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THERMAL IMAGING CAMERAS FOR FIRE DETECTION AND PREVENTION ON BOARD OF MS ZAANDAM

FINAL RESEARCH

HZ UNIVERSITY OF APPLIED SCIENCES DE RUYTER ACCADEMY
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De Ruyter Academy

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Abstract

Cruise ship fires are not uncommon. Fire on board of the cruise ships is one of the most dangerous accident that can occur at any moment. The damage caused by fire is huge and can negatively affect the company's reputation. There is a product on the market that can, according to the manufacturers, detect the fire at the earliest stage, namely thermal imagers, therefore the goal of this research is to investigate what is the additional value of thermal imaging to the current fire detection and monitoring system on board of MS Zaandam in order to provide an improved safety environment and an effective fire monitoring to reduce the fire risk.

In order to establish the most dangerous places on board of MS Zaandam and figure out what are the most frequent causes of the fire occurrences, firstly the analysis of the previous fires on board of other cruise ships over the last 20 years has been done. The results of the analysis were applied and compared with the present situation on board of MS Zaandam.

From the analysis follows that fire accidents on board of cruise ships were occurred due to following circumstances:

- Fuel oil, thermal oil, hydraulic oil spraying onto the hot parts of the machineries.
- Major electrical failures
- Two fires were caused by thermal oil leakage into the burner furnace
- Another three fire accidents were occurred in the galleys and all three were caused by overheating of the cooking fat in the fryers.

Also, some of the fires were caused by the human's fault (welding in unauthorized places, irresponsible human activities…)

The places where fire can be caused by the fuel leakages onto the hot parts of the machineries were investigated with FLIR thermal imaging camera on board in order to establish the hotspots around. This has been done in order to establish what are the possibilities of fire occurrence in case of fuel oil sprays. Also, as much as possible information was assembled about all high voltage installations and machineries such as transformers, asynchrony and synchrony induction motors and high voltage switchboard in order to establish if thermal imaging camera can be used as an addition aid to the current fire detection systems. From analysis follows that places such as mooring decks, galleys, battery room, paint locker and laundries are fire hazardous as well, therefore, all these areas were investigated for present fire detection and prevention systems on board of MS Zaandam.

After investigation it seems that thermal imaging cameras have no any additional aid to the current fire detection systems on board of MS Zaandam. Places where fire can be caused by fuel oil sprays onto the hot parts of machineries are equipped with "Leakage alarm detectors". Also, due to high background temperatures in comparing with average fuel oil temperature, thermal imaging camera will never sound alarm at the good time. All high voltage machineries and installations are equipped with temperature sensors. Fire risk in places such as paint locker, battery room and mooring decks is very low. During the last 15 years the fire has never been occurred in these areas, therefore it is not understandable to buy an expensive camera for the places where fire has never been occurred before.

No further research is required for determination of any additional aid of thermal imaging camera to the current fire detection systems installed on board of MS Zaandam.

Contents

1. Introduction

This chapter comprises an introduction of Holland America line, a brief description of MS Zaandam where the internship will take place, an introduction of the research and research question and the main goal of this research. The last paragraph contains a brief reading guide.

1.1. Introduction of Holland America Line

From 1873 to 1989 Holland America line was a Dutch shipping line, a passenger line, a cargo line and a cruise line operating between the Netherlands and North America. Nowadays Holland America Line is a British-American owned cruise line. The Headquarter is based in Seattle. Holland America Line's fleet consist 14 ships of the different classes (S, R, Vista, Signature, Elegant Explorer, Pinnacle) and offer more than 500 cruises to 350 ports in more than 100 countries.

The fleet list of Holland America Line:

1. MS Koningsdam (2016) with passenger capacity of 2648 persons.
2. MS Nieuw Amsterdam (2010) with passenger capacity of 2106 persons.
3. MS Eurodam (2008) with passenger capacity of 2104 persons.
4. MS Noordam (2006) with passenger capacity of 1972 persons.
5. MS Westerdam (2004) with passenger capacity of 1916 persons.
6. MS Oosterdam (2003) with passenger capacity of 1916 persons.
7. MS Zuiderdam (2002) with passenger capacity of 1916 persons.
8. MS Princendam (2002) with passenger capacity of 835 persons.
9. MS Amsterdam (2000) with passenger capacity of 1380 persons.
10. MS Zaandam (2000) with passenger capacity of 1432 persons.
11. MS Volendam (1999) with passenger capacity of 1432 persons.
12. MS Rotterdam (1997) with passenger capacity of 1404 persons.
13. MS Veendam (1996) with passenger capacity of 1350 persons.
14. MS Maasdam (1993) with passenger capacity of 1258 persons.

1.2. Introduction of MS Zaandam

MS Zaandam is a cruise ship owned and operated by Holland America Line. The ship was delivered in 2000 and is a part of the "R-class". The ship is powered by diesel propulsion with maximum speed of 23 knots. The length is 237 m and the breath is 32.2 m. The ship has 10 decks with a maximum passenger capacity of 1432 and 615 crewmembers.

During the summer MS Zaandam sails near Alaska and during the winter in Mexico and Hawaii. In December and January, the Zaandam cruises the Antarctic and South America.

1.3. Introduction of the research

Fire on board of cruise ships is one of the most serious risks for property and persons, as well as for the surrounding environment. On board of a merchant ship there are tons of liquid fuel, electrical equipment, air-conditioning plants, engines, boilers, stores of flammable material and crew accommodation areas (kitchens, mess rooms, lounges, cabins, WCs). To all this the load or cargo must be added. In passenger ships the load consists of accommodation and other recreation areas for the passengers. Thus a fire on board of a ship during navigation represents an extremely high-risk situation which may cause harm or death to passengers or crewmembers. The fire can also cause a considerable damage to the structure and equipment. All merchant ships have hazardous liquids on board, such as lubrication oil, diesel oil, heavy fuel, liquid gasses. The structure damage caused by fire can lead to the spilling of the dangerous liquids into the sea. The fire can also seriously damage the ships propulsion whereby the ship can lose the manoeuvrability. Consequently, it can lead to the grounding or collision with other traffic around. To extinguish the fire, sometimes a large quantity of water is used whereby the ship can capsize as a result of instability.

Generally, the majority of fires on board of all marine vessels originate in the engine room. Flammable oil can spill onto a high temperature surface whereby engine room fires can occur. In addition, many engine room fires are cause by electrical components, such as electrical short-circuits and thermal overheating in the switchboards.

"*According to International Convention for the Safety of Life at Sea (SOLAS), the maximum surface temperature of machinery, parts and components in a vessel's engine room should not rise above 220°C. In order to avoid ignition and fire development, all surfaces above 220°C are to be insulated and protected"* (IMO).

All areas on board of cruise ships are equipped with fire alarms such as smoke detectors and heat detectors. In case of a fire, the alarm will be raised immediately, however, serious accidents still happen. There is a product on the market that can, according to the manufacturers, detect the fire before it occurs, namely thermal imagers. Despite the potential benefits of thermal imagers, there are some significant disadvantages such as high cost, thermal energy reflections… Also, the field of application of thermal imagers as a fire detection and prevention system is restricted, for instance, there are a lot of situations happened in which the fire occurred spontaneously due to fuel leakages on the hot surface areas in the engine room. However, it can be possible that thermal imagers can be used on board of MS Zaandam in addition to the current fire detection system for some specific cases.

The research question is as follows:

Can thermal imaging camera be used on board of MS Zaandam as an additional value to the current fire detection systems?

To answer the research question properly, there are following sub questions drawn up:

1. What are the most fire hazardous areas on board of MS Zaandam?
2. What are the most effective locations for thermal imagers and how many of them should be installed in order to provide an improved safety environment and an effective fire monitoring on board of MS Zaandam?
3. In which cases can thermal imagers be applicable as an additional fire prevention aid to the current fire detection system?
4. What is the best suitable thermal camera's type for on board of MS Zaandam?

1.4. The goal of the research

The main goal of this research is to investigate what is the additional value of thermal imaging to the current fire detection and monitoring system on board of MS Zaandam. First of all, the current fire detection system on board of MS Zaandam will be observed. Thereafter, the most fire hazardous areas on board of MS Zaandam will be established. After that, every area will be carefully analysed in order to establish the advantages and disadvantages of thermal imaging cameras for the specific situations. Also, the attention will be paid to the choice of the best thermal solution (quality/applicability) for Holland America Line.

2. Theoretical framework

This chapter comprises the following paragraphs:

- Thermal imaging cameras
- Current Fire Alarm Systems on board of MS Zaandam
- Thermal Imaging Cameras for fire prevention and detection in industry
- Cases in which thermographic cameras prevented fire occurrence
- Passenger ship fires over last 20 years

2.1. Thermal imaging cameras

A thermographic camera is a device that forms an image using infrared radiation. The device collects the infrared radiation from the objects and creates an electronic image based on information about the temperature differences. Most thermal-imaging devices scan at a rate of 30 times per second. They can sense temperatures ranging from -20^{O}C to 2000^{O}C, and can normally detect changes in temperature of about 0,2^{O}C. Thermal imagers have a lot of advantages and also some significant disadvantages, however, the applicability field of thermal imagers is very large. (How suff works TECH, 2015),

The working of thermal imaging cameras is based on basic principles of infrared thermography. For more information about electromagnetic spectrum, energy distribution and emissivity of various objects please refer to the web article “Using thermal imagers- the basics” (Land Instruments International, 2005)

There are two different types of thermal imaging devices, namely cooled and uncooled infrared detectors. For more information about these detectors please refer to the web article “Cooled or uncooled” (FLIR, 2015).

For more information about general advantages and disadvantages of thermal imaging devices please refer to the following web articles “Infrared Thermography and Energy Efficiency” (Energypedia, 2014) and “Limitations of Thermal imaging cameras” (Monroe Technology , 2015).

2.2. Description of current fire detection and prevention systems installed on board of MS Zaandam.

2.2.1. General fire detection system installed in board of MS Zaandam

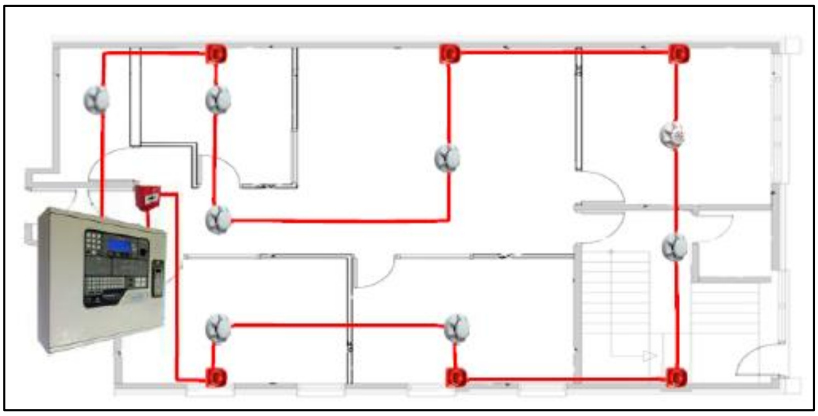

Figure 1: Addressable fire alarm system (Century fire and security, 2016)

MS Zaandam is equipped with an addressable fire alarm system “Consilium”. An addressable fire alarm system is made up of a series of fire detectors and devices that are connected back to a central control panel. With addressable systems, each device has an address or location, enabling the operator to know the exact location of an activated device. For more information about these system please refer to the web article “Fire Alarm Systems” (Century fire and security, 2016)

The engine room and entire accommodation on board of MS Zaandam are divided in six different fire zones. Every zone is equipped with different fire detectors. In case If one of these detectors will activate, an alarm will sound in the engine control room and on the bridge giving the exact location of the detector. The engine control room and bridge are equipped with a fire alarm panel giving a proper overview of the present situation.

2.2.2. Fire prevention and detection system overview installed in the engine room on board of MS Zaandam

2.2.2.1. CCTV cameras

CCTV cameras are installed in the most fire hazardous places around engine room. Video recording is provided to the screens located in engine control room.

CCTV cameras are installed in following locations:

1. There are five diesel generators installed in the engine room, four cameras are installed in front of each diesel generator
2. Two cameras are installed in the main propulsion electric motor room
3. Four cameras are installed around incinerator
4. installed in the boiler room
5. Four cameras are installed in the purifier room
6. Two cameras are installed in the main switchboard room.
7. Two cameras are installed in the stern thruster room
8. One camera is installed in the emergency diesel generator room

2.2.2.2. Smoke detectors

Smoke detectors are installed everywhere in the engine room. If one of these detectors will activate, an alarm will sound on the bridge, giving the exact location of the detector. The same will happen if someone pushes a manual call point. If a detector is activated, the First response team will investigate the situation. If there is a confirmed fire, the first stage emergency alarm will be sounded and the fire team will take over from the first response.

2.2.2.3. Flame detectors

Flame detectors are installed in the following locations:

1 Boiler room
2 Incinerator room
3 Switchboard room
4 Purifier room
5 Diesel generators 1 to 5
6 Maine electric propulsion room

Same as smoke detectors. If one of these detectors will activate, an alarm will sound on the bridge and in the engine control room, giving the exact location of the detector.

2.2.2.4. CO_2 Installation

Following areas are equipped with CO_2:

1. Engine room spaces

2. Emergency generator room
3. Garbage room
4. Engine control room

Fixed CO_2 installation is used when a fire cannot be extinguished by manpower. The whole area will be evacuated and closed off by closing all fire doors and fire dampers. By filling the area with CO_2 there is no more oxygen to feed the fire.

2.2.2.5. High fog release system

The fire extinguishing system uses water under high pressure. The specially designed spray heads cause the water to enter the space as fine fog (mist) at high speed. The small droplets yield a very large total water surface area, providing efficient cooling of the fire and surrounding gases. The high speed of the small droplets enables the fog to penetrate hot fuel gasses and reach the combustion source and hidden fires.

The system has the following components:

- A pump unit with high pressure pumps providing a continues flow of water
- An electric control and monitoring system, including a relay control unit on the pump and a release panel at the ECR
- Stainless steel piping
- A separator and filter for the feeding system, as well as strainers in the spray heads.
- Manual release system from the engine room
- Spray heads for machinery spaces.

The system covers the following machineries and areas:

- Separator room (22 heads)
- Boiler room (15 heads)
- Incinerator room
- Forward engine room (20 heads)
- Main engine room aft (32 heads)
- Garbage room (17 heads)
- Chemical store (2 heads)
- Miscellaneous store (2 heads)

When the system is activated, the pumps will start to supply the system with a continuous flow of water at a maximum pressure of 140 bar. The full pressure can be maintained for a given number of active sections. With additional sections activated, the pressure will decrease. The system pressure will eventually level out, always providing the minimum required water flux density for the full design area.

2.2.2.6. LAS-10 "Leakage Alarm System"

The functionality of the Leakage Alarm System is based on a very large amount of air flow – 10000 litters per minute- which is led through a detection chamber and trough a specially designed filter mesh. The electronics in the detector combines and analyses the content of both the oil spray and gasses, which are detected by a sudden increase of collected oil or by the electronic gas sensor.

The LAS-10 Leakage Alarm System is developed especially for the detection of leakages in high pressure fuel and hydraulic oil systems to avoid fire, explosion and pollution.

The following areas are equipped with "Leakage Alarm System"

- Boiler room
- Diesel generator compartments
- Incinerator room
- Purifier room
- Emergency diesel generator room

2.2.3. Fire prevention and detection systems overview installed in the accommodation and other recreation areas.

2.2.3.1. Fixed Fire Suppression Systems

MS Zaandam is equipped with a wet and a dry Sprinkler Supressing System. The wet sprinkler system will be automatically activated whenever the temperature in a space rises above the breaking temperature of the glass bulb causing a pressure drop in the system, activating the pumps. The dry sprinkler system covers the AFT+FWD mooring decks and stores. The wet sprinkler system is used in the crew's and passenger's cabins, corridors, laundry, paint locker, bridge, restaurants and other recreations areas.

2.2.3.2. Smoke detectors

The smoke detectors are installed everywhere around the ship namely cabins, laundry, paint locker, offices, bridge, corridors, restaurants and other recreation areas. If one of these detectors is activated, an alarm is sounded on the Bridge, giving the exact location of the detector. The same will happen if someone pushes a manual call point. If a detector is activated, the First response team will investigate the situation. If there is a confirmed fire, the first stage emergency alarm will be sounded and the fire team will take over from the first response.

2.2.3.3. Heat detectors

The heat detectors are commonly used in the crew galley and the main galley. Same as the smoke detectors, if one of these detectors is activated, an alarm is sounded on the Bridge, giving the exact location of the detector.

2.2.3.4. CO_2 Installation

Following areas are equipped with CO_2:

- Galley areas in the exhaust ducts
- Paint locker

The fixed CO_2 installation is used when a fire cannot be extinguished by manpower. The whole area will be evacuated and closed off by closing all fire doors and fire dampers. By filling the area with CO_2 there is no more oxygen to feed the fire.

