness of fire incidents (Bennett, 1964).

Inspection and maintenance is a highly adopted and implemented practice that aims at promoting preparedness for fire safety prevention. It involves checking fire equipment and systems to ensure little chances of failure in case of fire event on board ship. The inspection process also involves risk evaluation to determine the likelihood of combustible materials present as well as potential eruption fire. In this way, the crew is able to establish appropriate prevention and control strategies to counteract fire startups.

Additionally, assessment of fire detection and firefighting equipment and systems ensures proper performance in case of a fire event on board ship. This is also a recommendation provided by IMO as well as a policy in most of maritime organisations. Firefighting equipment and systems can be tested during fire drills to evaluate their efficiency. Fire drills help the crew to work as a cohesive unit that is guided by a well-prepared firefighting plan.

4.5.6 Fire drill:

The sole objective of fire drills is to test the efficiency and effectiveness of the crew organisation on board ship by providing different kind of challenges in case of a fire catastrophe. Therefore fire drills are objective oriented in that they target to provide a solution framework to situation in question. As such, a successful drill need a defined goal before being undertaken and it therefore involves objective definition, duration determination as well as the procedure to be adopted to deal with the problem in question. Through fire drills, the crew has the opportunity to learn efficient planning and applying fire control techniques, systems and procedures in fire suppression situations as well as mastering the necessary fire responses and control strategies (Bennett, 1964).

Figure 8: *Fire drill.*

Before the drill is conducted it is important to notify the individuals on board about it so as to avoid any fear and suspicion. The drill then commences with sounding of the fire alarms and loud communication followed by subsequent reaction speed to the incident area or location. The attack strategy implemented on the fire will depend on the scenario (source, size and the surrounding). Fire drills integrate various kinds of chaos to evaluate the response and ability of the crew to contain the situation. With regard to the drill, an assessment of whether the objective of the drill was attained can be performed so as to determine the lessons gained through the drill. This helps the concerned personnel to improve the standards of firefighting competence among the crewmembers hence perfecting the firefighting system on board ship (Bennett, 1964).

As a result of fire drill training the crew develops into a critical safety system that well equipped, skillful and knowledge in handling the firefighting process. This training provides these personnel with adequate expertise in assessment and effective decision-making aimed combating the fire incident on board ship

V. Conclusion:

Based on this research it is evident that the application of modern firefighting systems and technology help in early fire and smoke detection on the ship thus championing rapid response using effective equipment and methods installed on the ship. This has had a major positive impact in combating fire incidents on board ship thus protecting lives and property. Similarly, designing and building of automatic fire sensors linked to the ship systems enable the crew to establish a better and quality monitoring system that enable easy detection of potential fire threats on board ships thus initiating timely and effective decisions to suppress the incident.

The study has evidently illustrated how technology (recent types), systems (different types used onboard ships), and people (drilling, firefighting training) work cohesively to attain efficient and effective fire suppression on board ship. The research shows that recent development in firefighting systems has enhanced in fire suppression procedures and techniques making it easy to combat the fire menace on sea vessels.

Additionally, crew training through drills help equip the ship crew with sufficient information, knowledge skills and expertise in firefighting process. This knowledge also triggers proper and effective decision making that is particularly aimed ensuring protection and safety of lives and property onboard as well as preventing fire spread. The study has also recognised that firefighting on board ships is an element that is globally recognised and well defined through established conventions that provide proper frameworks of safety and security of lives and property in the sea. In general, recent developments in firefighting have revolutionised the concept of firefighting to a more applicable and effectual framework.

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