Nadarajah, S., Kulatunga, U., Weerasooriya, D. and Rathnasinghe, A.P., 2024. Fire under control: Enhancing warehouse safety through strategic fire prevention and risk management. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ranadewa, K.A.T.O. and Chandanie, H. (eds). *Proceedings of the 12th World Construction Symposium*, 9-10 August 2024, Sri Lanka. pp. 518-531. DOI: https://doi.org/10.31705/WCS.2024.41. Available from: https://ciobwcs.com/papers/

FIRE UNDER CONTROL: ENHANCING WAREHOUSE SAFETY THROUGH STRATEGIC FIRE PREVENTION AND RISK MANAGEMENT

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ABSTRACT

Warehouse fires represent a global challenge, inflicting economic losses, damaging reputational integrity, disrupting business operations, leading to job losses, and negatively impacting the environment. Despite strict fire regulations and codes of practice aimed at safeguarding warehouse facilities, the prevalence of catastrophic fires persists globally, including notable incidents in Sri Lanka. This persistence prompts an inquiry into the adequacy and appropriateness of current protective measures. This research addresses the urgent need to discern the root causes of warehouse fires and the consequent damages to devise effective preventative strategies. Through a combination of literature review and semi-structured interviews with ten experts, this study employs manual content analysis to explore underlying factors. Key findings indicate that failures often stem from the absence, inadequacy, or improper maintenance of fire detection and protection systems, the specific nature of storage configurations, the size of the facilities, and the combustible characteristics and volume of stored goods. The study proposes adhering to the Construction Industry Development Authority (CIDA) fire regulations, which mandate the provision and maintenance of active and passive fire protection measures. It further recommends the regular execution of fire risk assessments, the enforcement of stringent housekeeping protocols, the strategic separation of commodities based on their class and compatibility, and the isolation of battery re-charging operations from storage areas as critical steps to mitigate fire risks in warehouses. These insights guide warehouse owners, tenants, fire risk assessors, and other professionals who enhance fire safety in warehouse settings.

Keywords: *Fire Hazard; Fire Safety; Sri Lanka; Warehouse.*

1. INTRODUCTION

Warehouse fires represent a persistent global challenge that damages property, disrupts supply chains, inflates downtime, and tarnishes corporate reputations. Such incidents result in significant economic losses due to direct damage to buildings and contents and incur additional costs related to interrupted operations and third-party claims (Ronken, 2019; Spieler, 2016). For instance, notable incidents in Sri Lanka include fires at a Bata

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warehouse in Rathmalana in 2004, at a Sri Lanka Ports Authority facility in 2013 (Kavirathna et al., 2021), and at a private textile firm in Lansiyahena in 2018 (Pabasara et al., 2019), which collectively underscore the severity of these events.

Despite frequent warehouse fires, only large-scale, disastrous fires receive significant attention. This focus overshadows the smaller fires that collectively pose a substantial risk (Ren, 2012; Twigg et al., 2017). This discrepancy highlights the need for a comprehensive approach to fire safety that encompasses emergency response and preventive strategies. The current fire safety regulations, while extensive, often fall short of effectively mitigating the risk of large-scale fires, particularly in oversized and densely stocked warehouse environments where fires can escalate rapidly due to high temperatures and abundant combustible materials (Alvarez et al., 2013; Hakes et al., 2017; Islam & Hossain, 2018; Qin et al., 2016).

Moreover, the environmental and health hazards posed by fire effluents, such as toxic gases and contaminated runoff, further complicate the impact of warehouse fires, affecting the immediate vicinity and the broader ecosystem (Perez, 2020). Considering the above, this paper argues for a critical revaluation of fire safety practices in Sri Lankan warehouses, emphasising the necessity of integrating modern technologies and revising existing guidelines under the CIDA fire regulation framework to enhance the efficacy of fire prevention and mitigation strategies. To achieve this, the remainder of this study is structured as follows: Section 2 synthesises the literature on factors influencing fire development in warehouses and existing fire safety regulations. Section 3 describes the methodology employed in this study, involving interviews with experts. Section 4 discusses the findings from these interviews. The conclusion reflects on the implications of this research and suggests avenues for future investigation.