2.2.3.5. CCTV Cameras.

CCTV cameras are installed everywhere around the accommodation. The main purpose of these cameras is for the security monitoring and not for the fire monitoring.

2.2.3.6. Flame detectors

Flame detectors are used in the following locations:

- Garbage room
- Emergency diesel generator room
- Additional diesel generator room

2.3. The list of thermal imaging cameras applicable for fire prevention and detection

This paragraph contains a list of thermal imaging cameras that can be used for fire prevention and detection on board of the cruise ships.

FLIR A65/A35/A15/A5

These cameras are affordable, compact, have good image quality and have a high sensitivity. For more information and detailed technical specifications please refer to the web article “FLIR A65/A35/A15/A5” (FLIR, 2016)

FLIR A300/A310

These cameras are expensive, have excellent image quality and high sensitivity. They can measure temperature differences and can be used for critical equipment monitoring. Further these cameras have alarm function which can be set to go off as a function of analysis. For more information and detailed technical specifications please refer to the web article “FLIR A300/A310” (FLIR, 2016)

FLIR A315/A615

These cameras are compact and affordable and fully controlled by a PC. FLIR A615 has a superior image quality and can be used for the long distances. A315 produces thermal images of 320x240 pixels. For more information and detailed technical specifications please refer to the web article “FLIR A315/A615” (FLIR, 2016)

FLIR A310 f

This camera produces a picture of 320x240 pixels and makes visible any temperature differences. FLIR A310 f can be used for various applications that require temperature measurement capabilities including: substation, transformer, waste bunker, and coal pile monitoring. For more information and detailed technical specifications please refer to the web article “FLIR A310 f” (FLIR, 2016)

FLIR A310 ex

FLIR A310 ex can be used in explosive atmospheres. This camera has an IP rate of 67, it means that it can be used in dusty environment. The Flame-Proof Enclosure “d” prevents any explosion transmission from the inside of the enclosure to the outside. For more information and detailed technical specifications please refer to the web article “FLIR A310 ex” (FLIR, 2016)

FLIR A310 pt

The FLIR A310 pt can pan +/- 360° continuous and tilt +/- 45°. It can cover large areas. FLIR A310 pt can be used for various applications that require temperature measurement capabilities including: substation, transformer, waste bunker, and coal pile monitoring. For more information and detailed technical specifications please refer to the web article “FLIR A310 pt” (FLIR, 2016)

FLIR FC-Series R

This camera is calibrated for fire detections, safety and thermal monitoring of equipment. Durable enclosure protects camera from dust, water, and is submersible up to one meter. This camera is resistant against shock, vibration and corrosion. For more information and detailed technical specifications please refer to the web article “FLIR FC-Series R” (FLIR, 2016)

FLIR A66xx

This camera is used for automated inspections, process control, condition monitoring, fire detection and continuous optical gas imaging. FLIR A66xx can detect any temperature differences, capture high speed processes, measure temperatures of very small targets and synchronize with other measuring devices. For more information and detailed technical specifications please refer to the web article "FLIR A66xx" (FLIR, 2016)

2.4. Thermal Imaging Cameras for fire prevention and detection in industry

2.4.1. Thermal Fire Guard System

2.4.1.1. System Description

"Thermal Fire Guard is fire preventions system (see figure 2). It is based on the combination of thermal imaging cameras and special software that can early recognize hot spots and undesirable temperature change of the observed objects." (Thermal Systems, 2015) The biggest advantage of thermal imagers in comparing with other fire detection systems is that they are able to provide an early warning response at the moment when the hot spots are detected. Thermal imaging cameras can provide a video recording of the hot spots on a remote video or PC monitor in real time, and tell a viewer the precise temperature and location of those spots. Thermal imagers can also be programmed to set the temperature at which an alarm signal is generated, and multiple target spots and alarms can be used. The alarm output can be directly connected to an alarm device, annunciator, programmable logic controller or a PC-based monitoring and control system. When an alarm occurs, personnel can directly establish the cause of the alarm and its exact location. Thermal imagers do not require lighting to keep monitoring and they are able to see through the smoke. This means that in case a fire should break out they can be used to guide firefighters to the source of the fire and to see if there are still people in the smoke filled room. (FLIR, 2015)

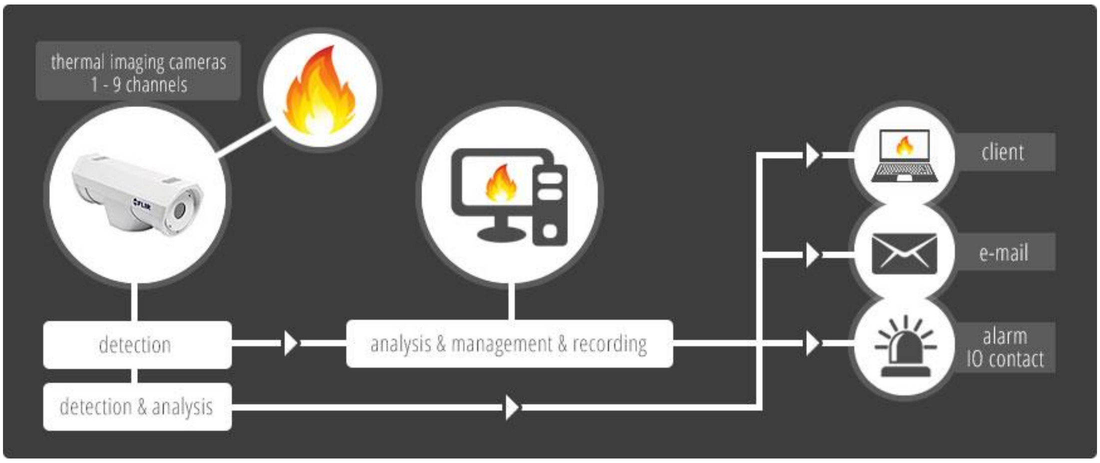

Figure 2: Fire detection scheme (Thermal - Fire Guard System , 2015)

2.4.1.2. *Example of system configuration in a warehouse*

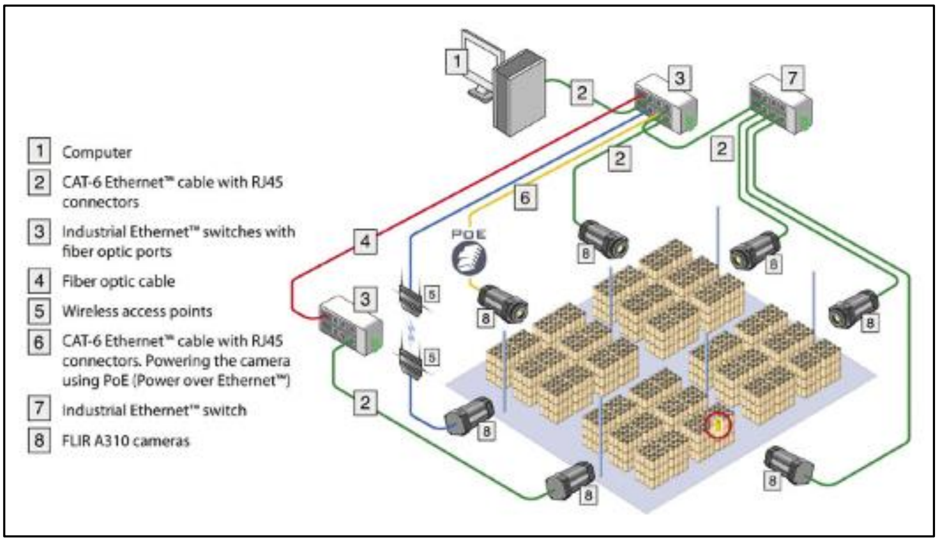

Figure 3: Concept of a warehouse equipped with thermal imaging cameras (FLIR, 2015)

Figure 3 shows a concept of a warehouse equipped with thermal imaging cameras in order to keep a continuous fire monitoring. All thermal imaging cameras installed in the warehouse can be connected to one computer via the Ethernet switches providing a thermographic video image of monitored areas. The temperature data is one of the primary inputs to the PLC or PC controller. In addition to viewing thermographic video images, temperature data can be stored an analysed to produce a trend analysis. There are software's that allows a PC to display up to nine camera images at a time, and switch between additional camera groups as needed. (FLIR, 2015)

2.4.2. Key Features of the system

Thermal imaging camera can provide a signal to an audible or visual alarm device, but they can also be combined with a PLC or PC controller to create an advanced monitoring system.

- High, low and average temperature in an image
- Temperature set-point alarms
- Multiple target spots and alarms
- Delays to ignore temporary temperature increases due to crew presents in a monitored area
- Temperature trend analysis to establish problems before a set-point is reached
- Ethernet connections to a central controller
- Connecting multiple cameras to central monitor
- Alarm messages and images via Ethernet, email or FTP
- Multi-screen display (layout mode 1x1, 2x2, 3x3)
- Playback of records
- 24/7 automatic operation (no need for operator)
- User friendly interface
- Quick search of video sequence by date, time or logged events (Thermal Systems, 2015)

2.4.3. Additional value of thermal imaging to the conventional fire detections systems

Technology	Advantages	Disadvantages
CCTV camera	CCTV cameras are relatively inexpensive at purchase	Because this solution needs lights it is relatively expensive in the long run
	Can monitor a large area	Need light to produce an image
		High maintenance costs and energy bills due to installed lights
		Can not see through smoke
		Provide response to a fire that has already broken out
		Need contrast between smoke and the environment in order to see the smoke
Smoke detectors	Relatively inexpensive to buy	Provide response to a fire that has already broken out
		Generate a lot of unwanted alarms
		High maintenance cost
Thermal imaging	Need no light whatsoever	Thermal imaging cameras are more expensive than CCTV at the initial purchase.
	See through smoke	
	Give an alarm BEFORE a fire breaks out.	
	Can monitor a large area	
	Produce good contrasted images.	
	Practically no unwanted alarms	
	Can guide a fire extinguishing system in order to minimize damage.	
	No maintenance	

Figure 4: Advantages and disadvantages between the various fire monitoring systems (FLIR, 2015)

Figure 4 shows the comparing between the smoke detectors, thermal imaging cameras and CCTV camera. Every system has his own advantages and disadvantages. Smoke detectors are mostly used on board of the ships. They are cheap, but generate a lot of false alarms. CCTV cameras can monitor the large areas and are relatively cheap. However, they cannot see through the smoke and same as smoke detectors provide a late response. Also, there is a need in contrast between the smoke and the environment in order to see the smoke. (FLIR, 2015)

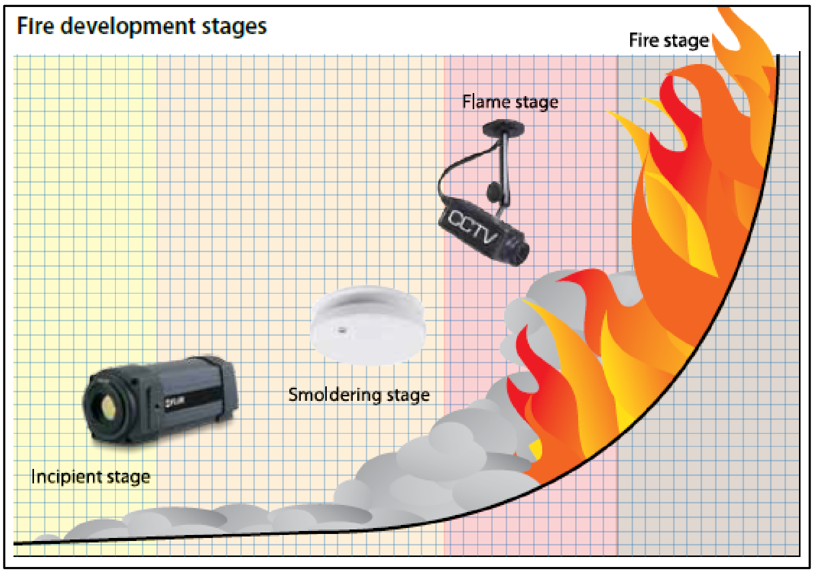

Figure 5: Thermal imaging camera detects fire at incipient stage (FLIR, 2015)

"Depending on the previously set temperature alarm a thermal imaging camera will detect fire in the incipient or the smouldering stage. A smoke detector relies on smoke production to detect the developing fire, so it will only detect the fire at the end of the smouldering stage or at the beginning

of the flame stage."(FLIR, 2015) The big disadvantage of smoke detectors is that they start to operate when a protected area is completely in the smoke. Depending on the size of the area, sometimes it can take a lot of time before the smoke detector generate an alarm. CCTV cameras are on colour contrast, so it will only detect the fire in the fame or fire stage, depending on lighting condition. Thermal imaging cameras require no power consuming lighting to be effective, also, there is need in maintenance. Thermal imaging cameras generate fewer unwanted alarm in comparing with smoke detectors and CCTV cameras. (FLIR, 2015)

Advantages and disadvantages of smoke detectors

Advantages of Smoke Detectors:

- Detect invisible products of combustion
- Provides for earlier detection than other types of smoke detectors or thermal detectors

Disadvantages of Smoke Detectors:

- High false alarm rate
- Detect the presence of smoke only, not toxicity (Field's Fire Protection, 2015)

Advantages and disadvantages of heat detectors

Advantages of heat detector:

- Low costs
- More reliable than smoke detectors
- Not affected by dusty or dirty environments
- Minimal maintenance

Disadvantages of Fixed Thermal Detection:

- Slower to respond than smoke detectors
- Will not detect products of combustion
- Only suitable for protection property (Field's Fire Protection, 2015)

Advantages and disadvantages of flame detectors

Advantages of Flame Detection:

- Extremely fast acting

Disadvantages of Flame Detection:

- Narrow field of vision
- Expensive
- Require unobstructed field of view
- Difficult to maintain (Field's Fire Protection, 2015)

2.5. Cases in which thermographic cameras prevented fire occurrence

2.5.1. Thermal imaging camera detected fire occurrence in a warehouse

"*Worldwide, warehouses are stocked with highly valuable goods, therefore the fire occurrence is the biggest danger. Fire can destruct an entire warehouse within an extremely short timeframe. The value of the destroyed goods during a fire can be tremendous and the cost of a life that is lost during a fire is impossible to calculate. Statistics show high increase in assets loss due to fire although warehouses are equipped with fire alarms and firefighting systems*." (FLIR, 2015)

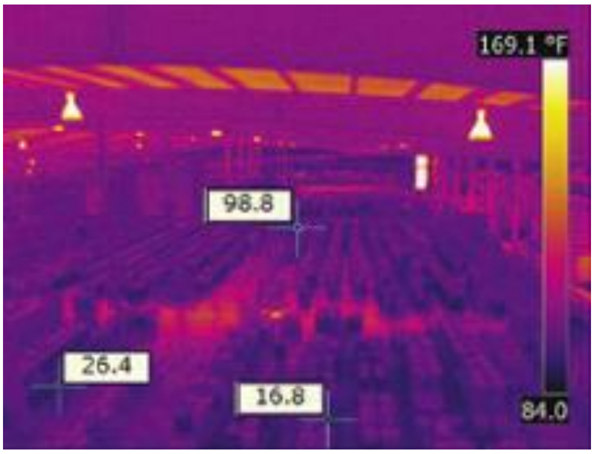

Figure 6: Thermal imaging detected a hotspot (FLIR, 2015)

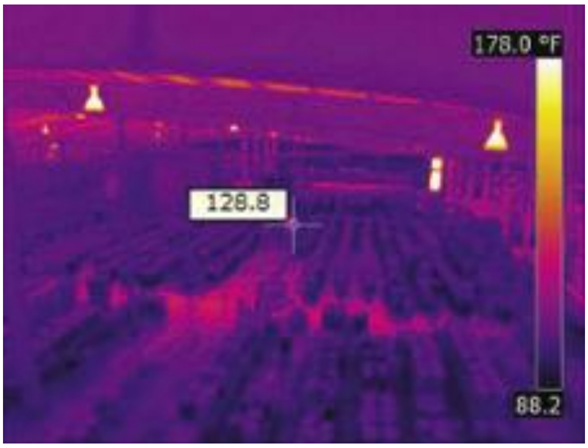

Figure 7: Thermal imaging camera monitored temperature increasing (FLIR, 2015)

Figures 6 and 7 represent a thermal video recording of a warehouse stocked with wood. From figure 6 can be clearly observed that there are three different temperature readings. The first two temperature spots are -3.1°C and -8.4°C and the third temperature reading is 37.1°C. Comparing the difference between the readings it is obvious that the last reading is abnormally high. Figure 7 shows that thermal imaging camera kept the hotspot monitoring and observed a further temperature increasing. At the moment when temperature increasing reached the set point established by user thermal imager activated alarm. (FLIR, 2015)

2.5.2. Thermal imaging cameras help prevent fires in waste incineration plants

In order to reduce the waste volume and gain some extra energy, the waste is thermally processed in municipal waste incinerator. The incinerator in the Prague has been operational since 1998 and takes care of the transformation of waste into thermal and electric energy. The acquired energy is used as heating of domestic water and heating of residential buildings. (FLIR, 2015)

"The most common causes of fire at waste incineration plants are spontaneous chemical combustion of waste and hot particles given off by the vehicles that collect municipal waste. A contributing factor to the risk of fire or devastating explosion is the increased concentration of methane, which is released from the waste during the decay process." (FLIR, 2015)

In order to reduce the risk of fire the Czech company "Workswell" has invested in purchasing of thermal imaging cameras. The main goal of the system is to monitor the plants waste storage for emerging fires. The waste is imported into a storage tank. This tank is used for the homogenization of materials and to ensure sufficient reserve of waste so that the plant can operated continuously. (FLIR, 2015)

The Waste Bunker Monitor system combines the non-contact temperature measurement from two thermographic cameras with an intelligent software which informs the plant operator about the critical areas whit abnormally high temperatures. Whenever the temperature will exceed a certain value in the monitored area, an alarm will occur.

