Research Article

Using the hierarchy of controls to improve maritime safety: Case of hot work on board ships

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DOI:10.51513/jitsa.1090589

Abstract: Hot work is considered a hazardous process that causes many accidents on board ships. So, actual risks of hot work actions are assessed like any other hazardous operations in ships. Since the intelligent transport systems require increased safety level; all assessed hazards should be eliminated with robust and systematic hazard identification and clustering system for sea transportation. In this regard, a preventive study has been undertaken in order to raise awareness of safety and health issues in hot work activities aboard ships. In the study, the hierarchy of controls is applied to identify ship-specific hazards, hazard sources, and hazardous environments in order to develop preventative control measures in a more effective way. Based on the hierarchy's components, control measures have been developed including elimination, substitution, engineering controls, administrative controls, and personal protective equipment. Therefore, it enables to implementation of feasible and effective control measures for hot work hazards onboard ships from a hierarchical perspective.

Key words: Intelligent transportation systems, the hierarchy of controls, hot work, occupational hazards,

Deniz emniyetini arttırmak için kontrol hiyerarşisinin kullanılması: Gemilerde sıcak çalışma örneği

Özet: Sıcak iş, gemilerde birçok kazaya neden olan tehlikeli bir süreç olarak kabul edilir. Bu nedenle, sıcak iş eylemlerinin gerçek riskleri, gemilerdeki diğer tehlikeli işlemler gibi değerlendirilir. Bilindiği üzere, akıllı ulaşım sistemlerinin temel gereksinimlerinden birisi, ileri emniyet uygulamaları olmaktadır. Bu nedenle, değerlendirilen tüm tehlikeler, deniz taşımacılığı için tasarlanmış sağlam ve sistematik tehlike tanımlama ve kümeleme sistemi ile ortadan kaldırılabilir. Bu bağlamda, gemilerde yapılan sıcak iş faaliyetlerinde güvenlik ve sağlık konularında farkındalık yaratmak amacıyla önleyici bir çalışma yapılmıştır. Çalışmada, önleyici kontrol önlemlerini daha etkin bir şekilde geliştirmek için gemiye özgü tehlikeleri, tehlike kaynaklarını ve tehlikeli ortamları belirlemek için kontroller hiyerarşisi uygulanmaktadır. Hiyerarşinin bileşenlerine dayalı olarak, eleme, ikame, mühendislik kontrolleri, idari kontroller ve kişisel koruyucu ekipman dahil olmak üzere kontrol önlemleri geliştirilmiştir. Bu nedenle, hiyerarşik bir perspektiften gemilerde sıcak iş tehlikeleri için uygulanabilir ve etkili kontrol önlemlerinin uygulanmasını sağlar.

Anahtar Kelimeler: Akıllı ulaşım sistemleri, kontrol hiyerarşisi, sıcak çalışma, mesleki tehlikeler

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Received 20.03.2022; accepted 30.03.2022
Peer review under responsibility of Bandirma Onyedi Eylul University.

1. Introduction

Safety is one of the main concerns of intelligent transportation systems. Therefore, hazardous operations should be eliminated or mitigated through systematic approaches. In the maritime, hot-work is considered a hazardous operation, as there are various accidents occurred due to hot-work based errors in the past. For this reason, hazards of such operations should be reviewed systematically to increase operational safety for sea and water transportation.

Hot-work is a process that utilizes electric arc or gas welding equipment as well as cutting burner equipment in order to repair, cut or re-build various system components. In general, this procedure is applied when a ship at shipyard, however; it can be done in some circumstances when there is a requirement on-board especially when there is no other option. Since it can produce heat, sparks, flame and high temperature; hot-work is known as one of the most dangerous operations in maritime industry. Past studies address that at least 16% of machinery space fire events have been caused by hot-work operations (Ikeagwuani & John, 2013). Fire on-board a ship is a critical issue as it may cause serious consequences. According to the past studies, 13% of injuries and 9% of incidents caused by fire and explosions are sourced by hot work in Great Britain between 1998-2000 (Bradley, 2002). Apart from the fire, hot work operations produce toxic gases, fumes, vapours, noise, molten metal in a working environment which make it risky and hazardous job (Osha, 2021). Even so, during the hot work operations, the main risk is fire whilst the secondary risk is body burn based injuries (Dixit, 2021). These forms of hazards should also be mitigated by some countermeasures.