2. LITERATURE REVIEW

2.1 FACTORS THAT ARE INFLUENCING THE FIRE DEVELOPMENT IN WAREHOUSES

Various factors influence the development and spread of fires in warehouses. Firstly, the size and layout of the warehouse play a crucial role (Lawson, 2001). According to Dinaburg and Gottuk (2012), large, undivided spaces allow fires to spread rapidly, as firefighters may struggle to reach the seat of the fire quickly due to increased distances and time spent laying out hoses. Moreover, the configuration of storage areas, especially in height and aisle width, impacts fire development. As storage heights increase (Overholt et al., 2011), so does the fire risk, with fire patterns transitioning from horizontal to vertical spread (Neale, 2017). Flue spaces, which provide ventilation and aid sprinkler effectiveness, become critical factors in fire control (Abdulrahman et al., 2021).

Additionally, the types of commodities stored, and their arrangement contribute significantly to fire hazards (Gollner et al., 2011). For example, certain materials may burn more rapidly when their surface area is maximised, and packing materials such as plastic films can hinder sprinkler effectiveness (Ebeling, 1990). Categorising commodities based on their burning and spread rates is essential for designing appropriate fire suppression systems (Overholt et al., 2011). Furthermore, the configuration of storage areas, including flue spaces, influences fire behaviour by providing pathways for air supply. According to Moran and Knight (2021), creating fire breaks between storage racks or piles can help slow the spread of fire, while open areas allow sprinklers to control

the blaze (Security, 2019) effectively. Understanding and mitigating these factors are pivotal for effectively preventing and managing warehouse fires.

2.2 CONTRIBUTING CAUSES FOR FIRES IN WAREHOUSES

A combination of oxygen, fuel, and heat often initiates fires in warehouses. Once ignited, they can spread rapidly, fuelled by various sources within the warehouse environment. Electrical malfunctions are a significant contributor, with arc faults and electrostatic sparks being familiar ignition sources (Baalisampang et al., 2018). Exposed wires, overheating, and faulty connections are frequent culprits, highlighting the importance of regular maintenance and predictive techniques like thermography to detect potential faults (Yang et al., 2024). Ground faults and static electricity buildup pose risks, emphasising the need for ground-fault circuit interrupters and proper grounding programs. Mechanical equipment, such as mixers and elevators, can generate frictional heat or sparks during operation, while exhaust systems from diesel engines may ignite nearby combustibles. Battery charging operations present another hazard due to the release of hydrogen gas, necessitating proper ventilation or dedicated charging areas with fire-rated construction (Murphy et al., 2023).

Self-ignition can occur in materials stored for extended periods, especially during hot and moist conditions, while improper storage of chemicals can lead to unexpected reactions and fires (Saffarinia, 2021). Smoking materials and arson are additional causes, with reckless disposal of cigarettes and intentional fires being significant risks. Implementing designated smoking areas, security measures, and surveillance systems can help mitigate these risks. Therefore, warehouse fires result from various factors, including electrical faults, mechanical operations, battery charging processes, self-ignition of stored materials, chemical reactions, smoking, and arson. Preventative measures such as regular maintenance, proper storage practices, and enhanced security protocols are essential for reducing the likelihood and severity of warehouse fires.

2.3 FIRE PROVISIONS GIVEN FOR THE WAREHOUSES

Fire regulations, standards, and codes of practice, both locally and internationally, are crucial for ensuring the safety of warehouses. These guidelines cover various aspects such as fire alarm systems, access to fire service appliances, compartment sizes, structural fire resistance, and fire protection systems. Fire alarm systems are required in storage occupancies, but exemptions apply based on factors such as fire hazard level and the presence of automatic sprinkler systems (Meacham, 2023). Manual alarm systems and video image fire detection may be required for larger or unmanned storage areas. Access roads for fire service appliances must be broad enough to ensure effective response (Zhou & Zhang, 2020). Further, compartment sizes are regulated to limit fire spread, with considerations for sprinkler protection and building height. Fire protection systems including sprinklers, portable extinguishers, and hose reels are mandated based on warehouse size and hazard level (Bag & Ganguly, 2023). External fire hydrants may be required for larger areas.