2.5.3. Thermal imaging cameras prevent fires at Korean coal power plant (indoor)

The Korea East-West Power Company, the owner of the plant in Dangjin Coal Fired Power Complex (DCFPC), has invested in purchasing of thermal imagers in order to reduce the risk of spontaneous combustion in the coal conveyor system. (FLIR, 2015)

"Huge quantities of coal are stored in bunkers, silos, hoppers and open air stockpiles, but coal is a combustible material, making it susceptible to a variety of ignition scenarios. One of the most frequent and most dangerous causes of coal fires is spontaneous combustion. This can occur in any location where coal is stored or transported. Coal can start oxidizing with the oxygen in the air. This causes a rise in temperature. At first the coal's temperature climbs just above the ambient temperature, but if left unchecked it can rise to above 400 degrees Celsius, causing the coal to bursts into flame." (FLIR, 2015)

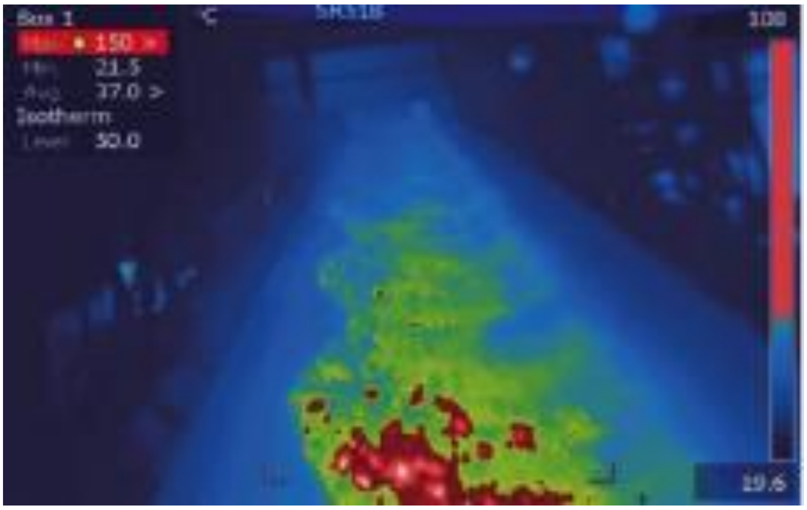

Figure 8: Abnormal high temperature is detected during transport (FLIR, 2015)

To transport the coal to the boilers a conveyor system is used. During the transport the chance of spontaneous combustion is very high. If the fire will occur during this transportation the produced damage will be costly and huge. Therefore, the owner of the conveyor system has installed several infrared thermal imaging cameras above the conveyor along the way.

At the moment when thermal imaging cameras will notice an abnormal temperature increasing, the conveyor will immediately stop, the alarm will go off and the sprinkler system will activate. The advantage of this fire guard system is that thermal imaging cameras will provide an early warning in comparing with the smoke detectors. (FLIR, 2015)

2.5.4. Thermal imaging camera keeps fire risk under control in coal pile storage site

Nastup Mines Cooperation has invested in purchasing of thermal imaging cameras in order to keep the fire occurrence risk under control. The thermal fire guard system provides an effective solution for continuous, remote monitoring of temperatures in the coal piles. (FLIR, 2015)

"Bulk storage of any combustible materials leads to fire risk in many large storage areas such as waste bunkers, wood or paper stockpiles, as well cement and coal storage yards. Self-ignition usually starts within the bottom layers of a stock-pile as a result of temperature increases in the material. By

continuous monitoring of the surface layers, hot spots can be detected in an early stage and action can be taken to prevent fires from breaking out." (FLIR, 2015)

Figure 9: Thermal video recording of the coal yard (FLIR, 2015)

Figure 10: Thermal imaging camera mounted on the steel mast (FLIR, 2015)

The use of portable thermal imaging cameras is not a practical solution due to the large size of the storage yard. Therefore, the coal owner has chosen for the automated system that keeps continuous monitoring of the coal yard.

The fire guard system consists five thermal imaging cameras mounted on steel masts at strategic locations around the site (see figures 9 and 10). The cameras are configured to generate an alarm to an operator if previously defined maximum temperature is exceeded. An acoustic alarm and display alarm on a monitor will draw the operator's attention to a possible spontaneous fire development. (FLIR, 2015)

2.5.5. Thermal Imaging Camera protect electrical substation in Stavanger

The Lyse Energy electrical substation has decided to install thermal imagers for perimeter protection and for condition monitoring of the critical equipment.

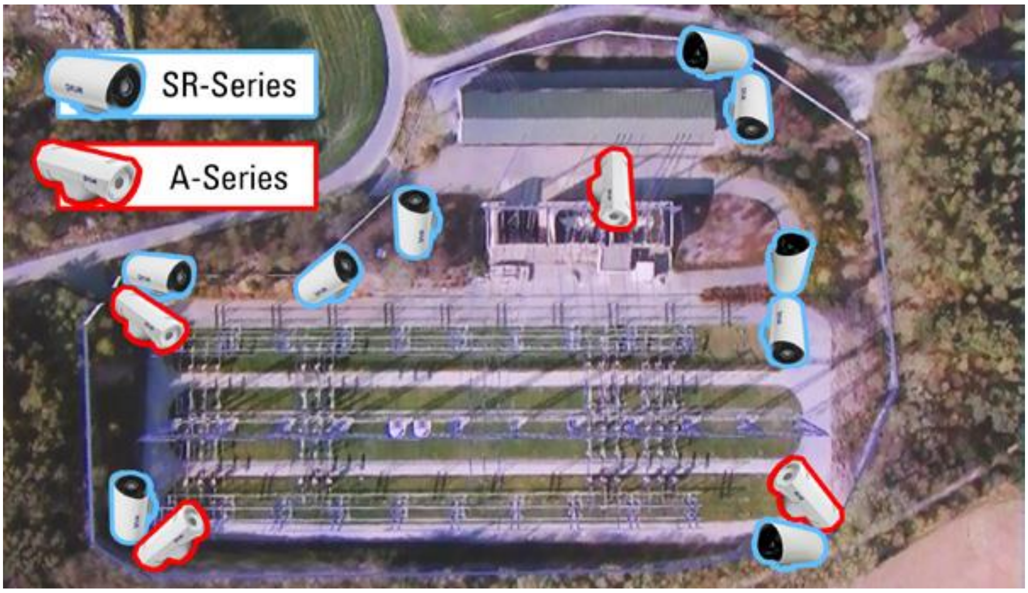

Figure 11: The location of thermal imaging cameras for perimeter protection and for condition monitoring (FLIR, 2015)

Figure 11 shows the electrical substation equipped with thermal imaging cameras. The A – Series are used for condition monitoring of the critical equipment such as transformers and electrical distribution networks. The SR- Series are used for the perimeter protection. (FLIR, 2015)

"Thermal imaging cameras are mounted in a waterproof housing around electrical substation. These radiometric thermal imaging cameras produce thermal images at a resolution of 320x240 pixels. Each pixel in the thermal image is non-contact temperature measurement with a thermal sensitivity better than 50 mK (0.05 °C), enabling it to capture the finest image details and temperature differences. The built-in logic, memory, and data communications allow them to compare the temperatures in their images with user-defined settings, and send that data to a central monitoring station for trend analysis and alarm functions. In the case of the Lyse Energy substation in Stavanger the thermography monitoring system will automatically sound the alarm if particular areas within the thermal image reach above the previously determined threshold temperature." (FLIR, 2015)

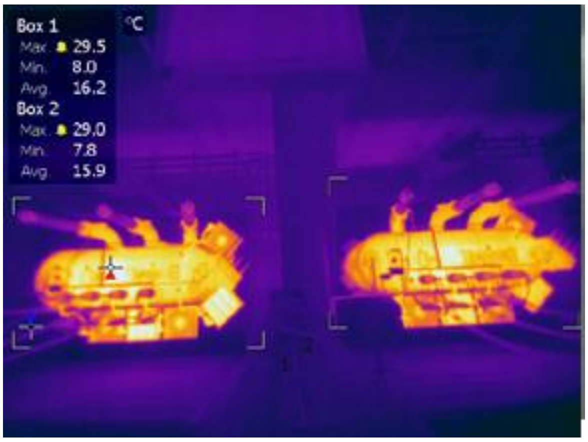

Figure 12: Condition monitoring of the transformers (FLIR, 2015)

Figure 12 shows a thermal video recording of two similar transformers. As can be seen, the temperatures are approximately the same, it means that there are no abnormal temperatures increases inside the electrical components.

Figure 13: Critical components within the substation (FLIR, 2015)

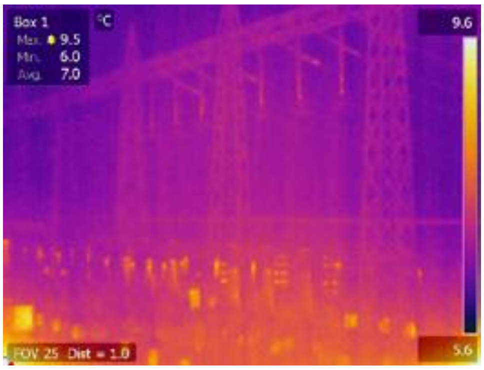

Figure 14: Thermal video recording of the critical components (FLIR, 2015)

Four thermal imaging cameras monitor critical components within the substation. If any point within the camera's field of view reaches a temperature that is higher than the previously determined threshold temperature an alarm will go off (see figures 13 and 14). (FLIR, 2015)

2.6. Passenger ship fires over the last 20 years

2.6.1. Overview of the fire accidents

To establish the most dangerous places on board of MS Zaandam, firstly, the passenger ship fires over the last 20 years will be analysed. As much as possible fire incident reports of the cruise ships and ferries will be assembled in order to make an overview of the fire hazardous areas. The purpose of this analysis is to establish the causes and the circumstances of the fire accidents in order to figure out for which situations thermal imagers could be useful as an additional value to the installed fire detection system.

MS Carnival Triumph

The fire occurred in the engine room near diesel generators. The reason of fire: Fuel oil sprays on the hot surface area

A flexible pipe on the fuel oil return line forward of the No.6 Engine, located in the centre section of the Aft Engine Room, failed in service. Fuel oil, mist and vapour can be considered to be present, under a reported pressure of 10 bar and temperature of 122^{O}C, sprayed upwards from below the floor plates. The fuel oil reached a height of approximately 5 meters, between the turbo chargers at the forward end of the No.6 engine in the Aft Engine Room. Fuel oil contacted a hot spot in the vicinity of the turbo charger for the No.6 diesel generator, resulting in a flash fire that severely damaged diesel generator Nos.5 & 6.

The fire detection system: Smoke detectors, heat detectors, flame detectors. (Bahamas Maritime Authority, 2013)

MS Commodore Clipper

The fire occurred on the main vehicle deck. The fire occurred due to overheating in an electrical cable that provided power from the ship to one of the refrigerated trailer units.

The fire detection system: Smoke detectors, CCTV camera. (MAIB, 2011)

MS Corona Seaways

The fire occurred on the main deck of the ro-ro cargo ferry. The fire was caused by an electrical defect on one of the vehicles engine starting system.

Fire detection system: CCTV camera, smoke detectors. (MAIB, 2014)

MS Edinburg Castle

Fire occurred in the main galley. The fire was caused by overheating of the cooking fat in the fryers, this resulted in ignition.

The power contactor of one deep fat fryer had welded closed. This prevented interruption of power as the fats temperature increased.

The fire detection system: Heat detectors. (MAIB, 1999)

MS Grandeur of the Seas

The fire occurred in the centre portion of the aft mooring area on deck 3. The exactly reason is unknown.

"Although a forensic fire investigation was carried out, the source of the ignition or the material that was initially ignited has not been established. The suggestions that a cigarette end discarded from an adjacent or upper deck ignited stored rags or mooring rope, or self-ignition of rags (such as oiled towels discarded from the spa), or an electrical fault may have been the root cause are speculative." (Bahamas Maritime Authority, 2013)

The fire detection system in the area: CCTV cameras. (Bahamas Maritime Authority, 2013)

MS Statendam

The fire occurred in the main switchboard room and the adjacent engine control room. The reason of the fire is that the main circuit breaker for one of the diesel generators suffer a catastrophic failure.

The DG 2 circuit breaker tripped twice, at 1805 and at 1820. The reason of the first tripping is unknown; the second tripping was caused by an overload. However, at this time the total power being consumed was about 63 % of the total available power. This would indicate that these trips were cause by an abnormally present either within the circuit breaker itself or within its protection relays. (Transportation Safety Board of Canada , 2002)

MS Joseph and Clara Smallwood

The fire occurred on the lower vehicle deck. The fire was emanating from one of the tractor-trailers parked on vehicle deck 1.

The fire detection system: Smoke and heat detectors. (Transportation Safety Board of Canada, 2003)

MS Queen of Surrey

The fire occurred in the engine room. Fire was caused by failure of the fuel oil pressure gauge pipe at No.2 Main Engine. The diesel oil sprayed onto the hot exhaust manifold of the engine. This is resulted the ignition.

Fire detection system in the area: Smoke and heat detectors. (Transportation Safety Board of Canada , 2003)

MS Columbia

The fire occurred in the engine room in the auxiliary engine No. 2. The fire was caused by a breakdown in the generators wiring insulation.

"An electrical event or events, caused aging or hard spots in at least one of the windings near the bottom of the generator. This caused a short between turns which increased the current in that coil. The heat was eventually enough to cause additional turns to become shorted and then to start the melting process in the winding. As the molten copper started to flow, it shorted windings phase to phase, and the event quickly became a catastrophic failure" (National Transportation Safety Board , 2003)

MS Malaspina

Fire occurred in the engine room in the sewage treatment room. The fire was caused by human's fault.

"The failure of the shore side work crew and fire watch to ensure that proper cooling had occurred before leaving the area where the repair work was conducted. Contributing to the accident was the work crew's improper use and application of a welding curtain, placed horizontally as opposed to vertically, which allowed molten material to burn through the curtain and fall into the space below." (National Transportation Safety Board , 2012)

MS Vistafjord

Fire occurred in the laundry storeroom.

"The possible ignition sources for the fire in the laundry storeroom included the electrical detergent pump-dispenser panels, the electrical distribution panels, discarded tobacco-related smoking materials, and a deliberate act."

Fire detection system in the area: Heat detector. (National Transport Safety Board, 1997)

MS Dieppe Seaways

Fire occurred in the engine room in the furnace of the port thermal oil heater. The crack in the thermal oil heater coil allowed thermal oil to enter the furnace, resulting in an uncontrolled furnace fire.

"The fire in Dieppe Seaways' port thermal oil heater started because a fracture developed in the coil carrying the oil through the furnace, and this allowed thermal oil to enter the furnace and ignite. The nature of the fire was such that it created a succession of small explosions, some of which were powerful enough to cause the burner unit to hinge open. The aperture in the heater furnace caused by the opening of the burner unit then allowed the fire to migrate to the boiler room." (MAIB, 2015)

MS Pride of Canterbury

Fire occurred in the engine room. Fire was caused by a ruptured pipework spraying hydraulic oil onto the exhaust uptake. The oil ignited, causing a significant fire in the main engine room.

"The fire was initiated following the spray of hydraulic oil, from a ruptured pipework joint in the starboard CPP system, onto the hot exhaust uptakes of the starboard main engines. The flanged joint ruptured because the CPP system became over pressurised as a result of the back pressure valve (PSV3) becoming jammed in the closed position." (MAIB, 2015)

MS Sally Star

Fire occurred in the engine room. The fire was caused by the failure of a bolted flange joint on the low pressure fuel system of No. 4 main engine, allowing flammable fuel oil vapour to come into contact with part of the engine exhaust system.

Fire detection system: Heat and smoke detectors. (MAIB, 1995)

MS Spirit of Tasmania

The fire occurred in the ship's photographer shop and was caused by a short circuit in the extension lead under the sink in the store area supplying power to the fridge. The short circuit in the extension lead was caused by the breakdown of the insulation between the conductors in the lead. The breakdown of insulation was the result of the imposition of a mechanical load on the lead.