In order to mitigate the risks, hot-work actions are approved by a work permit mechanism thus whole process must be supervised strictly. A hot work permits on-board a ship is a safety review process to ensure necessary countermeasures are taken and all conditions are proper for such hazardous operation. These countermeasures can focus on different aspects of safety process; for instance, humans are not allowed to enter a confined space without a ventilation process is carried out prior to the operation. This can be about non-human elements as well; to exemplify, situation of equipment to be utilized, lighting of working environment, housekeeping and other elements must be checked properly. In addition to these, hot work permits are not restricted with operations on-board but also in shipyards, docks and other offshore units. These strict rules are extended according to some ship types due to their additional hazardous situations sourced by their special purposes. To illustrate, tanker ships are not permitted for hot-work actions on their deck unless the ship is gas free (IMO, 2021).

Despite the countermeasures taken by international organizations, accidents sourced by hot-work actions are still occurred in shipping industry. For instance, BBC Xingang ship required a hot work process on 11 December 2017. Prior to operation, a safety meeting was held. However, the hot work caused a fire due to ignition of molten metal on the surface of cargo coverings. It extinguished before it was too late, nevertheless not all accidents were ended in this way (ATSB, 2018). In October 2018, MV Balgarka a fire erupted during a hot work operation in forepeak tank. One of the crew members escaped from the fire, another one injured seriously and a fitter found died (MSIU, 2019). Similar cases can be seen in the reports of maritime accident investigation organizations (MARDEP, 2015). Evidences suggest that these accidents are mainly caused by human factors as human operators can be failed when following the procedures. Besides, lack of communication, lack of training and lack of understanding can be concluded from the past accidents. On the other hand, the studies related with hot-work operations have not been studied elaborately. Besides, despite the hot-work based accidents, the literature is scarce in this field. Nevertheless, some studies account for hot-work in their research. For instance, Tukur and Zhoude (2013) reviewed the safety procedures and guidelines for hot-work and welding operations. Moreover, Saputra et al. (2015) analysed past accidents to reveal safety issues on hot-work operations executed in conveyor belt area of a self-unloading bulk carrier vessel. Similarly, Yilmaz (2021) carried out research for shipboard fires and explosions and put emphasis on hot surface and hot-work actions in order to increase fire safety in the engine room. On the other hand, Marek and McGowan (2021) developed a governance model and safety management system for fire events on naval ship maintenance activities. According to their study, the most important factor which leads fire accident by hot work action is carrying the operation in improperly prepared areas. They highlighted that hot work-based fire accidents are a universal problem and should be researched more comprehensively.

Considering the scarce literature and ongoing safety issues on hot work-based accidents, the underlying safety issues and operational steps should be identified (Xu et al., 2014). For this reason, this study aims to identify the most frequent errors of hot-work activities conducted in the engine room. For this reason, a hierarchical task analysis is applied to a hot-work action plan in order to identify critical steps of the planned operation. Therefore, a comprehensive finding related to the hot work operations can be revealed and contributed to the literature.

2. Hazards of hot work on-board ships

The International Safety Management (ISM) Code is aimed to offer a worldwide standard for safe ship management and operation, as well as pollution prevention (ISM Code, 2010). Since a wide range of ships operates in a variety of conditions and all shipping companies or shipowners are unique, the ISM Code is founded on broad concepts and objectives, such as assessing all recognized hazards to ships, seafarers, and the environment and putting in place suitable measures (ISM Code, 2010). The safety management system (SMS), which is an essential component of the ISM Code, describes all of the critical policies, technique, and procedures of the organization to guarantee the safe operation of ships at sea (ISM Code Part A Regulation 1.1.4). In that way, each ship complies with the appropriate safety requirements, as well as the regulations, codes, guidelines, and standards implemented by relevant maritime organizations and authorities. Therefore, the on-board SMS should provide enough instructions on hot work control and be robust enough to assure compliance (IMO, 2003).