Smoke ventilation systems or smoke control measures may be necessary depending on compartment size and fire protection systems in place (Short et al., 2006). Structural materials must have specified fire-resistance periods, with requirements varying based on building height and sprinkler protection (Kallianiotis et al., 2022). Signage is essential for indicating maximum storage heights and maintaining clearance below sprinkler heads.

Regular maintenance and testing of active and passive fire protection systems ensure their effectiveness over time (Hsiao & Hsieh, 2023). Fire regulations, standards, and codes of practice provide comprehensive guidance for mitigating fire risks in warehouses, encompassing various aspects of fire prevention, detection, suppression, and structural resilience. Compliance with these regulations is essential for safeguarding life and property in warehouse environments.

2.4 THE CURRENT FIRE REGULATIONS RELATED TO WAREHOUSES IN SRI LANKA

The current fire regulations related to warehouses in Sri Lanka encompass local and international standards to ensure safety and prevent fire incidents. According to the National Fire Protection Association (NFPA) guidelines, fire alarm systems are mandatory for all storage facilities, except when the content is of low fire hazard, or an automatic sprinkler system protects the warehouse. Additional measures include the requirement for manual alarm systems in single-story warehouses exceeding 400 m² and video image fire detection in unmanned storage areas with large open spaces or high ceilings. Furthermore, warehouses with floor areas over 800 m² must be equipped with manual call points and automatic fire detection systems, fire extinguishers, hose reels, landing valves, and automatic fire sprinklers.

Accessibility for fire service appliances is another crucial aspect of the regulations, mandating a clear path around warehouses. Roads leading to premises must have a minimum width of 3.7 meters between kerbs, with the actual width determined in consultation with local fire services. The storage building access should not be less than 4 meters in width. Compartment sizes are limited unless automatic fire sprinklers or similar protections are installed to prevent fire spread. For instance, in non-sprinkler warehouses with high fire hazards, compartment sizes are limited to 2,000 m² with a maximum height of 12 meters. The regulations also emphasise the importance of maintaining and periodically testing both active and passive fire protection systems and implementing control measures such as preventive maintenance of electrical equipment, proper storage practices, designated smoking areas, and installation of CCTVs to mitigate arson risks. While these regulations provide a robust framework for fire safety in warehouses, further study is still needed to address evolving risks and emerging technologies. Continuous research and updates to the fire safety codes are essential to ensure comprehensive protection and adapt to new challenges in warehouse management.

3. RESEARCH METHODOLOGY

The research problem is “Are the existing fire safety in warehouses in Sri Lanka adequate or improvement needed?”. Consequently, the research problem is subjective. A subjective presentation of the findings is required. Instead of attempting to prove a hypothesis about a phenomenon, such as "how many", it aims to examine and answer questions such as "what?" and "why?" As a result, the qualitative approach was used to perform this research. Therefore, this research was conducted using a qualitative approach. For this study, data was collected through semi-structured interviews, which helped the researcher conduct an in-depth inquiry into the study. The literature review helped identify fire causes, fire safety issues in warehouses in other countries and appropriate mitigating solutions. Qualitative content analysis is one of the methods used to analyse data (Hsieh, 2023). It starts with ideas about the hypotheses or issues that may arise and looks for them

in the data that has been collected. Therefore, the qualitative content analysis method was selected to analyse data as it gains a rich, detailed understanding of a specific context and a more creative and flexible design in this study. Table 1 presents the profile of the experts.

Table 1: Profile of experts

Participants	Designation/field experience	Experience (years)
R1	Retired chief fire officer and fire consultant	40
R2	Retired chief fire officer and fire consultant	30
R3	Retired chief fire officer and fire consultant	28
R4	Chief fire officer	25
R5	Chief fire officer	15
R6	Fire consultant and fire incident investigator	35
R7	Fire consultant and fire system installer	15
R8	Fire consultant and fire system installer	20
R9	Fire risk assessor	22
R10	Fire officer and fire risk assessor	20

Ten non-random purposive samples were used to select the experts for this study. Palinkas et al. (2015) stated that purposive sampling is broadly used in qualitative research to obtain rich information from a limited resource. According to Gounder (2021), a larger sample size is needed for quantitative research, whereas for qualitative research, even a small sample size will be sufficient to obtain data saturation. After ten semi-structured interviews, the saturation level was reached.