The fire detection system in the area: Smoke detectors (Australian Transport Safety Bureau, 2011)

MS Ecstasy

The fire occurred on the aft mooring deck. The fire was caused by the unauthorized welding by crewmember in the main laundry that ignited a large accumulation of lint in the ventilation system and the failure of Carnival Cruise Lines to maintain the laundry exhaust ducts in a fire-safe condition.

"Contributing the extensive fire damage on the ship was the lack of an automatic fire suppression system on the aft mooring deck and the lack of an automatic means of mitigating the spread of smoke and fire through the ventilation ducts" (NATIONAL TRANSPORTATION SAFETY BOARD, 1998)

The fire detection system in the area: Smoke detectors

MS Columbia

The fire occurred in the main switchboard in the engine control room. The fire might have been caused by a faulty connection within the main switchboard that initiated an arc fault, which spread within the two switchboard units and damaged them. Also, the fire might have been caused by a conductive object falling onto the switchboard bus bars.

"The probable cause of the fire in the Columbia was the absence of an effective maintenance and inspection program for the electrical switchboards, resulting in a switchboard fire by arcing, most like due to a faulty connection or a conductive object." (NATIONAL TRANSPORTATION SAFETY BOARD , 2000)

MS Universe Explorer

Fire occurred in the main laundry. Fire accident is unknown.

"The National Transportation Safety Board determines that the probable cause of fire was a lack of effective oversight by New Commodore Cruise Line and the predecessor of V. Ships Marine, who allowed physical conditions and operating procedure to exist that compromised the fire safety of the Universe Explorer, ultimately resulting in crewmember deaths and injuries from a fire of undetermined origin in the vessel's main laundry. Contributing to the loss of life and injuries was the lack of sprinkler systems, the lack of automatic local sounding fire alarms, and the rapid spread of smoke through open doors into the crew berthing area." (NATIONAL TRANSPORTATION SAFETY BOARD , 1996)

Fire detection system in the area: None

MS Nieuw Amsterdam

The fire occurred in the crew cabin. The fire was caused by an electrical equipment

"The National Transportation Safety Board determines that probable cause of the fire on board the Nieuw Amsterdam was the unauthorized use of an electrical appliance that had been left unattended and plugged into an electrical outlet in a crew cabin." (NATIONAL TRANSPORTATION SAFETY BOARD, 2000)

Fire detection system: Smoke detectors

MV Azamara Quest

The fire occurred on diesel generator no. 4 in the engine room. The fire was caused by fuel oil spraying on the hot surface area.

"It was apparent from the physical evidence that the fire was caused by a fuel oil leak from a fuel oil return pipe on the aft part of DG no. 4. The fire occurred when fuel oil came in contact with a hot source near the turbo chargers or possibly the exhaust gas pyrometers, a nearby indicator cock, or a part of the exhaust manifold where the latter leaves its insulated containment and enters the turbo charger casing. This would have been enough to ignite the fuel oil. An instantaneous intensive fire propagation would have then occurred when the fire ignited the fuel oil around the prime mover as well as the fuel oil escaping from the pipe flange at a pressure of seven bar." (Malta Transport Centre , 2012)

Fire detection system: Smoke detectors, CCTV camera, heat detectors.

MV Zenith

The fire occurred in engine room. The gas oil came in contact with the exposed hot surface of the unshielded part of the exhaust manifold and ignited.

"An inspection of the area in close proximity of the fire seat revealed that the fire was caused by the fracture of a low carbon steel pipe on the starboard father main engine's damping cylinder. The damping cylinder formed part of the low pressure fuel line supply to the fuel gauge on the main engine instrumentation panel.

The fuel pipe had fractured from the outlet connection of the damping cylinder close to the union nut that formed part of a T-connection. This fracture led to the release of gas oil, at a pressure of about 6 bars, which sprayed to an area between the cylinder head of unit no. 1 and the turbocharger casing. The gas oil came in contact with the exposed hot surface of the unshielded part of the exhaust manifold and ignited." (Marine Safety Investigation Unit, 2014)

The fire detection system: CCTV cameras, smoke detectors and heat detectors.

MV Norsea

Fire occurred in the engine room. The fire was caused by fuel oil spraying onto the hot surface area.

"The fire was caused by leakage of fuel from the fretting failure of a low-pressure fuel pipe on the aft diesel-driven generator, in the aft engine room, because of incomplete securing arrangements. Ignition of the associated vapour was probably from contact with the diesel engine's exhaust manifold." (MAIB, 2002)

The fire detection system: Smoke detectors and heat detectors.

MV Oscar Wilde

The fire occurred in the engine room. The reason of fire: Fuel oil sprays onto the hot surface area.

"The fire occurred when a pressure regulating valve's actuator diaphragm ruptured and fuel oil sprayed onto an exposed high-temperature surface on an adjacent auxiliary engine." (MAIB, 2011)

The fire detection system: Smoke and heat detectors.

MV Pride of Le Havre

The fire occurred in the engine room. The reason of fire: Hot thermal oil sprays onto the hot pump casing.

"Probable cause of the fire is believed to be failure of the mechanical seal on the starboard thermal oil pump allowing thermal oil at a temperature of about C to leak aft into the bearing housing and out towards the ball-bearing assembly. The collapsed ball-bearing race then allowed thermal oil at a pressure of about 10 bar to leak out aft towards the electrical drive motor. The pressurised oil impacted with the front end of the motor and rebounded back towards the pump casing. Although the temperature of the thermal oil was below its flash point, it is likely to evaporate into oil mist when in contact with the hot pump casing" (MAIB, 1999)

The fire detection system: Smoke and heat detectors

MV Pride of Le Havre

The fire occurred in the switchboard room in the engine room. The fire was caused by the switchboard explosion.

The explosion is considered to have been caused by a direct connection being made between two phases of the 660-volt incoming supply.

"The two leads connected to the test meter used by the electro-technical officer were both black, and understood to be entangled with each other This made it difficult to separate out the ends of individual leads and increased the risk of a mistake being made." (MAIB, 1999)

MS Amsterdam

The fire occurred in the battery room. The probable cause of the fire is one of the battery failure.

"The most likely cause of the incident is that one battery was failing, and as its impedance increased, the battery drew more and more current until it overheated. The battery most likely began to overheat during testing of the emergency diesel generator. The emergency diesel generator had been tested on load, and to test automatic starting, power to the emergency switchboard was interrupted. During the 30- second delay before the emergency diesel generator reconnected to the switchboard, the batteries were discharging. After the emergency diesel generator test, power to the emergency switchboard was re-established, and the batteries would have had an increased charging rate, and with the increased impedance of the involved battery, it probably overheated and exploded" (Holland America Line, 2016)

MV Queen of the West

The fire occurred in the engine room. The probable cause of the fire was the failure of pressurized component on the port main propulsion hydraulic system, resulting in hydraulic oil spraying onto the port engine's exhaust piping and igniting.

The fire detection system: Smoke and heat detectors.(Nationa Transportation Safet Board, 2009)

MV Saga Rose

The fire occurred in an electrical locker beneath the master's cabin. The fire was caused by a fault on a secondary electric cable to one of the transformers in an electrical locker room.

"The cause of the fire has not been identified positively Although damaged cabling linked to the defective fire door control on the main deck was considered to be a contributory factor, subsequent investigation of the damaged equipment suggests the most likely cause to be a fault on a secondary cable connected to one of the mounted transformers." (MAIB, 1999)

MV Star Princess

The fire occurred on an external stateroom balcony. The cause of the fire is unknown.

"The cause of the fire has yet to be determined. However, the seat of the fire was on an external stateroom balcony sited on deck 10 on the vessel's port side. The fire spread rapidly along adjacent balconies, and within 10 minutes had spread up to decks 11 & 12 and onto stateroom balconies in two adjacent fire zones. It also spread internally as the heat of the fire shattered the glass in stateroom balcony doors" (MAIB, 2006)

No fire detection system on the balconies.

The Calypso

The fire occurred in the engine room. The reason of fire: Fuel oil sprays onto the hot surface area.

"The subsequent investigation discovered that the fire had been caused by a failed low pressure fuel pipe flange on the starboard Wartsila Vasa32 main engine. The lack of an effective guard allowed fuel to spray onto the adjacent turbocharger and/or exhaust piping causing spontaneous ignition." (MAIB, 2007)

The fire detection system: Smoke and heat detectors.

MV Royal Princess

The fire broke out on diesel generator no. 4 in the engine room. The reason of fire: Fuel oil sprays onto the hot surface area.

"The fine spray of fuel from the split in the fuel line aft provided the fuel for the initial fire at the aft end and the greater volume of fuel released from the opened flange at the forward end provided the fuel for the major fire that ignited at the forward end." (Government of Bermuda, 2009)

The fire detection system: Smoke and heat detectors.

MV Stena Pioneer

Fire occurred in the main switchboard room in the engine room. The fire was caused by mechanical breakdown of the main circuit breaker. (MAIB, 2004)

MV Isle of Inishmore

The fire occurred in the engine room. Thermal oil was leaking into the thermal oil heater's furnace from the heater coils. A fire then broke out in the thermal oil heater and flames flashed out of the burner air intake igniting lagging and other materials in the engine room.(MAIB, 2008)

MV Stena Lynx III

The fire occurred in the engine room. The reason of fire: Fuel oil sprays onto the hot surface area.

"On investigation it was found that an, on engine, low pressure fuel pipe had fractured because it was incorrectly fitted. The engine vibration and stresses set up in the pipe caused it to fail, spraying fuel over the hot cylinder exhaust causing ignition." (MAIB, 2004)

MS Westerdam

The fire occurred in the boiler room in the engine room. The cause of the fire is unknown. (shipdetective, 2016)

MS Sun Vista

The fire occurred in the main switch board room in the engine room. The cause of the fire is unknown.(MaritimeMatters, 2010)

MV Carnival Splendor

The fire broke out on diesel generator no. 5 in the engine room. The fire was caused by a major mechanical failure of DG 5.

"As a result of fatigue fracture of the connecting rod for diesel generator 5, engine components, and fuel and lube oil were ejected from the engine casing and created a pool fire on the deck plates between diesel generator 5 and diesel generator 6. The initial fire ignited cables in the wire ways and bundles causing a deep seeded secondary fire located directly above DG5 and DG6." (United States Coast Guard, 2013)

The fire detection system: Heat detectors, smoke detectors, flame detectors and CCTV cameras.

MV Nordic Empress

The fire occurred in the engine room. The reason of fire: Fuel oil sprays onto the hot surface area.

According to Royal Caribbean, *"A ruptured fuel line between the third and fourth main propulsion engines is the suspected cause of the fire."* (U.S. Coast Guard , 2007)

MV Majesty of the Seas

The fire occurred in the galley. The fire was caused by overheating of the cooking fat in the fryers, this resulted in ignition. (Cruisecritic, 2004)

MV Costa Romantica

The fire occurred in the engine room. The fire was caused by one of the diesel generators. (Cruiseminus, 2009)

MS Ryndam

The fire occurred in the galley. The fire was caused by the deep fat fryer.

"An Executive Chef asked an Assistant Cook to drain the deep fat fryer in the main galley in preparing for cleaning. The Assistant Cook turned off the unit, waited 30 minutes for the oil to cool, drained and stored the used cooking oil, and then left the area. About three and a half hours later other galley crew arrived to clean the unit and saw a small fire un the fryer well. They immediately alerted the bridge, and then verified that they fryer was switched off, covered it with a fire blanket, and placed a metal lid over it. No smoke detectors arrived. When the Safety Officer arrived, he isolated power to the fryer and used CO_2 extinguisher to put out the fire." (Holland America Line, 2016)

2.6.2. Summary

2.6.2.1. Fire hazardous areas overview

According to the analysis of the fire accidents the following facts were established:

- 27 fire accidents occurred in the engine room
- 5 fire accidents occurred in the recreation areas
- 3 fire accidents occurred in the main vehicle deck (Ferries)
- 3 fire accidents occurred in the laundry
- 3 fire accidents occurred in the galley

2.6.2.2. Engine room fires

According to the analysis of fire accidents, the most fire hazardous place on board of the cruise ships is the engine room (27 fire accidents).

The following places of the fire occurrence were established in the engine room:

- 9 fires occurred in the auxiliary generator room

- 6 fires occurred on the main engine
- 4 fires occurred in the main switch board room
- 4 fires occurred in the boiler room
- 2 fires occurred on the CPP system
- 1 fire occurred in the sewage treatment room
- 1 fire occurred in the battery room

The following causes of the fire accidents were found:

- 15 fires were caused by fuel oil, thermal oil, hydraulic oil spraying onto the hot parts of the machineries.
- 7 fires were caused by major electrical failures
- 2 fires were caused by thermal oil leakage into the oil heater's furnace
- 2 fire origins are unknown
- 1 fire was caused by human's fault

2.6.2.3. Main vehicle deck fires (Ferries)

The vehicle deck fires caused by cars, trailers, trucks and other cargos on board of the ferries will not be taken into account due to the irrelevancy for this research.

2.6.2.4. Laundry fires

The analysis shows that three fires accidents were occurred in the main laundry. One accident was caused by the human's fault (unauthorized welding) and the causes of other two fire accidents are unknown.

2.6.2.5. Galley fires

The analysis shows that three fire accidents were occurred in the galley and all three were caused by overheating of the cooking fat in the fryers.

2.6.2.6. Recreation area fires

The analysis shows that five fire accidents were occurred in the accommodation: crew cabin, external stateroom balcony, ship's photographer shop, aft mooring deck and electrical locker beneath the master's cabin.

The fire in the crew cabin, ship's photographer shop and electrical locker was caused by an electrical issue.

The origins of fire occurrences in the aft mooring deck and external stateroom balcony are officially unknown, however, there are some suggestions about: burning cigarettes, electrical issues, self-ignition.

3. Method

This chapter comprises an explanation of how the research question will be answered. This project is based on qualitative research. Some common methods include focus groups, individual interviews, participation/observation and case study. The most applicable method for this research is case study and analysis of the various data's.

3.1. Research method

At the present time, the current fire detection systems on board of MS Zaandam are unknown, therefore before starting with this research, firstly, the current fire alarm systems will be observed in order to establish the present situation. After that, an overview of the passenger ship fires over the last 20 years will be studied in order to establish the most fire hazardous areas on board of cruise ships. The results of this study will be compared with the present situation on board of MS Zaandam and then, by using these results, the fire hazardous areas will be established on board of MS Zaandam. This information will be used as a background for the areas where thermal imaging cameras can be applicable in order to reduce the fire risk on board of MS Zaandam. Thereafter the cases in which thermal imagers prevented fire occurrence will be analysed in order to discover the situations where thermal imagers can be applicable as an additional fire prevention aid to the current fire detection system. The information received from the cases will be compared and applied for MS Zaandam. Thereafter the features and technical specifications of each camera will be compared and analysed in order to establish the best thermal solution for MS Zaandam.

In summary, all information and obtained results from theoretical framework such as the current fire detection and monitoring system, the most fire hazardous places on board of the ships, the cases in which thermal imagers prevented fire occurrence will be analysed and compared with each other and will be applied to the present situation of MS Zaandam.

The assembled information will hopefully give a proper answer to the main research question.

3.2. Limitations of the research

Due to the time limit, some of the topics will not be taken into account in this research.

- Connection of the cameras to the general fire alarm system
- Wiring for the cameras
- Software description, installation, right settings
- Right set up parameters for thermal imagers (emissivity, set point temperatures…)
- The prices of the cameras

4. Results

This chapter contains an investigation of probable fire hazardous areas on board of MS Zaandam for possible fire risks, a description of possible fire causes in fire hazardous areas and analysis of the applicability of thermal imaging cameras as an additional aid to the current fire detection system in some certain situations and as last the exact location where thermal imaging cameras can be installed in order to reduce the fire risk and the most applicable thermal imaging cameras for MS Zaandam

4.1. Investigation of probable fire hazardous areas on board of MS Zaandam for possible fire risks and assembling as much as possible information about these fire hazardous areas.

4.1.1. General overview of fire hazardous areas on board of MS Zaandam

From the analysis from the chapter two follows that the fire accidents on board of cruise ships were occurred due to the following circumstances:

- Some of the fires were caused by fuel oil, thermal oil, hydraulic oil spraying onto the hot parts of the machineries.
- Another big part of the fire accidents was caused by the major electrical failures
- Two fires were caused by thermal oil leakage into the burner furnace
- Another three fire accidents were occurred in the galleys and all three were caused by overheating of the cooking fat in the fryers.

For more information, please refer to the paragraph 2.6 “Passenger ship fires over the last 20 years”

Fires that were caused by the fuel oil, thermal oil, hydraulic oil spraying onto the hot parts of the machineries.

By applying these circumstances to the present situation on board of MS Zaandam it follows that in the following location this can happen:

- Purifier room
- Diesel generator compartment
- Emergency generator room
- Boiler room
- Incinerator room

Fires that were caused by the major electrical failures.