Since the hot work involves flames, incendiary sparks, or temperatures that are prone to causing flammable gas ignition, it can generate serious health hazards and hazardous areas. Thus, it can put seafarers in danger in a variety of ways. At this point, the master or a responsible ship officer should conduct a risk assessment to determine the specific hazards posed by performing hot work operations in order to take the all-necessary precautions. Considering ship-specific hot work hazards have not been highlighted in regulations, codes, or standards, the study looked through related publications, resolutions, and guidelines to uncover them (IMO, 2003; ICS, 2014). According to the investigation conducted as part of the current study, the primary hazards associated with hot work activities on board ship are fire/explosion, electrical hazards, toxic fumes, burns and scalds (flame, surface contact, or radiation), falling from a height, and eye injuries. The aforementioned hazards were identified through recommendations, common principles, instructions, and guidelines developed by shipping industry stakeholders. A permission system for hot work operations should be established, as specified by the IMO regulation, in order to adequately investigate space intended for hot work and close attention should be paid to take all required actions to prevent or mitigate the detected hazards (IMO, 2003). Since the most of the time it is not possible to designed a permanent safe space for hot work activities on board ships, a responsible officer should conduct a risk assessment before each hot work to increase seafarers' awareness of safety and related hazards. In light of the identified risks, the work area should be thoroughly prepared and isolated before practicing hot work. Finally, all necessary precautions should be maintained until the hot work is completed (IMO, 2003).

3. Hierarchy of control

The hierarchy of control is a framework that has been used by occupational safety and health professionals, safety engineers, and safety practitioners to determine strategies for dealing with workplace hazards. The main purpose of the hierarchy of control is to assess hazards and promotes intervention methods in a consistent and systematic way. Although, removal of the hazard and elimination of the risk of exposure is not always possible, it is always preferable. The use of the hierarchy in initial risk assessments and those done after controls have been established helps to more properly estimate risk and to enhance controls over time.

It is mainly established on the sense that rather than relying on worker to decrease exposure, the best way to manage a hazard is to eliminate it from the workplace. The traditional concept of hierarchy of control was defined by Barnett and Brickman (1986). The traditional concept of the hierarchy of controls was further developed by the National Safety Council, a non-governmental and non-profit safety advocate organization in America, (Plog, Niland & Quinlan,1996).

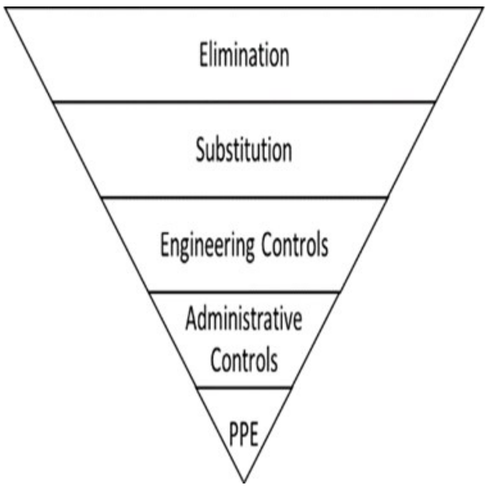

Figure 1. *The hierarchy of controls*

After a hazard has been discovered and assessed, the first action should be to either remove or mitigate the risk to an acceptable level. Since preventing worker exposure to occupational risks is the most fundamental way of worker protection, the hierarchy of controls has been utilized to determine how to deploy realistic and effective control measures. The rationale behind this hierarchy is that the strategies at the top of the map may be more effective and protective than those at the bottom (see Figure 1). The hierarchy of control structure covers Elimination, Substitution, Engineering Controls, Administrative Controls, and Personal Protective Equipment (PPE). Elimination implies that the practice or task should be modified to physically remove or completely eliminate the hazard. Focusing on elimination to entirely remove the hazard can contribute to minimizing catastrophic accidents or casualties in the working environment. Thus, this is considered the most effective risk-control technique available, and it should always be explored after a risk has been recognized. Substitution, on the other hand, is the process of replacing a traditional substance or procedure with less hazardous alternatives. Therefore, substitution demands a broader perspective in order to be aware of potential alternatives that are less hazardous. In the substitution step, if the use of hazardous substances cannot be avoided, it may be considered to remove the activity permanently. If elimination or substitution is really not possible to achieve due to technical constraints, engineering controls may be one of the feasible and effective approaches for removing the hazard or reducing the likelihood of the risk of exposure (de Castro, 2003; Morris & Cannady 2019). Engineering controls are meant to mitigate a hazard at its source and entirely protect employees from harm, allowing workers to fulfil their work responsibilities without being exposed to any workplace hazards (de Castro, 2003). It is essentially the removal or isolation of a hazard through use of technology. Accordingly, engineering controls is concerned with the source of the hazard or the line of transmission (de Castro, 2003). Administrative controls are policies that try to minimize worker exposure to a hazard, and are often implemented through work assignments. Administrative controls are generally focused on training and job rotation, although they may not necessarily address the actual vulnerabilities and risks (Morris & Cannady 2019). Adopting standard operating procedures or safe working practices, permit to work, isolation as well as ensuring adequate training, instructions, or information to limit the risk of injury and/or ill health impacts to workers, are examples of administrative controls (HSA, 2021). In cases when no deliberate control has been imposed, the ultimate level of the hierarchy of control is to deploy PPE. Even if PPE appears to be the simplest or most cost-effective option, the risk or hazard remains in the workplace. In addition to the purchase price of the equipment, periodic training needs and PPE maintenance should also be considered. Furthermore, research reveals that, while PPE might reduce the risk present in some work conditions, it can also influence human senses and even diminish performance in some circumstances (Morris & Cannady 2019). Hence, workers may find the usage of PPE quite challenging and stressful.