4. DATA ANALYSIS AND RESULTS

4.1 CAUSES THAT CONTRIBUTE TO FIRES IN WAREHOUSES IN SRI LANKA

Six leading causes contributing to fires in warehouses were identified from the literature, and expert interviews were used to identify causes related to Sri Lanka. According to the experts, no proper investigation has been carried out in Sri Lanka to find the most common ignition source of fire. A summary of the causes of fires identified by each respondent is given in Table 2.

Table 2: Cause of fire

Causes of Fire	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Electrical source	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Unsafe hot work	✓	✓	✓	✓	✓	✓	✓	✓	✓	×
Incompatible materials	×	✓	✓	✓	×	×	×	✓	✓	✓
Battery charging inside the warehouses.	✓	✓	✓	✓	×	✓	✓	×	✓	✓
Deliberate acts	✓	✓	✓	✓	×	✓	✓	✓	×	✓
Smoking	✓	×	×	×	×	×	✓	×	✓	✓

Causes of Fire	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Storing flammable liquid inside the warehouse	×	×	×	✓	×	×	×	×	✓	×
Self–reactive materials	×	✓	✓	✓	×	×	×	×	×	×
Lightning	×	×	×	×	×	×	✓	×	✓	×

According to the table, all interviewees agreed that the electrical source was a cause of the warehouse fire in Sri Lanka. However, many respondents stated that unsafe hot work, auto ignition of some specific materials, chemical reactions of incompatible materials stored together, arson, and the battery charging inside the buildings cause fires other than the electrical source. Agreeing with that, R9 mentioned that even though the leading causes for warehouse fires are the electrical source and unsafe hot work, other sources such as the chemical reaction of incompatible materials stored, self-ignition of some materials, arson and careless smoking also initiate fires". However, R4 commented that *"even though battery charging causes a fire, battery charging operation inside the warehouses is rare in Sri Lankan context*". Similarly, three interviewees (R4, R6, R10) highlighted that arson causes warehouse fires; in Sri Lankan contexts, the probability is low.

According to R5, the fire-contributing factors of warehouses are electrical and hot work. Two responders agreeing with R5 added that lightning and the sparks from forklifts used in warehouses for loading and unloading purposes and smoking may also initiate a fire. R7 highlighted that lightning also initiates fires if no appropriate lightning protection is provided. In addition to that, two interviewees (R4, R9) stated that flammable liquids with points less than 320C 32 to the points are less than 320C 32 to the points are less than 320C 32 to the points are less than 32^{0C}. The regulation does not allow flammable liquids and reactive materials to be stored inside a warehouse as they initiate fire, yet many warehouse owners store them. Therefore, if any spark is introduced accidentally, it may form a flammable mixture and initiate fire.

4.2 CAUSES OF RAPID-FIRE DEVELOPMENT IN WAREHOUSES IN SRI LANKA

Respondents highlighted that numerous factors contribute to fire development in warehouses. Table 3 lists the leading causes of rapid-fire development in warehouses identified by respondents.

Table 3: Causes of rapid-fire development in warehouses

Causes of rapid-fire development	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Presence of a large amount of O_2	✓	×	✓	✓	✓	×	×	✓	✓	✓
High fire load	✓	✓	✓	✓	✓	✓	×	✓	✓	✓
No compartmentation to hold fire spread	✓	✓	✓	✓	✓	×	✓	✓	✓	✓
Storage Configuration	✓	✓	✓	✓	✓	✓	×	×	✓	✓
Delaying identifying the fire	✓	✓	✓	✓	✓	✓	✓	✓	×	✓
Lack/absence of fire protection	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Most respondents pointed out that oxygen, the supporting agent for fire growth, is available sufficiently in warehouses as the warehouses have high volumes and large natural openings. Two respondents (R1, R3) explained that openings such as roller shutters/doors in warehouses also supply oxygen continually to the fire, as they are kept open to usual access and exit. R10 further added that the best practice of keeping the access and exit doors when not in use to prevent oxygen supply to the fire is not practised in Sri Lanka'. All experts pointed out that the absence of compartment walls to hold fire in large warehouses where the fire originates causes fire to spread.

