UTILIZATION OF MFSA METHODOLOGY IN CONDITION ASSESSMENT AND PERFORMANCE OPTIMIZATION OF A MARINE DIESEL ENGINE OF SHIP IN OFFSHORE ENVIRONMENT

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Abstract: Comprehensive Maritime Formal Safety Assessment (MFSA) methodology is applied in marine diesel engine of a ship that is used in offshore environment to improve engine performance by reduction, prevention and mitigation of risk associated with its operation. The research focused on risk of crankcase explosion of the diesel engine, high pressure fuel line bursting, turbo charger explosion, suffocation from asphyxiating gases, burns, exposure to noise, vibration and explosions and fires in the exhaust manifold, which are estimated using expert engineering judgement. Possible ways of risk reduction and prevention that can ensure best output of the marine diesel engine are revealed, together with cost implications. Most preferred ways for the risk reduction and operational efficiency of marine diesel engine is recommended.

Keywords: Marine diesel engine, risk, MFSA, hazards, operations, ship

Introduction

Shipping operations in offshore environment is risky. Several measures can be taken by mariners to reduce the risk of operations of various systems and subsystems of a ship. Maritime Formal safety assessment (MFSA) is one of the ways by which mariners can keep a check on these risks and find ways to keep them to the minimum (Kirwan, 1994). MFSA is a systematic method of enhancing maritime safety, which is done through a careful process of risk assessment and evaluation. According to Trbojevic and Carr (2000), MFSA is the process of identifying hazards, evaluating risks and deciding on an appropriate course of action to manage these risks in a cost effective manner. Marine and offshore accidents that happened in the past made the United Kingdom Maritime and Coastguard Agency (UK MCA, previously known as Marine Safety Agency) propose to the International Maritime Organisation (IMO) in 1993 that MFSA should be applied to ships (Wang, 2001). The application to ship will improve the safety of ships and drastically reduce the rate of environmental pollution. The UK MCA recommended that the application of MFSA should be from the design of ship to its operation because of its enormous benefits such as (Wang, 2001): (1) a consistent regulatory regime that addresses all aspects of safety in an integrated way; (2) cost effectiveness, whereby safety investment is targeted where it will achieve the greatest benefit; (3) a pro-active approach, enabling hazards that have not yet given rise to accidents to be properly considered; (4) confidence that regulatory requirements are in proportion to the severity of the risks; and (5) a rational basis for addressing new risk posed by ever-changing marine technology. International Maritime Organization (IMO) has adopted this process as interim guidelines for their rule making process after studying three notable incidents. These are (Wang, 2001): (1) Lord Carver's report on the investigation of the capsize of the Herald of Free Enterprises which was published 1992 (House of Lords, 1992); Lord Cullen's report on the Piper Alpha accident published 1990; and Lord Donaldson's report on the grounding of the tanker Braer published 1994.

These reports and other incidents such as Herald of Free Enterprise disaster, 1987; Amoco Cadiz accident, 1978; Estonia accident, 1994; Scandinavian Star disaster, 1990; Wreck of the Derbyshire, 1980; Loss of Flare, 1998; Prestige accident, 2002; Brava accident, 1977; Piper Alpha accident, 1998 and Ocean Ranger disaster, 1982 etc. that happened in the maritime and offshore industry made IMO to attempt application of MFSA on various vessels and systems so as to ensure a strategic oversight of safety and pollution prevention.

The applications of steps of MFSA to ship from its design stage to operation have advantage such as (Wang, 2001): (1) Improve the performance of the current fleet, be able to measure the performance change and ensure that the new ships are good designs; (2) Ensure that experience from the field is used in the current fleet and that any lessons learnt are incorporated into new ships; (3) Provide a mechanism for predicting and controlling the most likely scenarios that could result in incident. In view of this, companies started complying with IMO's guidelines on MFSA applications. They follow a set procedure in analysis of the biggest risks associated their ships operation and finding the most feasible solutions to reduce those risks in a cost effective manner. In this research, our focus will be on performing MFSA methodology on the marine diesel engine; aiming to identify hazards that can hamper its optimal operations; risk implications and cost implications of adoption of various method of preventing the identified hazards from occurring.