By applying these circumstances to the present situation on board of MS Zaandam it follows that in the following location this can happen:

- Bow thruster and stern thruster room
- Propulsion electric motor room
- Switchboard room (6.6 kV and 440 V)
- Emergency switchboard room
- Electrical substations
- Synchronous generators
- Battery room

Fires that were caused by the thermal oil leakage into the burner furnace.

By applying these circumstances to present situation on board of MS Zaandam it follows that there is no presence of thermal oil in the engine room. It means that this circumstance will not be taken into account due to the irrelevancy for this research.

Fire accidents that were caused by overheating of the cooking fat in the fryers.

By applying these circumstances to the present situation on board of MS Zaandam it follows that in the following locations this can happen:

- Crew galley
- Main galley

From the analysis from the chapter two follows as well that two fire accidents on board of cruise ships were caused in the laundries, however the sources of the ignitions are unknown. Totally there are two laundries on board of MS Zaandam, namely crew laundry and the main laundry.

There were no cases found in the analysis from the chapter two about the fire occurrences in the following area:

- Paint locker

However, this area should be considered as a fire hazardous areas on board of MS Zaandam due to the presence of the fire hazardous liquids and other stuff inside. Further in this chapter more information can be found about this area.

From the analysis from the chapter two follows that some fire accidents were occurred in the accommodation in the following areas:

- crew cabin
- ship's photographer shop
- electrical locker
- aft mooring deck
- External balcony

The origin of these ignitions is pretty much the same, all fires were caused by the electrical issues or by irresponsible human activities.

4.1.2. Fire hazardous areas in the engine room and investigation of the possible fire causes.

After applying the circumstances within the fire accidents were occurred on board of other cruise ships to the current situation on board of MS Zaandam and after an investigation around the engine room, it follows that the following places can be considered as the fire hazardous areas in the engine room of MS Zaandam:

- Boiler room
- Incinerator room
- Purifier room
- Diesel generator compartments
- Bow thruster and stern thruster room
- Propulsion electric motor room
- Switchboard room (6.6 kV and 440 V)

- Transformer rooms

Consequently, these areas would be mainly considered as a potential place where thermal imagers can be used as an additional value to the current fire detection systems on board of MS Zaandam. Further in this chapter, more information can be found about every fire hazardous area. Before establishing the places where thermal imagers can be installed as an additional value to the current fire detection systems, it is important to know what are the possibilities of the fire occurrence in these area. Also, it is important to know by which activities can the fire be occurred in one of the fire hazardous areas. Therefore, the areas where fire can be caused by fuel oil sprays onto the hot parts of the machineries will be investigated with thermal imaging camera on board for the presence of the hot spots and the hottest temperatures around and current fire detection and prevention systems. Areas where major electrical failures can cause fire will be investigated for any additional value of thermal imaging camera to the present fire detection system. This will be done by collecting as much as possible information about these electrical systems.

4.1.2.1. Boiler room, purifier room, diesel generators, incinerator room, emergency diesel generator room

Boiler room

In the boiler room on board of MS Zaandam there are two steam boilers installed, so there is no presence of thermal oil at all, therefore, the circumstances within the fire accidents were occurred in the boiler rooms on board of other cruise ships cannot be applied and compared with the present situation on board of MS Zaandam. However, the burners of the steam boilers operate on diesel oil and heavy fuel oil. The supply temperature of diesel oil to the burners is around 60°C and supply temperature of heavy fuel oil is around 90°C at a pressure of 3 bar. As already mentioned above the third fire accident was caused by the hot thermal oil sprays onto the hot surface. It can happen that instead of thermal oil, diesel oil or heavy fuel oil will spray onto the hot surface area, will turn into the mist and will cause the ignition.

In order to establish the risk of fire occurrence it is important to know the surface temperatures around the burners.

The temperature of the casing of an electric motor is around 90°C. The highest temperature around the burners is 173°C. The temperatures of the fuel supply lines to the burners are around 90°C (depending on the fuel). The temperature of the burner's hatch cover is around 90°C (see figures 15 and 16).

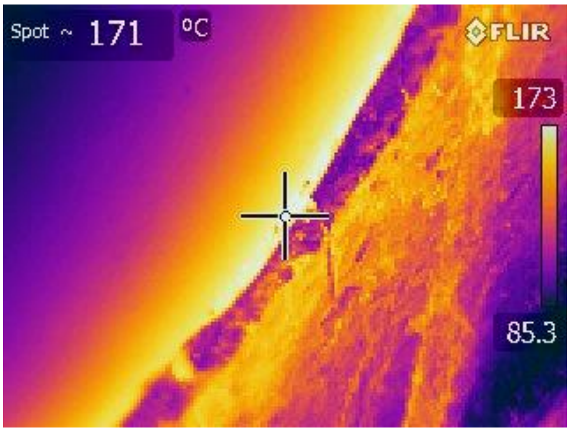

Figure 15: Highest temperature around the burner

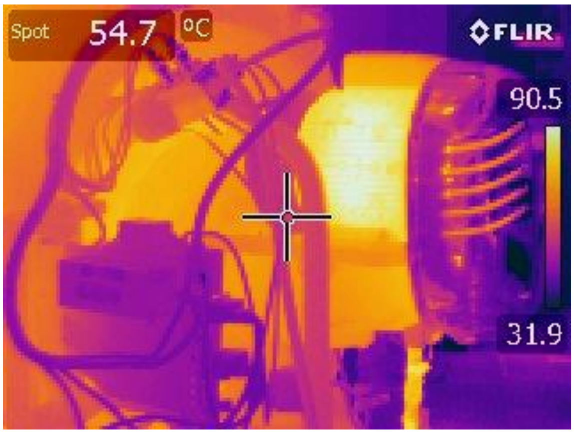

Figure 16: Temperature of the motor casing

The following fire detection system is installed in the boiler room on board of MS Zaandam:

- Two CCTV cameras in front of each oil fired burner (two boilers installed in the engine room)
- Two flame detectors in front of each oil fired burner
- High fog release system
- Three LAS detectors around the boilers

Purifier room

Totally there are nine purifiers installed on board of MS Zaandam: five Lub. oil purifiers, three fuel oil purifiers and one diesel oil purifier. Each purifier has a steam heater. Before entering the purifier, the product should be heated up till the optimal temperature. The average temperature of heavy fuel oil and lub oil after the steam heaters is around 95°C. The average temperature of marine diesel oil is around 50°C.

As already said before, the biggest risk of fire are the sprays of fuel oil onto the hot parts of the machineries. In order to establish the risk of the fire occurrence it is important to know

the surface temperatures around the purifiers.

The average supply temperatures of HFO and lub oil to the purifiers and discharge temperature from the purifiers are around 95 to 100°C. The hottest parts around the purifiers are the steam supply lines to the heater (146°C) and condensate traps (156°C). The average bowl temperature is around 85°C (see figures 17 and 18)

The following fire detection system is installed in the purifier room:

- Two CCTV cameras (at the entrance and at the end of the room)
- Two flame detectors (same position as CCTV cameras)
- High fog release system
- Four LAS detectors

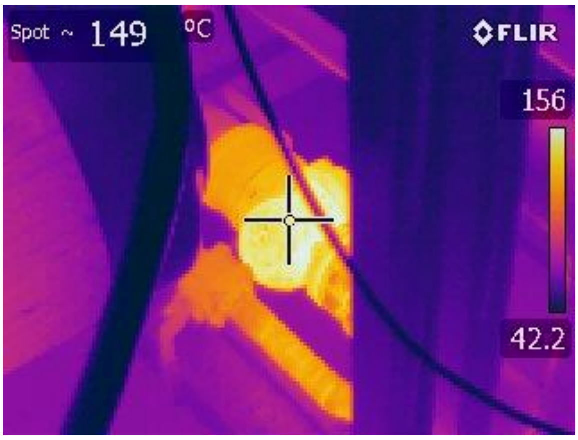

Figure 17: The temperature of the steam trap

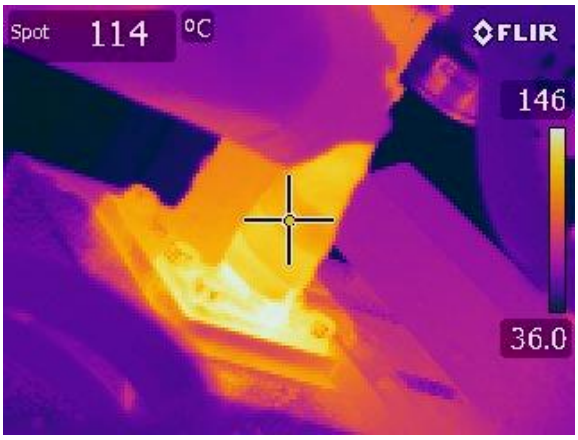

Figure 18: The temperature of the steam supply line to the heater

Beside the purifiers, there are two marine diesel oil/heavy fuel booster units installed in the purifier room. The possibility of heavy fuel leakage or marine diesel oil leakage onto the hot parts is high. After investigation with FLIR thermal imaging camera on board, it seems that the temperatures at some areas around the booster units are high. The surface temperature of a steam trap is 138°C and surface temperature of a booster pump is 139°C (see figures 19 and 20).

Figure 19: Temperature of the steam trap

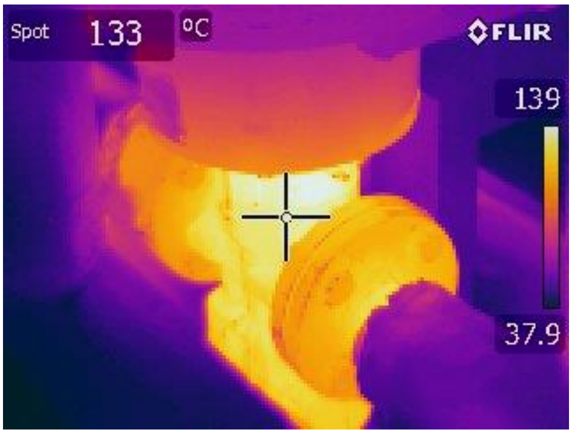

Figure 20: Temperature of the booster pump

Diesel generators

According to analysis from chapter two, eight fire accidents occurred on diesel generators. All of them were caused by fuel oil leakage onto the hot parts. Totally there are five diesel generators installed in the engine room. Three of them are installed in aft engine room and the last two in the forward engine room. All diesel generators are similar, therefore only one diesel generator will be observed in this research.

The pictures below represent the hotspots around diesel generator discovered by thermal imaging camera on board.

The one of the hottest places around the engine is duplex filter, the maximal temperature is 133°C. The average temperature of the engine casing is around 72°C. Another spot just beside the fuel supply line was found around 140°C. The maximal temperature around the cylinder heads is 191°C.

Totally two hotspots were found with thermal imaging camera. One is 234°C and another one is 301°C.

The heavy fuel oil supply temperature is around 110°C at an average pressure of 10 bar.

Figure 21: Hotspot near turbocharger

Figure 22: Hotspot near turbochargers

The following fire detection system is installed in the diesel generator compartments:

- One flame detector (in front of each diesel generator), so totally five
- Four CCTV cameras (in front of each diesel generator), so totally twenty
- High fog release system

- One smoke detector (above each diesel generator), so totally five
- Totally eleven LAS detectors in both diesel generator compartments

Incinerator room

MS Zaandam has the incinerator installed in the engine room and it is used to burn the garbage. There are two burners installed, namely primary burner and secondary burner. The primary burner keeps the temperature inside the incinerator around 725-900°C and secondary burner around 850-900°C. The burners operate on diesel oil. The average supply temperature of diesel oil to the burners is 50°C at a pressure of 3 bar.

There were no fire accident cases found in the incinerator room on board of other cruise ships. However, after a conversation with Chief engineer, it seems that in the past they had several fire occurrences in the incinerator room. All of them were caused by human's fault. For instance, somebody closed the hatch cover from the top not properly, it allowed the heat to release from the incinerator and ignite the objects in the vicinity. Another danger of incinerator are the burners. Both of them operate of diesel oil. Due to the high temperatures around the diesel supply lines, this area can be considered as a fire hazardous area.

The pictures below represent the hotspots around incinerator discovered by thermal imaging camera on board.

The average casing temperature is around 100°C. The temperature around the burners is around 120°C. Totally three hotspots were found with thermal imaging camera. One is 232°C, another one is 262°C and the last one is around 273°C (see figures 23 and 24).

Figure 23: Hotspot near the hatch cover

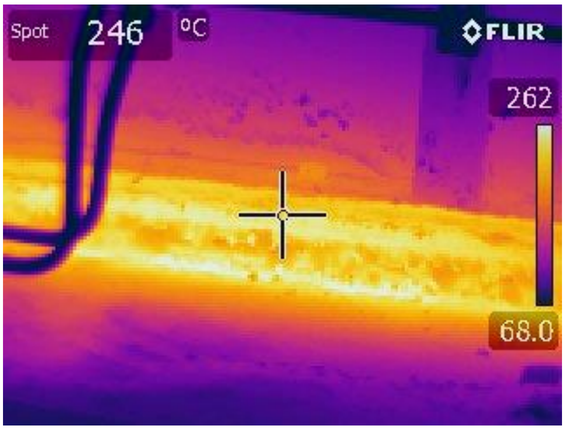

Figure 24: Hotspot near the secondary burner

The following fire detection system is installed in the incinerator room:

- Four CCTV cameras
- Two flame detectors
- High fog release system
- One LAS detector

Emergency diesel generator

As already said before the biggest risk of fire are the sprays of the fuel oil onto the hot parts of the diesel engines. In order to establish the possibility of the fire occurrence in the emergency diesel generator room, it is important to know what are the surface temperatures around the engines.

The pictures below represent the hotspots around emergency diesel generator discovered by thermal imaging camera on board.

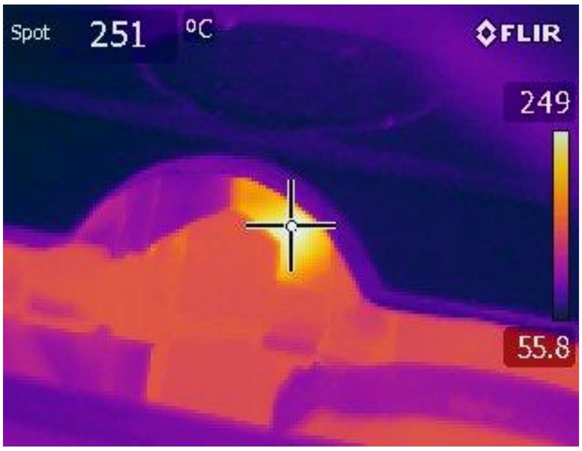

Figure 25: Hotspot between cylinders

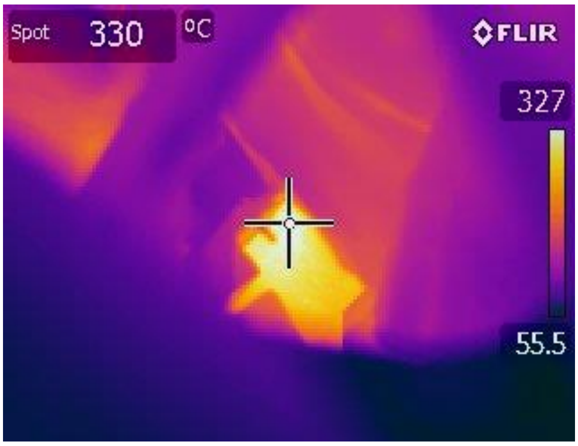

Figure 26: Hotspot between cylinders

The average temperature around the emergency diesel generator is $90^{O}C$. The average temperature on the filters is around 92 -$93^{O}C$. However, there were two hotspots found between the cylinders. One is $249^{O}C$ and another one is $327^{O}C$

Once a week the engineers test the emergency diesel generator for about 30 minutes under a supervision to reinsure that everything works properly. For the rest of the time the emergency diesel generator is not running.

The following fire detection system is installed in the emergency generator room:

- One CCTV camera
- One smoke detector
- One flame detector
- One LAS detector

Summary

According to International Convention for the Safety of Life at Sea (SOLAS), the maximum surface temperature of machinery, parts and components in a vessel's engine room should not rise above 220°C. In order to avoid ignition and fire development, all surfaces above 220°C are to be insulated and protected. After investigation with FLIR thermal imaging camera it follows that no temperatures above 220ºC were find in the boiler room and purifier room. It means that in case of a fuel oil spray onto the hot parts around the burners, the risk of ignition is present, but is quite low.

After investigation with FLIR thermal imaging camera two hotspots were found around diesel generator, incinerator and emergency diesel generator. It means that in case of a fuel oil spray or leak onto the hot parts of the machineries, the risk of ignition is present and the risk is high.

After a conversation with Chief engineer, it seems that over the las 15 years the fire has never been occurred in these areas.