Types of storage configurations play essential roles in fire spread and development. As with many respondents, R9 commented, "*Storage configuration and the tendency of hot smoke, gases, and flame travel upwards influence the fire spread"*. According to R1, fire development is very high in rack storage rather than in big stacks as its ignitable surface is high. The distances between the stacks and the storage height can influence the fire spread. R4 stated that when the height of the rack storage increases and the gaps between racks narrow, it leads to rapid-fire development.

All experts agreed that the absence of fire detection systems to identify the fire in its early stage and the unavailability of firefighting equipment to control the fire in its early stage led to fire development in warehouses. Similarly, R9 highlighted that inadequate, inappropriate, and faulty conditions of the fire detection and extinguishing systems in existing warehouses are the major issues in Sri Lanka. Further, R10 commented, "*inadequate and improper maintenance of firefighting system in the existing warehouses also let the fire to burn until the firefighters intervene to control fire".* According to most respondents, many combustible materials, either material itself or packing materials stored in warehouses, can also lead to uncontrollable fire spread.

4.3 LEVEL OF EXISTING FIRE PROTECTION SYSTEMS IN WAREHOUSES IN SRI LANKA

The CIDA fire regulation, comparable to other international regulations and codes of practice, emphasises the provision of active and passive fire protection to warehouses. Installation of fire protection such as portable fire extinguishers, hose reels, landing valves, external hydrants, smoke extraction systems, and fire sprinklers depends on the floor area of the compartment or area of the warehouses and vice versa. Similarly, compartment size is limited unless it is protected with fire sprinklers. Table 4 summarises the requirements of the CIDA Fire Regulation to protect warehouses and the respondents' views.

Table 4: Requirements of CIDA fire regulation and views of respondents

CIDAFR Requirement	Respondents' Comments
Compartment size should be limited unless an auto fire protection system is provided.	It is not practical to follow the compartment limitation in warehouses. Most of the warehouses have not provided sufficient fire protection.
A fire detection system should be provided in warehouses.	Some warehouses belonging to multinational companies provided sufficient protection. Most of the warehouses have not provided sufficient fire detection systems.

CIDAFR Requirement	Respondents' Comments
Fire protection and detection systems should be maintained periodically.	Most warehouses have not been maintained periodically. Some warehouses belonging to multinational companies are maintained periodically.
Clear external access to warehouses shall be provided and maintained	Even though many warehouses provided access, it was found obstructed. The old warehouse, built before CIDA came into force, was not provided.

All respondents agreed that most warehouses in Sri Lanka have not been protected adequately, and most of the warehouses in Sri Lanka do not comply with the CIDA fire regulation. R9 further added that many warehouses in Sri Lanka found only portable fire extinguishers even though the requirements are higher than that. In addition, R1 stated that some other warehouses that maintain ISO standards have sufficient fire protection. R8 highlighted that providing passive fire protection in the warehouse is difficult due to its nature. For instance, "*We cannot limit the compartment size as the warehouse needs a large open area. Therefore, we have to consider only the active fire protection"*, R8 further stated. According to R10, some warehouses exceeded the CIDA compartment limitation; nevertheless, there was no sprinkler system. CIDA fire regulation sets guidelines for installing fire sprinklers, hose reels, fire hydrants, and detection systems to protect the warehouse. As per most of the respondents, most of the warehouses in Sri Lanka do not comply with the CIDA fire regulation.

4.4 SUMMARY OF FINDINGS ON FIRE SAFETY MEASURES FOR WAREHOUSES IN SRI LANKA

Figure 1 presents the findings for fire safety measures for warehouses in Sri Lanka.