4. Hierarchy of control measures

Hot-work precautions on-board a ship is specified by IMO within the ISM Code. There are some guidelines must be done before initiating a hot-work operation. These guidelines aim to increase safety level through some countermeasures such as; removing any flammable materials from working area, ensuring that the area is gas free, all personnel must be informed prior to an operation, conditions of equipment must be checked, firefighting ability must be well ready, and permissions are needed. However, hot work precautions in a ship engine room is required some additional attentions due to its characteristics. For instance, bilges must be checked, any flammables and vapourable materials must be removed, work site must be shielded for sparks, pipe sections that extend beyond the engine room must be blanked, if any change in the condition is observed hot-work operation must be stopped, fire hoses and fire pump should be well prepared and according to the engine room's conditions, any special precautions should be taken. Therefore, various countermeasures can be applied by referencing the existing guidelines, however; hot-work based accidents on-board continue to occur. For this reason, various hazards of hot-work operation are analysed via hierarchy of control method. In this regard, hot-work based hazard types are considered as: fire and explosion, electrical hazards, toxic fumes, scalds, falling from height and eye injuries. These hazard types are collaborated with hierarchical control measure elements (elimination, substitution, engineering controls, administrative controls and PPE) in order to establish a matrix. This matrix is shown in Table 1.

Table 1. *Hierarchical control measures matrix*

	Hierarchical control measures				
Hazard Type	Elimination	Substitution	Engineering controls	Administrative controls	PPE
Fire and explosion			✔	✔	✔
Electrical hazards		✔	✔	✔	✔
Toxic fumes				✔	✔
Burns and scalds			✔	✔	✔
Falling from height	✔	✔		✔	✔
Eye injuries			✔	✔	✔

In this table, the relationship between possible control measures and hazard types are interrogated according to the existing solutions from the literature. For instance, if a hazard type can be eliminated completely; its marked correspondingly. Hence, findings and suggestions according to this matrix are introduced in the next section.