For more information about the CCTV cameras, flame detectors and smoke detectors please refer to chapter 2.4.3. "Additional value of thermal imaging to the conventional fire detections systems." For more information about high fog release system and LAS detectors see chapter 2.2.2. "Fire prevention and detection system overview installed in the engine room on board of MS Zaandam"

4.1.2.2. Main Switchboard and Main Switch board room (6.6 kV)

The output from the main diesel generators is routed through a 6.6 kV switchboard room, which is located on the B - deck level of the engine room. The main switchboard room contains 6.6 kV and 440 V switchboards and their associated bus bars, control and protection switchgear. Step-down transformers are located in a special transformer rooms located on B deck in the engine room.

The voltage produced by the diesel generators is connected to the 6.6 kV bus bars through five gas-filled (SF6) circuit breakers. The bus bars are in two parts, interconnected by a bus-tie breaker, with diesel generators 1,2, and 3 connected to one side, and diesel generators 4, and 5 connected to the other side. The 6.6 kV bus bars are connected, by similar gas-filled circuit breakers, to the 6.6 kV consumers such as the cyclo-converters for the propulsion electric motors, the stern and bow thrusters, the air conditioning compressors, and the transformers. Under normal conditions, the system is operated with the bus-tie breaker closed. This effectively forms a single bus bar that receives all the incoming power and feeds all the outgoing consumers.

According to the analysis from the chapter two, there were four fire accidents related to the main switchboard failures. Two of them were caused by the failure of the main circuit breaker for diesel generators.

The circuit breakers on board of MS Zaandam safely allows the diesel generators to electrically connect to, or disconnect from, the bus bars. It contains spring-activated moving and fixed contacts, and the mechanical linkages, cams, and levers associated with the operating mechanism. To suppress the considerable electric arc produced by opening the contacts, all the breaking parts of the circuit breaker are enclosed within a hermetically sealed epoxy-resin chamber, containing pressurized sulphur hexachloride (SF6) gas.

Three sets of poles connect the generated three-phase voltage of each diesel generator, with the three phases of the (live) bus bars. In this circuit breaker design, the three poles are housed in a single epoxyresin case that contains pressurized SF6 gas. Each pole assembly contains the fixed, main, and arcing contacts, along with their mechanical operating elements. The arcing contacts are enclosed in arcing chambers.

Each circuit breaker is mounted on rails and can be withdrawn from, or inserted into, the bus bars by a rack and pinion arrangement. Safety interlocks prevent breaker closure if there is a loss of SF6 gas charge along with connections to the engine-room alarm and monitoring system. On the front panel, a pressure gauge indicates the SF6 charge and a mechanical counter records cycles of operation.

The diesel generator circuit breakers on board of MS Zaandam are designed with a breaking capacity of 12.5 kA and a short time withstand current rating of 14.5 kA for three seconds. This is more than 10 times the normal rated current of 1.25 kA, giving the protection relays sufficient time to interrupt the circuit. Similarly, the bus-tie breaker has a breaking capacity of 31.5 kA.

Main Circuit Breaker Electrical Characteristics

- Rated voltage – 12 kV
- Rated normal current – 1.25 kA
- Rated breaking capacity (at 12 kV) – 12.5 kA
- Short-time withstand current (3 s) – 14.5 kA

The main circuit breaker has the following protection relays connected to its trip and lock-out relay:

- Generator differential

- Over-temperature
- Thermal image and inverse time negative over-current
- Voltage restrained over-current
- Reverse power
- Loss of excitation
- Earth fault over-voltage
- AC over-voltage
- Earth fault directional
- Automatic voltage regulator failure

Electrical characteristics of bus-tie breaker:

- Rated voltage – 12 kV
- Rated normal current – 3.15 kA
- Rated breaking capacity (at 12kV) – 31.5 kA
- Short-time withstand current (3 s) – 31.5 kA

The bus-tie breaker has the following protection relays connected to its trip and lock-out relay:

- AC over-voltage
- Voltage restrained over-current

In addition to that, all main circuit breakers and bus-tie breaker are equipped with the flam eyes. In case of any abnormal events, the flam eyes can detect any flashes inside the switchboards and initiate the electrical power breakdown to minimized the damage as much as possible.

The engineers can monitor the status of the main switchboard in the engine control room. The ABB system provide a good overview of all electrical circuit breakers. In case of something abnormal happened to the one of the breakers, the system will immediately sound an alarm (circuit breaker trip). So, this will inform the engineers that there is something wrong with one of the breaker.

Usually, diesel generators circuit breakers are more dangerous than other circuit breakers. For instance, transformer circuit breakers stay always in a closed position, meanwhile diesel generator circuit breakers are constantly in operation. The most dangerous moment when explosion can occur is during the opening or closing of the circuit breaker.

The switchboard room is equipped with one CCTV camera and two smoke detectors.

There were no fire accidents found about the catastrophic failures of the 440 V circuit breakers on board of other cruise ships. After a conversation with Chief Electrician, it seems that 440 V circuit breakers are less fire hazardous comparing with the main 6,6 kV circuit breakers because they always stay in closed position and the voltage is much lower comparing with the high voltage switchboard.

Another two fire accidents related to the switchboard failures are caused by the human's fault. The first one happened in 1999 on board of MV Pride of Le Havre. The two leads connected to the test meter used by the electro-technical officer were both black, and understood to be entangled with each other. This made it difficult to separate out the ends of individual leads and increased the risk of a mistake being made. The second fire accident occurred in 2000 on board of MS Columbia. The fire was caused by a faulty connection or by a conductive object within the switchboard.

4.1.2.3. Bow thrusters, stern thrusters, synchronous generators, main propulsion electric motors, step down transformers.

According to the analysis from the chapter two, one fire accident occurred on board of MS Columbia due to the breakdown of the wiring insulation in one of the synchronous generators.

"An electrical event or events, caused aging or hard spots in at least one of the windings near the bottom of the generator. This caused a short between turns which increased the current in that coil. The heat was eventually enough to cause additional turns to become shorted and then to start the melting process in the winding. As the molten copper started to flow, it shorted windings phase to phase, and the event quickly became a catastrophic failure" (National Transportation Safety Board , 2003)

It means that the same electrical event can cause the fire on one of the synchronous and asynchronous high voltage induction motors or transformers installed on board of MS Zaandam.

MS Zaandam has two bow thruster and two stern thrusters. The bow thrusters and stern thrusters are equipped with two asynchronous induction motors of 1900 kW. All four motors are feed by a high voltage electrical line of 6600 Volt. The electrical currents inside are very high (201.3 Ampere).

Two smoke detectors are installed in the bow thruster room and stern thruster room.

MS Zaandam has a diesel electric propulsion system. In the propulsion electric motor room there are two big synchronous electro motors of 2x6500 kW each, and they act as the main propulsion of the ship. Both motors are feed by a high voltage electrical line of 2x1700 V each. The electrical currents inside are very high (2x250 Ampere each motor). Inside this compartment there are also four big high voltage transformers. They reduce the voltage from 6600 Volt to 1800 Volt in order to feed the electrical motors with the appropriate voltage.

The following fire detection system is installed in the P.E.M. room:

- Two Flame detectors
- Two CCTV cameras
- Two smoke detectors

MS Zaandam has five synchronous generators of 10500kVA in the engine room. The output voltage of the generators is 6,6 kV.

Totally there are 7 stepdown transformers installed on board of MS Zaandam. Two main 6,6 kV/440 V transformers and five 6,6 kV/440 V transformers are installed in the five different electrical substations.

Every electrical substation has same fire monitoring system, namely two smoke detectors.

Main transformer rooms are equipped with one smoke detector.

For more information about CCTV cameras, flame detectors and smoke detectors please refer to the chapter 2.4.3. "Additional value of thermal imaging to the conventional fire detections systems."

Bow thruster's asynchronous induction motors, stern thruster's asynchronous induction motors, all step down transformers, main propulsion synchronous induction motors, all synchronous generators are equipped with the phases temperature indications and alarms. So, during the manoeuvrings or just in normal days the engineers can monitor the temperatures of each motor from engine control room and in case of any abnormal temperature differences on one of the high voltage machinery, engineers can directly establish it and switch it off before catastrophic failure occurs. Also, each asynchronous induction motor, step down transformer and synchronous generator is equipped with cooling air temperature sensors. Any abnormal electrical event affects cooling air temperature in a negative way. So, in case of abnormal temperature increasing on one of the coolers, engineers can establish it and switch a high voltage machinery off before a catastrophic failure occurs. For instance, a malfunction such as a short circuit, in a connected component can cause an increasing in electrical current flow. This can result in internal temperature increasing. Extreme high temperatures can damage the copper conductors or their own insulation. There is an additional safety system installed on the generators. If the temperature of the windings gets higher than 130ºC, the circuit breaker will immediately disconnect from the main bus bar in the main 6,6 kV switchboard.

After a conversation with Chief Engineer, it seems that over the last 15 years, they never had a fire on transformers, synchronous and asynchronous induction motors. All these transformers, synchronous and asynchronous machineries are equipped with the temperature sensors and alarms. It means that the risk of fire on these machineries is present, but the risk is minimal.

4.1.3. fire hazardous areas in the accommodation and investigation of possible fire causes.

4.1.3.1. Paint locker

There were no cases found in the analysis from the chapter two about the fire occurrences in the paint locker, however this area can be considered as a fire hazardous area due to presence of flammable liquids, various types of chemicals and paints inside.

Fire in the paint locker can be caused by poor storage of chemicals or paints resulting in mixing of flammable liquids. Chemical reaction between flammable liquids can cause ignition.

There is only one smoke detector installed in the paint locker, also, the paint locker is equipped with CO_2 release system.

After a conversation with Master, it seems that over the last 15 years, the fire has never been occurred in the paint locker on board of MS Zaandam

4.1.3.2. Battery room

According to the analysis from the chapter two, one fire accident occurred in the battery room on board of MS Amsterdam. The probable cause of the fire is one of the battery failure.

"The most likely cause of the incident is that one battery was failing, and as its impedance increased, the battery drew more and more current until it overheated. The battery most likely began to overheat during testing of the emergency diesel generator. The emergency diesel generator had been tested on load, and to test automatic starting, power to the emergency switchboard was interrupted. During the 30- second delay before the emergency diesel generator reconnected to the switchboard, the batteries were discharging. After the emergency diesel generator test, power to the emergency switchboard was re-established, and the batteries would have had an increased charging rate, and with the increased impedance of the involved battery, it probably overheated and exploded" (Holland America Line, 2016)

It means that the same electrical event can occur on board of MS Zaandam.

There is one battery room on board of MS Zaandam, the batteries supply 220 V consumers in case of blackout.

There are two smoke detectors installed in the battery room. For more information about the smoke detectors please refer to the chapter 2.4.3. “Additional value of thermal imaging to the conventional fire detections systems.”

MS Amsterdam is sister ship of MS Zaandam and the fire accident occurred recently, it means that the risk of a fire accident in the battery room on board of MS Zaandam is certainly present.

4.1.3.3. Miscellaneous areas

Analysis shows that fire accidents were occurred in the passenger areas such as shops, passenger cabins, balconies and other recreation areas. The causes of the fire accidents were mainly the same. The fires were caused by the electrical issues or by irresponsible human activities. Every single area is equipped with the electrical components such as lights, electrical suckers, TV’s, electrical extension cables... All these electrical components are fire hazardous and they can cause the ignition at any time. It is very difficult to predict where and when the fire will occur, therefore, these areas will not be taken into account for the further research. Also, after a conversation with the captain it seems that during the last 15 years they never had a fire in the passenger areas. All passenger areas are equipped with the smoke detectors and heat detectors.

4.1.3.4. Galleys

Totally there are two galleys on board: the crew galley and the main galley. According to the analysis form the chapter two, the galleys are fire hazardous places on board. Totally there are three fire accident reports found. All fires in the galleys were caused by the deep fat fryers.

From the analysis from the chapter two it follows that the fires in the galleys were occurred on board of the following ships: MS Edinsburg Castle, MS Ryndam, MV Majesty of the Seas.

MS Edinburg Castle

Fire occurred in the main galley. The fire was caused by overheating of the cooking fat in the fryers, this resulted in ignition.

The power contactor of one deep fat fryer had welded closed. This prevented interruption of power as the fats temperature increased.

MS Ryndam

The fire occurred in the galley. The fire was caused by the deep fat fryer.

“An Executive Chef asked an Assistant Cook to drain the deep fat fryer in the main galley in preparing for cleaning. The Assistant Cook turned off the unit, waited 30 minutes for the oil to cool, drained and stored the used cooking oil, and then left the area. About three and a half hours later other galley crew arrived to clean the unit and saw a small fire un the fryer well. They immediately alerted the bridge, and then verified that they fryer was switched off, covered it with a fire blanket, and placed a metal lid over it. No smoke detectors arrived. When the Safety Officer arrived, he isolated power to the fryer and used CO_2 extinguisher to put out the fire.” (Holland America Line, 2016)

MV Majesty of the Seas

The fire occurred in the galley. The fire was caused by overheating of the cooking fat in the fryers, this resulted in ignition.

According to the analysis, the deep fat fryers are the most dangerous units installed in the galleys. It means that the same event can occur in one of the galleys on board of MS Zaandam.

Before taking any conclusions it is important to investigate every galley for the current fire detection systems and the present equipment.

The main galley is equipped with one deep fryer, five ovens and five cooking plates.

There are four CCTV cameras installed in the hot galley. All of them are pointed to the most fire hazardous places namely, the cooking plates and the deep fat fryer.

Totally, there are 25 smoke detectors and 11 heat detectors installed around the main galley. At every exit of the main galley there is an emergency push bottom installed. The purpose of this bottom is in case of a fire, the galley team can activate it and generate an electrical shutdown to minimise any further damage. Also, the deep fat fryer is equipped with a special sprinkler system. In case of a fire, the galley team can activate it and generate a chemical release to the deep fat fryer. All main galley exhaust ducts are equipped with a special sprinkler system as well. In case of a fire in the main galley, the team can activate this system and generate a release of water mixed with special chemicals to minimise any further damage.

The main galley is 24 hours manned, there are two teams in service, namely the day team and the night team. It is very important information, because mostly of the time the fire occurs when nobody is around to take early actions to avoid or minimise the damage that can be caused by the fire.

The crew galley is much smaller that the main galley. There are two smoke and heat detectors installed, in addition to that there is one CCTV cameras pointed to the hot area (hot galley). Same as in the main galley, there is an emergency electrical shutdown push bottom installed at the exit of the crew galley. The deep fat fryer and all exhaust ducts are equipped with a sprinkler system.

The crew galley is manned only during the day. After a conversation with Master, it seems that over the last 15 years, they never had a fire in the galleys.

4.1.3.5. The Laundry

MS Ecstasy

The fire occurred on the aft mooring deck. The fire was caused by the unauthorized welding by crewmember in the main laundry that ignited a large accumulation of lint in the ventilation system and the failure of Carnival Cruise Lines to maintain the laundry exhaust ducts in a fire-safe condition.

"Contributing the extensive fire damage on the ship was the lack of an automatic fire suppression system on the aft mooring deck and the lack of an automatic means of mitigating the spread of smoke and fire through the ventilation ducts" (NATIONAL TRANSPORTATION SAFETY BOARD, 1998)

MS Vistafjord

Fire occurred in the laundry storeroom.

"The possible ignition sources for the fire in the laundry storeroom included the electrical detergent pump-dispenser panels, the electrical distribution panels, discarded tobacco-related smoking materials, and a deliberate act." (MAIB, 2015)

One fire accident was caused by the human's fault. The cause of the second fire us unknown, probably the fire was caused by the electrical issues or a deliberate act.

On board of MS Zaandam there are two laundries: the crew laundry and the main laundry. According to the analysis form the chapter two, fire accidents still happen in this area. One fire accident was caused by the human's fault. The cause of the second fire us unknown, probably the fire was caused by the electrical issues or a deliberate act. It is difficult to predict where is the source of ignition and in which circumstances can the thermal imaging camera be applicable as an additional aid to the current fire detection systems.

The following fire detection systems are installed in the main laundry

- 4 smoke detectors in the dry cleaning room
- 4 smoke detectors in the main laundry
- 4 heat detectors in the main laundry

There are two smoke detectors installed in the crew laundry

After a conversation with the Master it seems that over the 15 years they never had a fire in the crew laundry and main laundry.

The main laundry is 24 hours manned, there are two teams in service, namely the day team and the night team. It is very important information, because mostly of the time the fire occurs when nobody is around to take any early actions to avoid or minimise the damage that can be caused by the fire.

4.1.3.6. Aft and forward mooring decks

MS Grandeur of the Seas

The fire occurred in the centre portion of the aft mooring area on deck 3. The exactly reason is unknown.

"Although a forensic fire investigation was carried out, the source of the ignition or the material that was initially ignited has not been established. The suggestions that a cigarette end discarded from an adjacent or upper deck ignited stored rags or mooring rope, or self-ignition of rags (such as oiled towels discarded from the spa), or an electrical fault may have been the root cause are speculative." (Bahamas Maritime Authority, 2013)

The fire detection system in the aft mooring deck on board of MS Grandeur of the Seas were the CCTV cameras only.