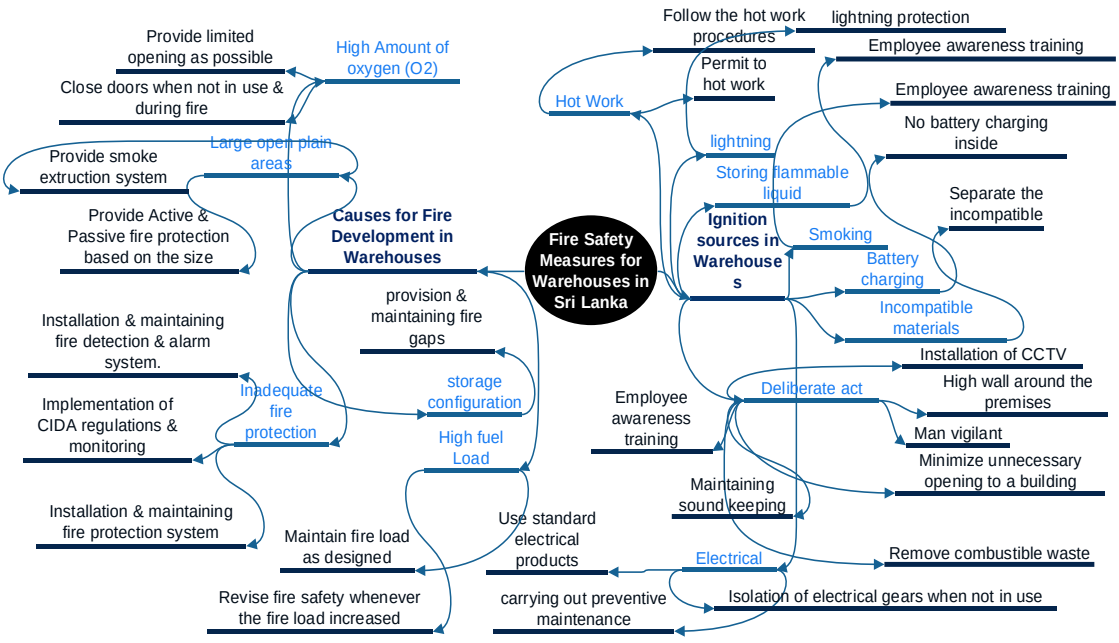

Figure 1: Summary of findings on fire safety measures for warehouses in Sri Lanka

According to most respondents, several factors contribute to warehouse fire development, including high fuel loads, ample oxygen supply, storage configurations, and inadequate or faulty fire protection and detection systems. Nine out of ten respondents emphasised that the high fuel load, due to the large amounts of combustible goods stored, is a leading cause of rapid-fire development. Additionally, high amounts of oxygen, facilitated by high roof levels and large open areas, create ideal conditions for fire growth. Respondents also highlighted that opening such as roller shutters and doors, often left open for access and exit, continuously supply Oxygen to the fire, exacerbating the situation. The absence of compartment walls in warehouses further allows the fire to spread unchecked from its origin.

Storage configurations play a crucial role in fire spread and development, with respondents noting that configurations like rack storage, with its high ignitable surfaces and narrow gaps between racks, can lead to rapid fire escalation. The storage height influences fire spread, as hot smoke, gases, and flames tend to travel upwards. Inadequate fire detection and protection systems significantly contribute to fire development in warehouses. Respondents pointed out that the absence of early fire detection systems and firefighting equipment allows fires to grow uncontrollably. Faulty or insufficient fire protection measures further delay the identification and response to fires, providing more time for the fire to develop and spread, underscoring the critical need for adequate fire safety measures in warehouses.

4.5 STRATEGIES TO MITIGATE FIRES AND FIRE DAMAGES IN WAREHOUSES IN SRI LANKA

This section analyses the primary data to find solutions to protect the warehouses and identify the parties responsible for implementing them. All respondents mentioned that the fire protection systems in existing warehouses in Sri Lanka are inadequate and need to be improved to mitigate the impact on the warehouses and save lives. R4 commented, *"The CIDA fire regulation guideline and code of practice are somewhat sufficient if implemented correctly. However, improvement should be made based on the content stored, structure, and storage height, which have not been addressed in the regulation".* Similarly, R10 argued that the CIDA regulation would be sufficient if implemented fully and monitored by the enforcement authority. However, R10 also agrees with improving fire safety in warehouses in Sri Lanka.

During semi-structured interviews, experts presented the findings of the Framework for Strategies to Mitigate Fire and Fire Damages. Figure 2 presents the findings.