Due to enormous benefits of MFSA, IMO used United Kingdom Maritime and Coastal Agency (UK MCA) to carry out a trial application of MFSA on bulk carrier (International Association of Classification Society (IACS), 2001). UK MCA applied MFSA methodology to dry bulk shipping activities, focusing on the risk of loss of life, which is IMO's safety objective. The scope of their work covered loading to discharge terminals through passage at sea motions, ballast water exchange at sea, life saving, main machinery configurations etc (Wang, 2001). The study was initiated by considering an exhaustive range of accident and incident categories for which the data was available in commercial databases, for example a total operating life of 145,582 vessel years were analysed to collect a historic data on loss of life (Wang, 2001). Some other MFSA studies that have been reported to IMO are passenger vessels (IMO, 1997; IMO, 1998a; Lois *et al.*, 2004), high-speed catamaran ferries (Vivalda, 2000), fishing vessels (Loughran *et al.*, 2001; Pillay *et al.*, 2003), ballast water management (Det Norske Veritas (DNV), 2000), helicopter landing areas on passenger vessels (Spouge, 1998; IMO, 1998b), life saving appliances for bulk carriers (IMO, 2001; Skjong and Wentworth, 2000). Additionally, MFSA illustrative case study regarding accidental pollution from crude oil tankers, bulk carrier FSA conducted in Japan, Korea and Norway, redundant propulsion study submitted by Germany and Joint Nordic project on safety assessment of High Speed Craft (HSC) operations conducted in sweden have also been reported to IMO (Wang, 2001). A company applied FSA methodology to their vessels as evidenced from P & O Cruises Ltd, UK. Various steps of

MFSA were comprehensively utilized in defined scope of the application, so as to reveal various operational status.

Description of principle of operations of marine diesel engine of a ship in offshore environment

The marine diesel engine is an internal-combustion engine that produces mechanical power from the chemical energy contained in diesel fuel, usually made available on an output shafts.

The marine diesel engine like all internal-combustion engines consists of one or more cylinders that are closed off at one end and have a piston driving up the other (Calder, 2007).

It is a compression-ignition engine. When air enters the cylinder, the piston is forced up into the air, thereby compressing the air. As the air is compressed, the heat contained in it is concentrated into a smaller space. The pressure and temperature rise steadily until the air is extremely hot to about 1,000^{0}F (538^{0}C). Diesel fuel ignites at around 750^{0}F (399^{0}C) and any fuel sprayed into a cylinder filled with air, that superheats to 1,000^{0}F is going to result to fire outbreak (Ferguson and Kirkpatrick, 2015). This is exactly what happens at a precisely controlled moment, fuel is injected into the cylinder and immediately starts to burn and no other form of ignition is needed (Calder, 2007). The main two types of marine diesel engine such as four-stroke and two-stroke marine diesel engines have their principle of operations. A marine diesel engine is classified as four or two strokes depending on number of times the piston travels in the cylinder from the top dead centre (TDC) to the bottom dead centre (BDC) (Mathur and Sharma, 2008).

Principle of operations of four – stroke diesel engine

In four stroke diesel engine, each piston travels from one dead centre to the other of its cylinder four times to complete the combustion cycle from intake to exhaust. The piston moving from the top to the bottom of its cylinder is known as a stroke. When the piston is at the top of its cylinder, the inlet valve opens as the piston goes down to the bottom of the cylinder. During such process, the descending piston draws or takes in air into the cylinder, which causes the inlet valve to close, thereby trapping the air inside the cylinder. Additionally, the piston travels up the cylinder, which causes the trapped air to compressed and rise of the pressure to between 450 and 700 pounds per square inch (psi) and temperature to above 1000^{0}F. This process is called the compression stroke. Furthermore, during or at the end of compression stroke processes, fuel enters the cylinder via the fuel injector and starts to burn. Temperature and pressure increase rapidly and this forces the piston down to its cylinder, which causes rotations of the crankshaft. This process is called the third or power stroke (Calder, 2007). Finally, exhaust stroke is experienced when the piston nears the bottom of the power stroke, the exhaust valve opens and the gas in the cylinder goes out, which causes the piston to travel back up the cylinder, thereby forcing the rest of the burned gases out through the exhaust valve. The inlet and exhaust valves open and close respectively at the top of the exhaust stroke.