It is possible that the same event can happen on board of MS Zaandam. For instance, somebody will throw a cigarette end on the mooring lines and will leave the area or something else will cause the ignition of the mooring lines.

In the forward mooring deck there are four mooring winches installed. Mooring lines are rolled over these four winches. Also, there are two places where the additional mooring lines are stored. Above every winch and storage place there is a heat detector installed. The position of the heat detector is very close to the mooring lines in order to detect the abnormal heat and give the alarm at the early stage of fire (see figures 27 and 28). Totally there are 7 heat detectors installed in the forward mooring deck. Also, there are 5 CCTV cameras installed, but the main purpose of these cameras is to provide a security supervision.

In the aft mooring deck there are three mooring winches installed. Same as forward. Mooring lines are rolled over these three winches. Also, there are two places where the additional mooring lines are stored. Above every winch and storage place there is a heat detector installed. The position of the heat detector is very close to the mooring lines in order to detect the abnormal heat and give the alarm at the early stage of fire. Totally there are 6 heat detectors installed in the aft mooring deck. Also, there are 9 CCTV cameras installed, but the main purpose of these cameras is to provide a security supervision.

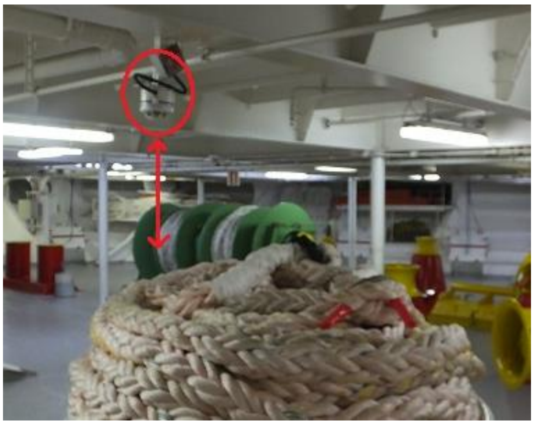

Figure 27: Position of the heat detector to the mooring lines

Figure 28: Position of the heat detectors to the mooring winches

4.2. Description of the possible fire causes in fire hazardous areas and analysis of the applicability of thermal imaging cameras as an additional aid to the current fire detection system in some certain situations.

The following causes of the fire accidents were found during the analysis from the chapter two:

- 15 fires were caused by fuel oil, thermal oil, hydraulic oil spraying onto the hot parts of the machineries.
- 8 fires were caused by the electrical failures
- 2 fires were caused by thermal oil leakage into the oil heater's furnace
- 2 fire origins are unknown
- 1 fire was caused by human's fault

In summary all these circumstances can be classed in four major categories, namely oil spraying onto the hot parts of the machineries, electrical failures, humans fault and two other fire origins are unknown.

One fire was caused by the human's fault and two fires have unknown origins. These scenarios will not be taken into account for the further research.

4.2.1. Oil spraying onto the hot parts of the machineries

These scenarios can occur in the engine room in the following areas:

- Boiler room
- Incinerator room
- Purifier room
- Diesel generators compartment
- Emergency diesel generator room

All these areas have pretty much the same fire detection and prevention system, namely CCTV cameras, flame detectors, LAS detectors and high fog release system.

For more information about the CCTV cameras, flame detectors and smoke detectors please refer to chapter 2.4.3. "Additional value of thermal imaging to the conventional fire detections systems." For more information about high fog release system and LAS detectors see chapter 2.2.2. “Fire prevention and detection system overview installed in the engine room on board of MS Zaandam”

“According to International Convention for the Safety of Life at Sea (SOLAS), the maximum surface temperature of machinery, parts and components in a vessel’s engine room should not rise above 220°C. In order to avoid ignition and fire development, all surfaces above 220°C are to be insulated and protected” (IMO).

It means that in the areas where the surface temperatures exceed 220°C can lead to the fire in case of the fuel oil sprays. Therefore, it is important to investigate every area for the presence of the hotspots.

After an investigation with thermal imaging camera on board for the presence of the hotspots, it is established that the following areas are “safe”:

- Boiler room
- Purifier room

The highest surface temperatures in the boiler room are between 90°C and 173°C. As already said before, in the purifier room there are 9 purifiers installed and two fuel oil booster units. The highest surface temperatures around the purifiers are between 96°C and 156°C.

After an investigation with thermal imaging camera for the presence of the hotspots, it is established that the following areas are “fire dangerous”:

- Diesel generator compartments
- Incinerator room
- Emergency diesel generator room

The highest surface temperatures on the diesel engines are around 72°C and 301°C. Totally two hotspots were found with thermal imaging camera one is 234°C and another one is 301°C.

The highest surface temperatures on the incinerator are between 100°C and 273°C. Totally three hotspots were found with thermal imaging camera one is 262°C another one is 273°C and the last one is 232°C.

The highest surface temperatures on the emergency diesel generator are between 90 – 327°C. Totally two hotspots were found with thermal imaging camera one is 249°C and another one is 327°C

It means that the possibility of ignition it these areas is quite high.

Boiler room, purifier room, incinerator room, diesel generator compartments and emergency diesel generator room.

After investigation with thermal imaging camera on board, no surface temperatures above 220°C were found around the burners in the boiler room and in the purifier room. However, some hotspots were found on the incinerator, diesel generators and emergency diesel generator.

As already mentioned before, the average HFO supply temperature to the consumers is around 90 to 100°C and the average supply temperature of MGO is around 40 to 50°C.

The average temperature of HFO and lubricating oil is around 95 to 100°C in the purifier room.

From pictures from the paragraph "4.2.2 The fire hazardous areas in the engine room and investigation of the possibilities of the fire occurrence in these areas" it is obvious that the background temperatures on the engines, boiler burners, incinerator, purifiers and the fuel booster modules are usually much higher than the average MGO/HFO supply temperatures around. So, in case of a big fuel oil leak, the thermal imaging camera will never sound the early response alarm due to the high background temperatures. Also, the fires are usually caused by the small fuel oil sprays or fuel oil mist spraying onto the hot surface areas under a high pressure. So, it is not sure if thermal imaging camera is able to catch it up. All these areas are equipped with LAS detectors. The Leakage Alarm System is developed especially for the detection of leakages in high pressure fuel and hydraulic oil systems to avoid fire, explosion and pollution. So, this innovative fire monitoring system is much more effective for an early detection of the fuel oil sprays.

The surface temperatures in the purifier room and in the boiler room are below 220^{o}C in addition to that these areas are equipped with several fire detection systems such as: flame detectors, smoke detectors, CCTV cameras, high fog release system and LAS detectors. Therefore, the thermal imaging cameras cannot be used as an additional aid to the current fire detection systems in these areas.

The surface temperatures in the incinerator room, diesel generator compartments and emergency diesel generator room are higher than 220^{O}C, however these areas are equipped with several fire detection systems such as: flame detectors, smoke detectors, CCTV cameras, high fog release system and LAS detectors. To decrease the possibility of the fire occurrence in these areas, much cheaper and effective way is to insulate the hotspots with a designated insulation material.

4.2.2. Electrical failures

The major and catastrophic electrical failures can occur in the following areas:

- Switchboard room (6,6 kV/440 V switchboards)
- Bow thrusters and stern thrusters
- Main propulsion electric motors
- Main generators
- Main transformers, substation transformers, propulsion electric motor transformers

All these electrical machineries and installations are powered by the high voltage.

The switchboard room is equipped with one CCTV camera and two smoke detectors.

The electrical substations where transformers are installed are only equipped with the smoke detectors.

The bow and stern thruster rooms are only equipped with the smoke detectors.

Main propulsion electric motor room is equipped with two smoke detectors, two CCTV cameras and two flame detectors.

Every electrical substation has the same fire monitoring system, namely two smoke detectors. The main transformer rooms are equipped with one smoke detector.

For more information about the CCTV cameras, flame detectors and smoke detectors please refer to chapter 2.4.3. "Additional value of thermal imaging to the conventional fire detections systems."

Bow thrusters, stern thrusters, main generators, main propulsion electric motors, transformers.

According to the analysis from the chapter two, the big possibility of the fire on the bow thrusters, stern thrusters, main generators, main propulsion motors and step down transformers is a short circuit between the turns which can increase the electrical currents in the coils. The molten copper can flow and short the windings phase to phase. But as already said before every high voltage electrical machinery is equipped with the temperature sensors. The sensors are placed on every phase. So the engineers can monitor the temperatures from engine control room at all time. Also, the sensors are equipped with alarm function. So, in case of any abnormal temperature increasing on one of the windings, the sensor will give the alarm. All transformers are equipped with two air coolers on both sides. Any abnormal electrical event affects the cooling air temperature in a negative way. So, in case of the abnormal temperature increasing on one of the coolers, the engineers can establish it and switch it off before a catastrophic failure occurs.

There is no any additional value of thermal imaging camera to the current fire detection systems for these electrical high voltage systems. As already described in the chapter two, thermal imaging cameras can measure the surface temperatures only. The short circuit between the turns or windings increase the temperature of the components inside the metal casing. The temperature sensors installed on every phase and on the air coolers will detect the temperature increasing and raise the alarm much faster than thermal imaging camera. Thermal imaging camera will measure temperature of the metal casing only. It means that inside the casing the windings can be very hot due to the short circuit, but due to the bad heat exchange between the windings and casing material (the air gap is to big) thermal imaging cameras will never raise the alarm at the good time. In this case, the smoke detectors will be much faster and efficient because the burned windings will produce the smoke.

High voltage switchboard (6.6 kV)

The most dangerous parts of the main switchboard are the high voltage circuit breakers. The most dangerous circuit breakers inside the switchboard are the high voltage diesel generator circuit breakers because they are constantly in operation. The most dangerous moment when explosion can occur is during the opening or closing of the circuit breaker. For more information, please refer to the paragraph “4.3.2.1 Main Switchboard and Main Switch board room (6.6 kV)”

Thermal imaging cameras have no any additional value to the current fire detection and prevention systems. All circuit breaker inside the main switchboard are equipped with efficient condition monitoring systems. In case of any abnormal activities inside the main switchboard, the flam eyes installed in the main switchboard can immediately detect any flashes and generate an electrical power shut down to avoid any further damage. Also, the fires caused by the electrical circuit breakers are the explosions. In this case thermal imaging camera can’t provide an early response alarm.

After a conversation with Chief Electrician it seems that over 15 years the fire never has been occurred in the main switchboard room.

4.2.3. Random scenarios in the galleys, laundry, paint locker, battery room and mooring decks

4.2.3.1. Battery room

The battery room on board of MS Zaandam is equipped with two smoke detectors.

The fire incident in the battery room happened recently on board of MS Amsterdam. MS Amsterdam is a sister ship of MS Zaandam. The most probable cause which can initiate the fire in the battery room is that during the charging one of the battery can overheat and explode.

In this case a properly positioned thermal imaging camera can certainly be used as an additional value to the installed smoke detectors because the battery can overheat and thermal imaging camera can measure the surface temperature. However, the possibility of the fire occurrence in this place can be decreased by applying the proper maintenance of the batteries. For instance, the impedance meters can be used in order to test the internal conductance and resistance of the batteries. This will allow a more accurate determination of when a battery will need to be replaced. Also, a hydrogen detector can be installed inside the battery room and be connected to the automatic system to provide audible alarms that warn of atmospheric issues.

After a conversation with the Master it seems that over the 15 years they never had a fire in the battery room. It means that it is not a good idea to to buy an expensive camera for a place where the fire never occurred. Much cheaper and efficient way to reduce the batteries explosions is to provide a proper maintenance program.

4.2.3.2. Paint locker

The paint locker on board of MS Zaandam is equipped with one smoke detector and CO_2 release system. The fire in the paint locker can be caused by the poor storage of paints and chemicals. It can happen that the chemicals and paints will mix together. The chemical reaction between the flammable liquids can result into the fire. Also, the oily rags inside can ignite spontaneously. The fire in the paint locker can be caused by the cigarette ends as well. For these scenarios a proper positioned thermal imaging camera can be used as an additional value to the smoke detector because thermal imaging camera can detect the abnormal temperature increasing in the unmanned areas and sound an alarm at the good time. In the paragraph "2.5.1 Thermal imaging camera detected fire occurrence in a warehouse" there is a description of the effectivity of thermal imaging cameras in the unnamed fire hazardous areas. After a conversation with the master it seems that the fire in the paint locker on board of MS Zaandam never has been occurred. However, theoretically the possibility of ignition in the paint locker is present, therefore it is not understandable to buy an expensive camera for the place where the fire never has been occurred. There is much cheaper way to avoid ignitions in this area. For instance, by organizing the proper storage instructions for the chemicals and paints to avoid the chemical reactions between the flammable liquids, by crew trainings, by storing the oily rags in the designated metal trash been, by keeping the place nice, organized and tidy… By performing all these activities, much safer environment in the paint locker can be achieved.

4.2.3.3. Galleys

As already mentioned before there are two galleys on board of MS Zaandam, namely the main galley and the crew galley. Both galleys are equipped with pretty much the same fire detection and prevention systems, namely heat detectors, smoke detectors, CCTV cameras, emergency electrical shut down bottoms, chemical release systems, sprinkler systems. For more information about the CCTV cameras, flame detectors and smoke detectors please refer to chapter 2.4.3. "Additional value of thermal imaging to the conventional fire detections systems." From the analysis from the chapter two it follows that the deep fat fryers are the most fire hazardous installations. All fires on board of other cruise ships were caused by the overheated cooking fat in the fryers. There are several reasons behind why the fire has been occurred in the deep fat fryers. The first fire on board of MS Edinburg Castle was caused by the electrical issue; the crew was not able to switch the fat fryer off to avoid the ignition. The second fire on board of MS Ryndam was caused by the human's fault, the cleaning process has been done by the improper instructed person. The cause of the fire occurrence in the galley on board of MS Majesty of the seas is unknown.

The main and crew galleys are equipped with the emergency electrical shutdown bottoms, moreover, the main galley is 24 hours manned, therefore the fire in the main galley can directly be detected by the night team. In addition to that the deep fat fryers in both galleys are equipped with a chemical sprinkler release system. It means that in case of a fire, the galley team can activate the chemical release on the deep fat fryer and press the electrical shutdown bottom before isolating the area.

The crew galley is manned during the day only. But before leaving the galley unattended, the galley team shutdown the electrical power supply to the crew galley in order to keep the risk of fire caused by the electrical issues minimal.

It seems that thermal imaging cameras have no any additional value to the current fire detection and prevention systems in both galleys. Also, after a conversation with the Master, it seems that the fire in both galleys has never been occurred before. Therefore, it is not a good idea to buy a camera for a place where the fire has never been occurred before. To avoid fire accidents caused by the human's fault, much more effective way is to provide a better crew training (proper instruction for use of equipment, action to be taken in case of fire and other emergencies…)

4.2.3.4. Laundries

It is not clear about the fire accidents in the laundries. Totally there were three fire accidents. One of them was caused by unauthorized welding and the causes of other two fire accidents are unknown. So it is difficult to predict for which situations can thermal imagers be used as an additional value to the current fire detection means.

Laundries are equipped with the electrical machineries which can cause the fire accidents. But it is only an assumption.

The main laundry is 24 hours manned, there are two teams in service, namely the day team and the night team. It means that there is always somebody who can see the smoke or any other abnormal activities and take the preventive actions at the early stage. Also, there are emergency electrical shut down bottoms at every exit of the main laundry. After a conversation with the Master it seems that the fire has never been occurred in the main and crew laundry on board of MS Zaandam. Therefore, it is not understandable to buy an expensive camera for places where fire has never been occurred before. To avoid fires caused by the hot work, much better and cheaper way is to prepare an area for welding in order to minimise the risk of fire and establish a fire guard during the welding operations.

4.2.3.5. Aft and forward decks

According to the analysis from the chapter two, the most probable cause of the fire accident in the aft and forward mooring decks is the ignition of the mooring lines. The ignition of the mooring lines can be caused by a deliberate act, by irresponsible human acts (for instance by cigarette ends), by hot work (welding) or by abnormal electrical events. Forward and aft mooring decks are equipped with the heat detectors and CCTV cameras. Every winch and every mooring line storage area is equipped with one or more heat detectors. The heat detectors are positioned very close to the mooring lines in order to detect any abnormal heat at the early stage. A good positioned thermal imaging camera can be used as an additional aid to the current fire detection means, because the thermal imaging cameras can detect any abnormal temperature increasing at the early stage and sound an alarm. In the paragraph "2.5.1 Thermal imaging camera detected fire occurrence in a warehouse” there is a description of the effectivity of thermal imaging cameras in the unnamed fire hazardous areas. However, after a conversation with the master it seems that the fire has never been occurred before in the aft and forward mooring decks, therefore it is not understandable to buy an expensive camera for the places where the fire risk is low.