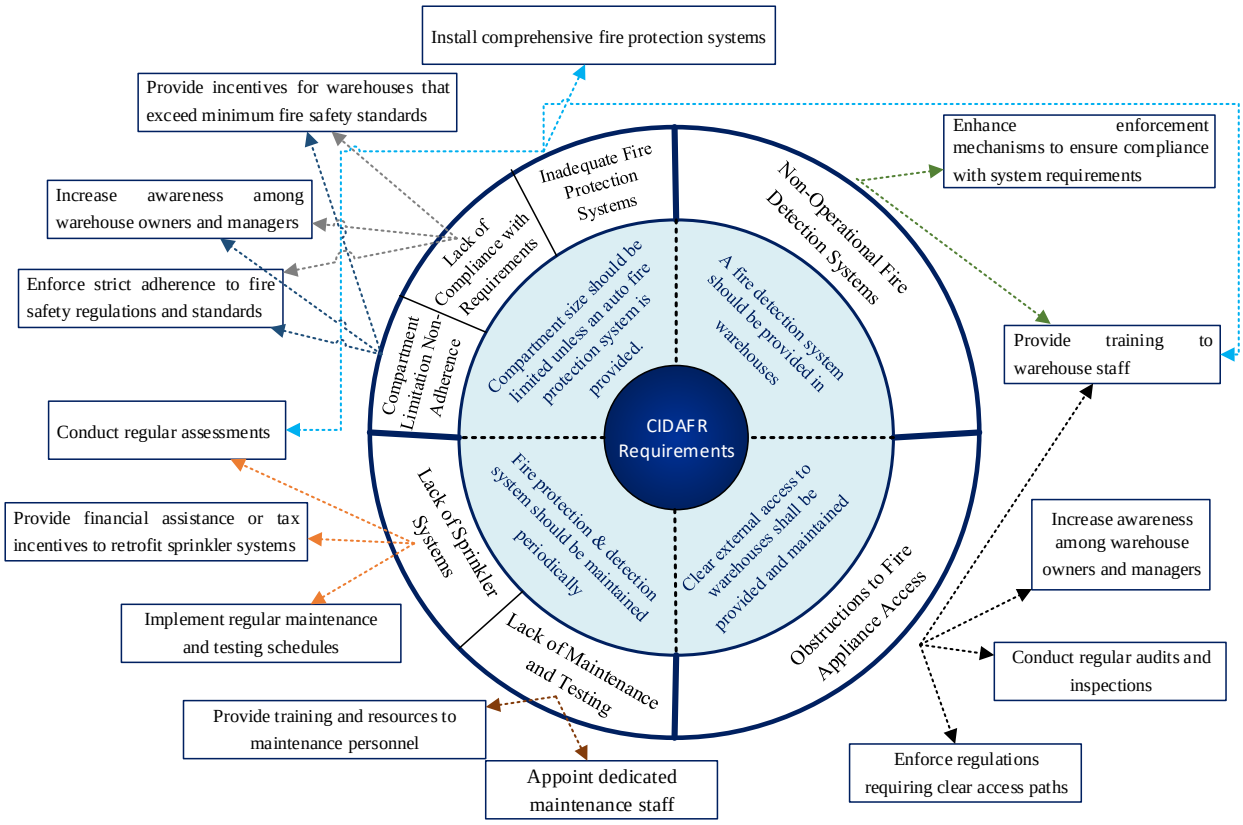

Figure 2: Framework for strategies to mitigate fires and fire damages

Many respondents agreed that the large areas used to store goods could be protected by providing sufficient fire gaps among storage stacks and walls to stacks as they can prevent fire spread due to flame impingement and radiant heat. Agreeing to the above, R1 added, *"maintaining fire gaps between storage piles and wall to racks, and ventilation arrangement such as smoke extraction system, and using a fire-rated structural material to build the warehouses could improve fire safety".* Similarly, R8 stated that installing a smoke extraction system could mitigate fire spread and potential damages. According to R6, to improve fire safety in warehouses, *"the designers should analyse the risk and come up with the suitable protection".* However, R4 mentioned that fire risk assessment should be carried out periodically to check whether the fire load and class of content have changed. This will help control the designed quantity and the type of goods unchanged and review the fire protection if any changes occur.