Principle of operations of two – stroke diesel engine

In this type of marine diesel engine, each piston travels from one dead centre to the other of its cylinder two times to complete the combustion cycle from intake to exhaust (Heywood, 1998). In two-stroke diesel engine, the piston is at the top of its cylinder on its compression stroke and the cylinder is usually filled with pressurized and superheated air. Diesel is injected and ignites. The piston moves down the cylinder on its power stroke and during such process the cylinder pressure and temperature fall. As the piston nears the bottom of its power stroke, the exhaust valve opens, which results to going out of burned gases out of the cylinder. During the movement of the piston down the cylinder, it uncovers a series of holes (called ports) in the cylinder wall. The pressurized air is blown out through these ports using a supercharger or turbocharger, which results to pushing of the rest of the burned gases out of the cylinder and refill it with fresh air. The piston has now reached the bottom of its cylinder and is starting back up again and the exhaust valve closes (Woodyard, 2004). The movement of the piston back up, results in blocking off of the inlet ports, thereby trapping the fresh air in the cylinder. As evidenced above, the piston has only covered a little over one stroke, however, it has already completed its power stroke, exhaust process and inlet cycle, unlike in four-stroke diesel engine. As the piston comes back up the cylinder on its second stroke, it compresses the fresh air and when it reaches the top of the cylinder, injection and compression take place (Birch, 1992).

Principal components of a marine diesel engine

Marine diesel engine has various components such as block, crankshaft, cylinders, cylinder head, piston, flywheel, camshaft, combustion chamber, connecting rod, crankcase, intake manifold, exhaust manifold, fuel injector, fuel pump, oil pump, oil sump, push rods, heat exchangers, turbo-chargers and super-charger and inter-coolers and after-coolers. These components can be described as follows:

- Block: It is the body of engine containing the cylinders (Richard, 2012).
- Crankshaft: It is a rotating shaft through which engine work output is supplied to external systems (Taylor, 1985).
- Cylinders: It is the circular cylinders in the engine block in which the pistons reciprocate back and forth (Pulkrabek, 2003).
- Cylinder Head: It is the piece which closes the end of the cylinders, usually containing part of the clearance volume of the combustion chamber.
- Piston: The cylindrical-shaped component that reciprocates back and forth in the cylinder, transmitting the pressure forces in the combustion chamber to the rotating crankshaft (Obert, 1973).
- Flywheel: It is a rotating component with a large moment of inertia connected to the crankshaft of the engine. (Woodyard, 2004).
- Camshaft: It is a rotating shaft used to push open valves at the proper time in the engine cycle, either directly or through mechanical or hydraulic linkage.
- Combustion chamber: It is the end of the cylinder between the head and the piston face where combustion occurs.
- Connecting rod: It is the rod connecting the piston with the rotating crankshaft.
- Crankcase: It is the part of the engine block surrounding the rotating crankshaft.
- Intake manifold: It is piping system which delivers incoming air to the cylinders, of the diesel engine.
- Exhaust manifold: It is the piping system which carries exhaust gases away from the engine cylinders.
- Fuel injector: It is a pressurized nozzle that sprays fuel into the cylinder of the engines.
- Fuel pump: It is electrically or mechanically driven pump that is used to supply fuel from the fuel tank (reservoir) to the engine.
- Oil pump: It is device used to distribute oil from the oil sump to required lubrication points.
- Oil sump. It is the reservoir for the oil system of the engine, commonly part of the crankcase.
- Push rods: It is mechanical linkage between the camshaft and valves on overhead valve engines with the camshaft in the crankcase.
- Heat Exchangers: It is used to remove heat from the engine coolant after the engine has been cooled.

- Turbo-charger and Super-charger: They are mechanical machines used to compressing air and forcing it into the combustion chamber of the engine.
- Inter-cooler and After-cooler: It is a device that serves as heat exchanger, fitted between the turbo chargers and the inlet manifold to reduce the temperature of the compressed air (Pulkrabek, 2003).

Methodology of Formal Safety Assessment

Formal safety assessment is a method of hazard identification, risk assessment and risk control options in a cost effective manner. It has five major steps such as hazard identification, risk assessment, risk control option, cost benefit assessment and decision making (MSA, 1993). MFSA has been successfully applied in marine engineering facilities as evidenced in various researches (Wang, 2001; IMO, 1997; IMO, 1998a; Lois *et al*., 2004; Vivalda, 2000; Loughran *et al*., 2001; Pillay *et al*., 2003; Det Norske Veritas (DNV), 2000; Spouge, 1998; IMO, 1998b; IMO, 2001; Skjong and Wentworth, 2000). The five steps can be described as follows:

- Hazard identification: Associated with identification of all hazards that might affect the proper functioning of engineering systems using brainstorming approach. The process is proactive and not confirmed only to hazards that materialized in the past and previous experience is properly taken into account.
- Risk assessment: Associated with assessment of occurrence likelihood and consequence of hazards, so as to focus attention on high risk hazards that will be evaluated and controlled. Additionally, is a comprehensive estimation of the possible consequences in a hazardous situation in order to select appropriate safety measures. Historical experience of the system under investigation and analytical methods are utilized during this step. The process could be qualitative or quantitative, depending on the availability of data.
- Risk control option: Associate with identification of ways of managing high risk hazards. In most cases, causal chains are used to develop appropriate measures at a selected control point. Identified risk control options can reduce the frequency of an event (i.e. preventative), while others can reduce the consequence of occurrence of an event (i.e. mitigating).
- Cost benefit assessment: Associated with cost estimates of the risk control options and benefits too. It shows whether the benefits of a risk control option outweigh its cost. The cost may be cost of equipment, cost of redesign and construction, cost of documentation, cost of training, cost of inspection, maintenance and drills, cost of auditing and cost of regulations. Whereas the benefits are reduction of costs for fatalities and injuries, reduction of cost for environmental damage, clean up, liability claims.
- Decision making: Associated with taking decision on the most cost effective risk control option, aiming to minimize cost and maximize benefit.

Application of MFSA Methodology to Marine Diesel Engine

Optimal functionality of marine diesel engine is facilitated using various machineries and systems that work together to provide power for the propulsion of the vessel. No systems is 100% safe, thus regular risk assessment need to be conducted so as to ensure optimal operations of the marine diesel engine. In view of the above, MFSA methodology is utilized in maintaining optimal operations of marine diesel engine.

Phase 1: Identification of marine diesel engine operational hazards

There are various hazards associated with the marine diesel engine during its operation. The hazards are identified using a brainstorming technique and literature search. The identified hazards are:

1. Crankcase Explosion of the Diesel Engine (MESM, 2018).
2. High Pressure Fuel Line Bursting.
3. Turbo Charger Explosion (Chybowski, 2016).
4. Suffocation from Asphyxiating Gases (EOHS, 1999).
5. Burns.
6. Exposure to noise.
7. Vibration (EOHS, 1999).
8. Explosions and Fires in the Exhaust Manifold (Marinediesel, 2000).

Phase 2: Risk assessment of marine diesel engine operational hazards

Marine diesel engine operational hazards identified in Sub-section 5.1 are evaluated, considering their frequencies of occurrence and the severity of their consequences using expert judgement and history of each marine diesel engine operational hazard. Based on this evaluation, the hazards are classified as high, medium and low risk ones.

1. Crankcase Explosion of the Diesel Engine. Explosion of ship’s crankcase is one of the most dangerous accidents in the ship’s engine room which can lead to catastrophic consequence. In the engine crankcase, oil particles are churned into smaller particles of up to 200 micro meters in diameter (MESM, 2018). These small particles ignites when it comes in contact with hot spot because it reduces the size, thus forming mist in presence of elements of fire such as lubricating oil (fuel source), air, and heat from a hotspot. The fire outbreak results to major explosion that will not only damage the engine but also take lives of crew members. However, historically, this hazard rarely occurs. Therefore, it is a low-risk hazard.
2. High Pressure Fuel Line Bursting. The high temperature and pressure fuel line which supplies fuel to the combustion chamber of marine diesel engines can explode due to continuous vibrations and lack of proper maintenance. This explosion can lead to the damage of the entire machinery space and even the vessel. It has a high probability of occurrence. Therefore, it is a high-risk hazard.
3. Turbo Charger Explosion. Turbo charger explosion on ships is caused when turbochargers are not properly cleaned for a long time. Improper cleaning of the turbo charger results to carbon deposits not allowing the parts affected to cool down properly. Consequently, the heated parts, fuel source and oil that gets into the exhaust side of the turbocharger through the cracks, form the perfect combination of an explosion (Chybowski, 2016). This can lead to loss of the engine, injuries and death to personnel. It has a low probability of occurrence, thus is a low-risk hazard.
4. Suffocation from Asphyxiating Gases. The exhaust gases from the process of combustion yields hazard of suffocation. This results from inhalation of asphyxiating gases (e.g. CO) or oxygen deficiency during maintenance, watch-keeping and cleaning operations (EOHS, 1999). The frequency of occurrence of asphyxiating gases (e.g. CO) is very high, because these gases are always released from the engine during operation. Furthermore, these gases fill the space, and since the engine room is an enclosed space, it is difficult to expel. This is a high-risk hazard and is the cause of

various respiratory tract diseases associated with the marine industry.