5. Findings and suggestions

The first hazard type is fire and explosion. Considering the hot work applications, this hazard cannot be removed completely as the processes require high temperature as well as ignition. Moreover, substituting the fire may not be possible in most of the times. If the process aims a cutting operation, water jet cutting technology can be suggested. Even so, most of hot work aims to combine or repair thus this suggestion is only available for minority of operations. Mostly, there are some specific countermeasures that should be considered in particular with respect to engineering controls, administrative controls, and PPE. To illustrate; reduce the number of seafarers who are at risk, any releases of dangerous substances should be collected, contained, and removed to a safe location, should take steps to avoid the formation of an explosive environment (proper ventilation etc.), take necessary precautions to prevent the spread of fires or explosions, and providing appropriate PPE to seafarers (HSE, 2013). For electrical hazards; electricity connection and transmission are required thus it cannot be eliminated or substituted. However, other countermeasure types can be done by responsible officers. For example; reduced arc flash energy effectively replaces a lower risk with a higher risk, a physical inspection of all electrical equipment, including the lead and plug connections, should be performed before use, establishing reporting procedures to notify responsible officer when any electrical equipment is removed from service for safety reasons, to avoid overloading, all necessary precautions should be taken to protect power circuits with an appropriate fuse or circuit breaker (Allen, 2009; Safe Work Australia, 2012). Toxic fumes are another hazard type of these operations. In addition to respiratory problems, burns, flu-like symptoms, and eye injury, toxic fumes exposure can cause Parkinson's-like symptoms, kidney damage, and nervous system damage, all of which are potential fume side effects (OSHA,2013). Since toxic fumes are produced during hot work as a result of chemical reactions, employing pre-mixed or diluted chemicals or alternative substances is not an option for eliminating the hazards in the hot work operations. Hence, adequate ventilation is crucial to provide during hot work operations. Grinding or sanding the surface to bare metal before welding should consider since they reduce the formation of fumes and vapours from paints and primers (Chang & Lin, 2006). Lastly, for all hot works, providing appropriate and effective PPE is essential. Next, burns and scalds are injuries that caused by thermal or radiant energy and mainly occur on the skin. It may emerge as a result of direct contact with a hot surface without the use of proper PPE. However, a hot spark or molten slag becoming stuck in footwear or clothing is the most likely source of burn injuries (OSHA, 2010). Hence, it's critical that all seafarers have attended a systematic and up-to-date training program and have been certified as not only qualified and experienced but also competent to undertake hot work operations (OSHA, 2010). For burns and scalds hazards, suitable PPE, such as a hood, face shield, or goggles (for eye protection), leathers, protective sleeves, and flame-resistant gauntlet-type gloves, is encouraged (OSHA, 2010). Falling from height can be completely eliminated, if necessary, measures are taken. Conducting hot-work from safer position with the support of long distance focused hot work tools; the process can be executed safely. This hazard can also be replaced with some other techniques such as safety rope, hydra ladder or boom lift based other hazards. Eye injuries are among the most common types of hazards faced by seafarers engaged in hot work (OSHA, 2010). Even though the majority of the effects of eye injuries are treatable, they have the potential to cause catastrophic vision loss in one or both eyes. Hence, due to its delicate nature, the hazards of eye injuries should be handled with the utmost attention (OSHA, 2010). The most common cause of eye injuries is airborne debris, which includes hot sparks and slag generated by the hot work. Since a majority of eye injuries occur when these materials enter the eye, they are easily remedied with proper PPE (OSHA, 2010).

6. Conclusion

Majority of assessed hazards can be eliminated by personnel with an easy and competent hazard identification system in order to increase safety level of an intelligence transportation mechanism. Therefore, enabling seafarers to identify and cluster potential hazards and hazardous environments may facilitate undertaking to monitor for these hazards. In this perspective, elimination of hazards can become a reality when people get familiar with a simple but secure hazard identification system. However, elimination of hazards cannot be possible in some situations such as hot work operations in a ship's ecosystem. Despite the strict rules and well-known countermeasures which have been acknowledged globally; hot work-related accidents continue to occur on board ships. Therefore, a guidance for safety practitioners can be beneficial regarding various hot work operations aboard.

In terms of a methodical approach to this subject, the literature is lacking when it comes to the hazards of hot work on board ship and viable countermeasures. For this reason, in this study; six critical hazards of hot work process are introduced to apply hierarchical control measures. The layers of hierarchical control measures are: Elimination, substitution, engineering controls, administrative controls and PPE. Then, these parameters of hierarchical controls are matched with the widely known hazard types of hot work operations, they are: fire and explosion, electrical hazards, toxic fumes, burns and scalds, falling from height, eye injuries. Therefore, critical hazards of hot work operations are interrogated with hierarchical control measures. The findings have been explained in details as it can be used as a countermeasure procedure which specifies priorities when removing safety issues in different situations. The safety practitioners and supervisors on board a ship can be benefitted from this matrix in order to reveal their priorities. Moreover, they can re-match the matrix according to different situations or possible solutions that they have. Therefore, countermeasures can be taken effectively through a hierarchical perspective.

However, there are some limitations of the study. Because of the many different ship types, sizes, working conditions, crew, and practices, each merchant ship has its own set of hazards which should be eliminated or mitigated. It is very challenging and mostly unknown to obtain technical or operational conditional data from them. Hence, the suggestions of this study prepared for ordinary ship conditions. If there are other hazardous conditions; the priorities may require some modifications. For this reason, for further studies; applications in different ship conditions can be conducted to reveal additional safety enhancements.

Researchers' Contribution Rate Statement

All researchers have equal contribution rates.

Acknowledgement and/or disclaimers, if any

There is no funding.

Conflict of Interest Statement, if any

There is no conflict.

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