5. DISCUSSION

Fire safety in warehouses is a critical concern, and the findings of this research highlight several key areas that demand immediate attention and improvement. The inadequacy of current fire protection measures in many Sri Lankan warehouses exposes these facilities to significant risks, underscoring the urgent need for comprehensive fire safety strategies. A proactive approach to fire safety begins with the strategic design and layout of warehouses. Ensuring sufficient gaps between storage racks, stacks, and walls is fundamental in preventing the rapid spread of fire. This measure, supported by many respondents, is complemented by creating fire breaks and maintaining open areas to optimise sprinkler coverage (Security, 2019). Proper ventilation, achieved through

transverse and longitudinal flue spaces within rack systems, enhances the dispersion of fire effluents and the effectiveness of sprinkler systems, a critical factor in fire mitigation.

Smoke extraction systems are another pivotal component of a robust fire safety strategy. These systems help control the spread of fire and ensure that clear escape routes are available for occupants, a recommendation strongly supported by some respondents. Additionally, incorporating fire risk analysis during the design phase and conducting periodic fire risk assessments are essential practices for adapting and updating fire protection measures as needed (Meacham et al., 2016). Early fire detection and rapid response are crucial for minimising damage. The widespread endorsement of fire detection systems among respondents highlights their importance, provided these systems are correctly installed and maintained. Installing fire sprinkler systems, specially tailored to specific storage configurations and commodity types, is widely recognised as a vital measure for controlling fire spread in warehouses (Meacham et al., 2016; Moran & Knight, 2021). The debate between the use of in-rack sprinkler systems versus ESFR systems reveals varying preferences based on storage types and configurations. While in-rack sprinklers are favoured for high-pile rack storage, ESFR systems, despite their limitations, offer rapid response capabilities that can be augmented with additional protections (NFPA, 2013).

Segregation of warehouse commodities according to their fire risk classes and implementing appropriate fire protection measures is another critical aspect respondents emphasise (Overholt et al., 2011). Controlling ignition sources, such as adequately maintaining electrical systems and equipment, is crucial for fire prevention. Additionally, precautions around battery charging operations and storing flammable liquids can significantly reduce fire risks (CIDA, 2018). Proper chemical storage practices, including maintaining safe distances between incompatible materials, are essential for preventing chemical-related fires (Saffarinia et al., 2021). Security measures, such as installing CCTV systems, employing security personnel, and rigorous housekeeping practices, prevent arson and unauthorised access (Meacham et al., 2016).

Finally, ensuring clear external fire access routes and conducting regular inspections are vital responsibilities for warehouse owners and fire departments. These measures ensure that in the event of a fire, emergency services can respond swiftly and effectively (Meacham, 2016). By addressing these findings and implementing comprehensive fire safety measures, warehouses in Sri Lanka can significantly mitigate the risk of fires and protect both property and human lives. The collective insights from this research provide a blueprint for enhancing fire safety protocols and fostering a safer working environment in warehouse facilities.

6. CONCLUSIONS

This study aims to devise strategies to diminish fire incidents and substantial damages in Sri Lankan warehouses. Employing a qualitative methodology, data was gathered via semi-structured expert interviews, supplemented by a rigorous content analysis of empirical findings. The literature review provided insights into the general construction attributes of warehouses, ignition sources, commodity types and their arrangements, fire behaviour, and existing fire protection measures. The interviews not only corroborated the literature but also tailored the findings to the Sri Lankan context, facilitating the development of a targeted fire safety framework. The results underscore the potential for

this framework to increase awareness of fire causatives and enhance preventive actions. Crucially, the study underscores the role of governmental regulation in enforcing suitable fire protection standards, which is pivotal for the practical application of these findings.

Despite the comprehensive approach, this research acknowledges certain limitations. It excludes high-hazard categories such as chemical or liquid gas storage. It does not consider smaller storage facilities, focusing primarily on property protection rather than life safety due to the time constraints of the research team. However, these limitations inform further areas for research, suggesting that future studies could apply the developed framework in case study scenarios to test its effectiveness and scope. Overall, while this study contributes to the existing body of knowledge by identifying common causes of warehouse fires globally and within Sri Lanka, it also significantly establishes a novel framework to reduce fire-related losses in warehouse settings. Further investigation through case studies is recommended to validate and refine the proposed framework.

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