5. Burns. It mainly occurs as a result of body contact of crew members with hot parts of marine diesel engine or leakage from the marine diesel engine. The frequency of occurrence is high, however, its consequences are not severe hence, it is a high risk hazard.
6. Exposure to noise. Marine diesel engine produces noise, when running, which causes discomfort and hearing problems to crew members on board vessel. Noise is always experienced during the operation of the marine diesel engine, thus this hazard has a high probability of occurrence. Noise can cause permanent damage to the crew members' ear. It is classified as a high-risk hazard.
7. Vibration. It occurs in a marine diesel engine during operations. Vibration causes loosening of engine fasteners such as bolts, nuts, keys, screws etc. which can lead to disconnection of parts, thus causing failures such as leakages, loss of pressure etc. The vibration of a moving engine component can cause misalignment and fracture of the part. All of these can lead to accidents and permanent damage of the component and even the engine (EOHS, 1999). Vibration causes marine diesel engine damage, discomfort to the crew members and sometimes lead to instability of the vessel. This is a high-risk hazard.
8. Explosions and Fires in the Exhaust Manifold. Usually occur in a large two stroke marine diesel engines when cylinder oil or unburnt fuel passes to the manifold and ignites. In two stroke marine diesel engines, if the engine is running at loads below 75% for periods in excess of 4 hours, then the cylinder oil consumption has to be reduced manually (Marinediesel, 2000). If the engine runs on reduced load without reduction of the cylinder oil consumption, the excessive cylinder oil can end up in the exhaust manifold. The rise in temperature in the exhaust channel will ignite the cylinder oil, when the load is increased. With the advent of wet exhaust manifold technology, this hazard rarely occurs. Hence it is a low-risk hazard.

Phase 3: Risk control options of marine diesel engine operational hazards

In this step, risk control measures for the high risk hazards are identified. From the evaluations in the Phase 1, the high risk hazards are high pressure fuel line bursting, suffocation from asphyxiating gases, exposure to noise, vibration and burns. Measures of controlling them are outlines as follows:

- Risk associated with high pressure fuel line bursting can be minimised as low as reasonably practicable or prevented by carrying out routine inspection of the fuel lines and clips; installation of leakage sensors along the length of the fuel line and periodic replacement of fuel lines.
- Risk of suffocation from asphyxiating gases can be minimised or prevented by installation of ventilation blowers; installation of special gas sensors that will detect when the concentration of poisonous gases has reached the harmful level or when oxygen levels are low; and provision of respiratory mask for crew members.
- High risk nature of exposure to noise can be minimised or prevented by use of ear muff by the engine room crew while in the engine room; sound-proofing of the entire engine and replacing noisy engines with engines with reduced noise production.
- Vibration risk can be minimised or prevented by use of vibration dampers and regular inspection of the diesel engine parts to ensure that there are no loose parts.
- Risk of burns can be minimised or prevented by labelling of hot equipment and parts for proper identification; use of appropriate Personal Protective Equipment (PPE) with the suitable quality and insulation of heat generating equipment and parts.

Phase 4: Cost benefit assessment of the risk control options of marine diesel engine operational hazards

There is great benefit in the identified various ways of minimising or prevention of marine diesel engine operational hazards as evidenced in phase 3. However, their cost implications differ. In this study, cost estimates of risk control options less or equal to $1000, greater than $1000 but less than $3000, greater or equal to $3000 are classified as low, medium and high, respectively.

High pressure fuel line bursting risk control options cost estimates

The cost of implementations of various options/ways of minimising or preventing risk of high pressure fuel line bursting is estimated as follows:

- Carrying out routine inspection of the fuel lines and clips will cost more in man-hour for inspection. The cost is estimated as high.
- Installation of leakage sensors along the length of the fuel line will cost $140 per foot of the fuel line. $120 is the cost of a sensor and $20 is the cost of installation. Therefore, the total cost of implementations of this option in a 10 m fuel line is more than $3000, therefore is high cost estimate.
- Periodic replacement of fuel lines will cost more than $3000 for 10 m fuel line; thus is high cost estimate.