4.3. Exact location where thermal imaging cameras can be installed in order to reduce fire risk and the most applicable thermal imaging cameras for MS Zaandam

After an investigation with FLIR thermal imaging camera for the hotspots in the engine room, after assembling as much as possible information about other electrical installations installed on board of MS Zaandam, galleys, laundries, mooring decks, battery room, paint locker and after an analysis of every area for the fire detection and prevention systems, it seems that thermal imaging cameras have no additional aid to the current fire detection systems. For more information, please refer to paragraphs: 2.2.2. “Fire prevention and detection system overview installed in the engine room on board of MS Zaandam”, 4.2 “Investigation of probable fire hazardous areas on board of MS Zaandam for possible fire risks and assembling as much as possible information about these fire hazardous areas” and 4.3 “A description of possible fire causes in fire hazardous areas and analysis of applicability of thermal imaging cameras as an additional aid to the current fire detection system in some certain situations.” There are some areas such as paint locker, battery room and mooring decks where thermal imager theoretically can be used as an additional ait to the current fire detection systems, however, fire has never been occurred in these areas over the last 15 years. Therefore, it is not understandable to buy an expensive camera for these areas.

The best thermal solution for MS Zaandam and the exact location of thermal imagers in order to reduce the fire risk will not be further considered in the research due to their infectivity on board of MS Zaandam.

5. Discussion

According to the results from the chapter four, it follows that thermal imaging cameras have no additional aid to the current fire detection systems on board of MS Zaandam.

The majority of fires on board of the cruise ships were caused by the following events:

- Some of the fires were caused by fuel oil, thermal oil, hydraulic oil spraying onto the hot parts of the machineries.
- Another big part of the fire accidents was caused by the major electrical failures
- Another three fire accidents were occurred in the galleys and all three were caused by overheating of the cooking fat in the fryers

Locations where fires can be caused by fuel oil, thermal oil, hydraulic oil sprays onto the hot parts of the machineries.

- Purifier room
- Diesel generator compartment
- Emergency generator room
- Boiler room
- Incinerator room

After investigation with FLIR thermal imaging camera on board of MS Zaandam it seems that thermal imagers are not able to catch up hot oil sprays due to the high background temperatures. Supply heavy fuel oil temperature to the consumers is 90-100^{O}C and supply diesel oil temperature is around 40-50^{O}C. Usually the background temperatures are higher than 100^{O}C. For more information, please refer to the chapter 4 “Results”. Also, after investigation with FLIR thermal imaging camera there were some hotspots (temperature above 220^{O}C) found around emergency diesel generator, main engines and incinerator. But it seems that much more effective way to avoid fires caused by the oil sprays is to insulate the hot areas with a designated insulation material. In the engine room on board of MS Zaandam there are LAS detectors installed in the areas where fires can be cause by the fuel oil sprays onto the hot parts of the machineries. It seems that it is a much more effective way to avoid fires caused by the fuel oil sprays.

Locations where fires can be caused by major electrical failures.

- Bow thruster and stern thruster room
- Propulsion electric motor room
- Switchboard room (6.6 kV and 440 V)
- Emergency switchboard room
- Electrical substations
- Synchronous generators

After assembling as much as possible information about high voltage transformers and induction motors, it seems that temperature sensors installed on every phase and air coolers are more effective than thermal imaging camera because thermal imaging camera measure only the surface temperatures, therefore the response of thermal imagers probably will be slower comparing with the temperature sensors. For more information, please refer to the chapter 4 “Results”.

Main switchboard (6,6 kV)

Thermal imaging cameras have no any additional value to the current fire detection and prevention systems. All circuit breaker inside the main switchboard are equipped with efficient condition monitoring systems. In case of any abnormal activities inside the main switchboard, the flam eyes installed in the main switchboard can immediately detect any flashes and generate an electrical power shut down to avoid any further damage. Also, the fires caused by the electrical circuit breakers are the explosions. In this case thermal imaging camera can't provide an early response alarm. For more information, please refer to the chapter 4 "Results".

Locations where thermal imaging cameras can probably be used as an additional aid to the current fire detection systems.

- Paint locker
- Battery room
- Mooring decks

A good positioned thermal imaging camera(s) can be used as an additional aid to the current fire detection systems, because thermal imaging camera can detect any abnormal temperature increasing at early stage and sound an alarm. In the paragraph "2.5.1 Thermal imaging camera detected fire occurrence in a warehouse" there is a description of the effectivity of thermal imaging cameras in the unnamed fire hazardous areas. However, after a conversation with the master it seems that the fire has never been occurred before in these areas on bard of MS Zaandam, therefore it is not understandable to buy an expensive camera for the places where the fire risk is low. From the analysis from the chapter two it follows that a battery explosion occurred in the battery room on board of a sister ship MS Amsterdam. It means that the risk of fire in the battery room on board of MS Zaandam is certainly present, however there is a much cheaper and effective way to avoid fire in this location. For instance, the impedance meters can be used in order to test the internal conductance and resistance of the batteries. This will allow a more accurate determination of when a battery will need to be replaced. Also, a hydrogen detector can be installed inside the battery room and be connected to the automatic system to provide audible alarms that warn of atmospheric issues.

Location where fire can be caused by the deep fat fryer

- Crew galley
- Main galley

For more information, please refer to the chapter 4 "Results". There is an extended explanation why thermal imager cannot be used as an additional aid to the current fire detection systems.

6. Conclusion

The main research question is as follows:

Can thermal imaging camera be used on board of MS Zaandam as an additional value to the current fire detection systems?

According to the results from the chapter four, it follows that thermal imaging cameras have no additional aid to the current fire detection systems on board of MS Zaandam.

To be more specified, during investigation there were some locations found where thermal imaging cameras can be used as an additional aid, however risk of fire in these locations is low, therefore the current fire detections systems installed in these locations are efficient enough.

Locations where thermal imaging cameras can probably be used as an additional aid to the current fire detection systems.

- Paint locker
- Battery room
- Mooring decks

A good positioned thermal imaging camera(s) can be used as an additional aid to the current fire detection systems, because thermal imaging camera can detect any abnormal temperature increasing at early stage and sound an alarm. In the paragraph "2.5.1 Thermal imaging camera detected fire occurrence in a warehouse" there is a description of the effectivity of thermal imaging cameras in the unnamed fire hazardous areas. However, after a conversation with master it seems that fire has never been occurred before in these areas on bard of MS Zaandam, therefore it is not understandable to buy an expensive camera for the places where fire risk is low.

From analysis from chapter two it follows that a battery explosion occurred in the battery room on board of a sister ship MS Amsterdam. It means that the risk of fire in the battery room on board of MS Zaandam is certainly present, however there is a much cheaper and effective way to avoid fire in this location. For instance, the impedance meters can be used in order to test the internal conductance and resistance of the batteries. This will allow a more accurate determination of when a battery will need to be replaced. Also, a hydrogen detector can be installed inside the battery room and be connected to the automatic system to provide audible alarms that warn of atmospheric issues.

Bibliography

Australian Transport Safety Bureau. (2011). *Independent investigation onto the fire and muster of the passengers board the Australian flag passeger ferry.* Australian Transport Safety Bureau.

Bahamas Maritime Authority. (2013). *Joint report of the investigation into an engine room fire CARNIVAL TRIUMPH.* Bahamas Maritime Authority.

Bahamas Maritime Authority. (2013). *Report of the investigation into a fire at sea Grandeur of the Seas.* Bahamas Maritime Authority.

Century fire and security. (2016, 07 08). *Fire Alarm Systems*. Retrieved from Century fire and security: http://www.centuryfireandsecurity.co.uk/fire-detection-prevention/fire-alarm-systems/

Cruisecritic. (2004, 02 5). *Majesty of the Seas Experiences Minor Fire*. Retrieved from Cruisecritic: http://www.cruisecritic.com/news/news.cfm?ID=1052

Cruiseminus. (2009, 02 25). *Costa neoRomantica*. Retrieved from Cruiseminus: http://www.cruiseminus.com/costa-neoromantica/

Energypedia. (2014, 10 7). *Infrared Thermography and Energy Efficiency* . Retrieved from Energypedia: https://energypedia.info/wiki/Infrared_Thermography_and_Energy_Efficiency#Disadvantages

Field's Fire Protection. (2015, 12 22). *Fire Alarm Systems*. Retrieved from Field's Fire Protection: http://www.fieldsfire.com/fire-alarm-systems

FLIR. (2015, 12 29). *Thermal imaging camera keeps fire risk under control in coal pile storage site*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=43078

FLIR. (2015, 12 22). *Thermal imaging cameras for warehouse asset protection*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=41992

FLIR. (2015, 12 28). *Thermal imaging cameras help prevent fires in waste incineration plants*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=64578

FLIR. (2015, 12 28). *Thermal imaging cameras prevent fires at Korean coal power plant*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=54341

FLIR. (2015, 12 29). *Thermal imaging cameras protect electrical substation in Stavanger, Norway*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=57081

FLIR. (2015, 11 28). *Thermal imaging warning system helps ensure the safety at Transpole*. Retrieved from FLIR: http://www.flir.co.uk/automation/display/?id=52283

FLIR. (2016, 01 11). *FLIR A310*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=41099

FLIR. (2016, 01 11). *FLIR A310 ex*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=63398

FLIR. (2016, 01 11). *FLIR A310 f*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=67557

FLIR. (2016, 01 11). *FLIR A310 pt*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=67552

FLIR. (2016, 01 11). *FLIR A315 / A615*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=41330

FLIR. (2016, 01 11). *FLIR A65 / A35 / A15 / A5*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=56341

FLIR. (2016, 01 11). *FLIR A6600/A6650*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=70605

FLIR. (2016, 01 11). *FLIR FC-Series R*. Retrieved from FLIR: http://www.flir.eu/automation/display/?id=70569

Government of Bermuda. (2009). *Investigation report into a fire on the cruise ship Royal Princess.* Hamilton: Government of Bermuda.

Holland America Line. (2016). *Investigtion summary.* Seattle: Holland America Line.

How suff works TECH. (2015, 12 26). *How Night Vision Works*. Retrieved from How suff works TECH: http://electronics.howstuffworks.com/gadgets/high-tech-gadgets/nightvision2.htm

IMO. (n.d.). Ch. II-2 Fire protection, fire detection and fire extinction. In IMO, *The International Convention for the Safety of Life at Sea (SOLAS)* (p. reg.15.2.10).

Land Instruments International. (2005, May). *Using thermal imagers - the basics*. Retrieved from Instrumentation and control: http://www.instrumentation.co.za/article.aspx?pklarticleid=3489

MAIB. (1995). *Report of the Investigation into fire on board Ro-Ro Passenger Vessel SALLY STAR .* Southampton: MAIB.

MAIB. (1999). *Final report of the investigation of a fire on the the Passenger Cruise Liner MV Saga Rose.* Southampton: MAIB.

MAIB. (1999). *Report of an Investigation into a switchboard explosion on MV Pride of Le Havre .* Southampton: MAIB.

MAIB. (1999). *Report of investigation into fire in main galley of Edinburgh Castle .* Southampton: MAIB.

MAIB. (1999). *Report of the Investigation into an engine room fire on MV Pride of Le Havre .* Southampton: MAIB.

MAIB. (2002). *Report of investigation into a fire in the aft engine room of ro-ro ferry Norsea.* Southampton: MAIB.

MAIB. (2004, August 17). *Fire in engine room on high speed passenger ferry Stena Lynx III*. Retrieved from gov.uk: https://www.gov.uk/maib-reports/fire-in-engine-room-on-high-speed-passenger-ferry-stena-lynx-iii-off-fishguard-wales

MAIB. (2004, August 27). *Fire in switchboard on ro-ro passenger ferry Stena Pioneer*. Retrieved from gov.uk: https://www.gov.uk/maib-reports/switchboard-fire-on-ferry-off-larne-northern-ireland

MAIB. (2006). *Fire on board the Bermuda registered passenger cruise ship Star Princess.* Southampton: MAIB.

MAIB. (2007). *Report on the investigation of the engine room fire on board the passenger cruise vessel The Calypso.* Southampton: MAIB.

MAIB. (2008, October). *Fire in engine room of ro-ro passenger ferry Isle of Inishmore*. Retrieved from gov.uk: https://www.gov.uk/maib-reports/fire-in-engine-room-of-ro-ro-passenger-ferry-isle-of-inishmore-in-pembroke-dock-england

MAIB. (2011). *Report on the investigation of the catastrophic failure of a capacitor in the aft harmonic filter room on board RMS Queen Mary 2 .* Southampton: MAIB.

MAIB. (2011). *Report on the investigation of the fire on the main vehicle deck of Commodore Clipper .* Southampton: MAIB.

MAIB. (2011). *Report on the investigation of The machinery space fire on board Oscar Wilde .* Southampton: MAIB.

MAIB. (2014). *Report on the investigation of the fire on the main deck of the ro-ro cargo ferry Corona Seaways.* Southampton: MAIB.

MAIB. (2015). *Report on the investigation of a fire on board the RoPax ferry Dieppe Seaways.* Southampton: MAIB.

MAIB. (2015). *Report on the investigation of a main engine room fire on board Pride of Canterbury.* Southampton: MAIB.

Malta Transport Centre . (2012). *Safety investigation into the fire on board the Maltese registered passenger ship AZAMARA QUEST .* Malta: Malta Transport Centre .

Marine Safety Investigation Unit. (2014). *Safety Investigation Report MV Zenith.* Marine Safety Investigation Unit.

MaritimeMatters. (2010, February 20). *The sinking of the SUN VISTA*. Retrieved from Maritime Matters: http://maritimematters.com/2010/02/a-cruise-to-remember-the-sinking-of-the-sun-vista/

Monroe Technology . (2015, 12 22). *limitations to thermal imaging cameras*. Retrieved from Monroe infrared: http://monroeinfrared.com/knowledgebase/a-guide-to-thermal-imaging-cameras/are-there-any-limitations-to-thermal-imaging-cameras

Nationa Transportation Safet Board. (2009). *Engineroom Fire On Board U.S. Small Passenger Vessel Queen of the West.* Washington: Nationa Transportation Safet Board.

National Transport Safety Board. (1997). *Marine Accident Brief.* Washington: National Transport Safety Board.

NATIONAL TRANSPORTATION SAFETY BOARD . (1996). *MARINE ACCIDENT REPORT Fire On Board the Panamanian Passenger Ship Universe Explorer .* Washington: NATIONAL TRANSPORTATION SAFETY BOARD .

NATIONAL TRANSPORTATION SAFETY BOARD . (2000). *FIRE ON BOARD THE U.S. PASSENGER FERRY COLUMBIA .* WASHINGTON: NATIONAL TRANSPORTATION SAFETY BOARD .

National Transportation Safety Board . (2003). *Marine Accident Brief .* Washington: National Transportation Safety Board .

National Transportation Safety Board . (2012). *Determination of Probable Cause Fire On Board Passenger Vessel Malaspina .* Washington: National Transportation Safety Board .

NATIONAL TRANSPORTATION SAFETY BOARD. (1998). *FIRE ON BOARD THE LIBERIAN PASSENGER SHIP ECSTASY.* WASHINGTON: NATIONAL TRANSPORTATION SAFETY BOARD.

NATIONAL TRANSPORTATION SAFETY BOARD. (2000). *FIRE ON BOARD THE NETHERLANDSREGISTERED PASSENGER SHIP NIEUW AMSTERDAM.* Washington: NATIONAL TRANSPORTATION SAFETY BOARD.

shipdetective. (2016, 01 03). *Passenger Ship Fires - 1979 to Current*. Retrieved from shipdetective: http://www.shipdetective.com/advice/safety/fires.htm

Thermal - Fire Guard System . (2015, 12 23). Retrieved from Thermalcam: http://www.thermalcam.eu/software/thermal-fire-guard

Transportation Safety Board of Canada . (2002). *MARINE INVESTIGATION REPORT SWITCHBOARD FIRE PASSENGER VESSEL STATENDAM .* Transportation Safety Board of Canada .

Transportation Safety Board of Canada . (2003). *MARINE INVESTIGATION REPORT ENGINE ROOM FIRE AND SUBSEQUENT FAILURE OF THE CO2 DISTRIBUTION MANIFOLD ROLL-ON/ROLL-OFF PASSENGER FERRY QUEEN OF SURREY QUEEN CHARLOTTE CHANNEL, BRITISH COLUMBIA .* Transportation Safety Board of Canada .

Transportation Safety Board of Canada. (2003). *MARINE INVESTIGATION REPORT FIRE ON VEHICLE DECK ROLL-ON/ROLL-OFF PASSENGER FERRY JOSEPH AND CLARA SMALLWOOD.* Transportation Safety Board of Canada.

U.S. Coast Guard . (2007). *Nordic Empress fire traced to three failed screws.* Washington: U.S. Coast Guard .

United States Coast Guard. (2013). *Report of Investigation into the FireOnboard the CARNIVAL SPLENDOR .* Washington: United States Coast Guard.

List of Figures