Suffocation from asphyxiating gases risk control options cost estimates

The cost of implementations of various options/ways of minimising or preventing risk of suffocation from asphyxiating gases is estimated as follows:

- Installation of ventilation blowers. The purchase of a unit blower will cost $350 and the cost of installation is $100. Therefore, the cost is $450, thus classified as low.
- Installation of special gas sensors that will detect when the concentration of poisonous gases has reached the harmful level or when oxygen levels are low. Sensor cost estimate is $40 and the cost of installation is $20 per sensor. Total cost estimate is about $180, depending on the number, thus classified as low.
- Provision of respiratory mask for engine room crew members. This mask will cost $200 per unit. Therefore, estimated cost is $600 dollars, thus classified as low.

Exposure to noise risk control options cost estimates

The cost of implementations of various options/ways of minimising or preventing risk of high exposure to noise is estimated as follows:

- Use of ear muff by the engine room crew members while in the engine room. Ear muffs cost $20 per ear muff. Total cost estimate is $200, thus classified as low.
- Sound-proofing of the entire engine. The cost of sound proofing the entire engine is about $3500, thus classified as high.
- Replacing noisy engines with engines with reduced noise production. The cost of a sound proof 8-cylinder catapillar diesel engine is $10,000, thus classified as high.

Vibration risk control options cost estimates

The cost of implementations of various options/ways of minimising or preventing risk of vibration is estimated as follows:

- Use of vibration dampers. The cost is $2,000 per damper. Total estimated cost is $6,000, thus classified as high.
- Regular inspection of the marine diesel engine parts to ensure that there are no loose parts. The cost is $200 per man-hour, thus classified as medium per annum if the exercise once per month.

Burns risk control options cost estimates

The cost of implementations of various options/ways of minimising or preventing risk of burns is estimated as follows:

- Labelling of hot equipment and parts for proper identification. The cost is $4 per sign. The sign glows when light shines on it. The cost is classified as low.
- Use of appropriate PPE with the suitable quality. High quality coverall, hand gloves and safety boots cost $100. Total cost estimates is about $300, thus classified as low.
- Insulation of heat generating parts. Insulation materials (fibre glass wrap) cost $15 per 5 m. Total cost is about $150, thus classified as low.

Phase 5: Decision making on risk control options of marine diesel engine operational hazards

This step involves making a decision on which of the risk control options are most suitable, considering their cost benefits.

Decision on most cost effective risk control option of high pressure fuel line bursting

Installation of leakage sensors along the length of the fuel line will ensure smooth operation of the diesel engine. However, it has high initial cost but is the most cost effective in the long run. In view of the above, carrying out routine inspection of the fuel lines and clips can serve as alternative with limited budget, reducing or preventing risk of high pressure fuel line bursting.

Decision on most cost effective risk control option of suffocation from asphyxiating gases

Installation of ventilation blowers is the most effective measure of controlling this hazard because it is efficient in expelling the gases and is cost effective in the long run. However, installation of special gas sensors that will detect when the concentration of poisonous gases has reached the harmful level or when oxygen levels are low can be used as an alternative, depending on the budgeted cost.

Decision on most cost effective risk control option of exposure to noise

Use of ear muff by the engine room crew members while in the engine room is the most efficient because it is user friendly and also it is cost effective in the short term and the long term.

Decision on most cost effective risk control option of vibration

Use of vibration dampers will ensure optimal performance of the engine, although it has high initial cost. However, it is cost effective in the long term. Regular inspection of the diesel engine parts to ensure that there are no loose parts can also be used as an alternative, depending on the budget, when the need arises.

Decision on most cost effective risk control option of burns

Use of appropriate PPE with the suitable quality and insulation of heat generating equipment and parts are the most suitable. Although use of appropriate PPE with the suitable quality protects the personnel from harm but it does not eliminate the hazard, thus the insulation of heat generating equipment and parts is the more preferred one.

Conclusion

MFSA was utilized in this research as a method for risk analysis of marine diesel engine of ship operational hazards, aimed at optimization of the engine performance and safety of the ship and engine room crew members. Hazards that posed to be a challenge and treat to marine diesel engine maximal operations and engine room crew members are analyzed, risk assessed and managed in a cost effective manner using the MFSA logical step by step approach. The study revealed that one of the most cost effective means of arresting high risk of high pressure fuel line bursting, suffocation from asphyxiating gases, exposure to noise, vibration and burns at long run are installation of leakage sensors, installation of ventilation blowers, use of ear muff, use of vibration dampers and use of appropriate PPE with the suitable quality and insulation of heat generating equipment.

Conflict of Interest

The authors declare that there is no conflict of interest related to this study.

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