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Analysis of Fire Safety Management in Construction Work at I Gusti Ngurah Rai Airport Bali

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Occupational safety; fire safety; construction; risk management.

Abstract
Fire safety is an important aspect of construction project management, especially in strategic areas such as airports that are highly vulnerable to fire hazards. This study aims to evaluate the implementation of fire safety management on a construction project conducted by PT X at I Gusti Ngurah Rai International Airport, Bali, in 2024. The author used a case study method with a qualitative approach, which involved field observations, in-depth interviews with project personnel, analysis of safety documents, and analysis of relevant regulations. The results showed that PT X has implemented several key elements of fire safety management, including hazard identification, provision of light fire extinguishers (APAR), evacuation training, and emergency response procedures. However, some weaknesses were identified, such as the lack of regular inspections of fire protection equipment and limited socialization of safety procedures to all workers. This study recommends increasing supervision, providing ongoing training, and aligning practices with the latest regulations for improvement. The findings are expected to serve as a reference for similar construction projects in high-risk areas particularly in Indonesia.

INTRODUCTION

Airports (Airports) as air transportation facilities are areas with a high level of operational complexity, both in terms of user safety, infrastructure management, and fire risk (Meacham, 2022) This risk becomes even greater during construction activities, such as terminal renovation, construction of supporting facilities, or runway expansion, which can introduce various new potential hazards such as the use of flammable materials (Başdemir, 2019)), hot work, an increase in the amount of temporary materials at the work site (Barua et al., 2024) failure to detect and control the presence of fire quickly (ILO, 2021).

I Gusti Ngurah Rai International Airport in Bali is one of the busiest airports in Indonesia that serves as a gateway for national and international tourism. With the high volume of passenger traffic and strict international safety standards, risk management, especially related to fires in construction projects, must be carried out systematically and integratedly (Darko et al., 2020) Fire safety management in construction work should include aspects of emergency planning, fire source control, flammable material surveillance (Zheng et al., 2022) as well as worker training for rapid response to fire incidents (Fong et al., 2006) However, in practice, some studies reveal that there are still many construction projects in public areas, including airports, that face challenges in the implementation of safety procedures, either due to lack of awareness, limited resources, and weak surveillance systems (Patel, 2017)

This research is important considering that construction accident data in Indonesia, including those related to fires, still shows a significant trend. In the global record of work accidents due to fires that cause a large number of deaths, it ranks second only to natural disasters such as earthquakes and tsunamis. From 2021 to 2022 in Indonesia, there were 1,630,393,796 working hours per day from construction work and currently there are 186,534 companies engaged in construction spread throughout the province of Indonesia ((BPS, 2024) With this amount, if it fails to prevent or control the danger of fire, it can cause enormous losses, not only in terms of physical damage to buildings, but can also disrupt airport operations, endanger the safety of workers, passengers, and damage the reputation of airport managers (Sivakumar, 2022).

With this background, this study aims to analyze fire safety management in construction work at I Gusti Ngurah Rai Airport Bali in 2024. The main focus of the research is to evaluate the readiness of fire safety management, the effectiveness of implementing fire procedures, and the identification of potential improvements to prevent and minimize fire risks during the implementation of construction projects. With the results of this study, it is expected to provide data-driven recommendations to improve construction safety standards in airport areas, in line with national occupational safety principles and international regulations such as ICAO Annex 14 (ICAO, 2018) and NFPA 241 (National fire protection association, 2004)

The urgency of this research lies in the high level of fire risk in strategic public areas such as airports, particularly during construction projects that involve high-risk activities such as welding, the use of flammable materials, and temporary electrical installations. Although national and international fire safety regulations are available, their implementation is often suboptimal especially in short-term projects characterized by dynamic conditions and multiple subcontractors. This underscores the need for a comprehensive evaluation of fire safety management practices on-site.

The novelty of thi study stems from its specific focus on construction projects within airport environments settings with complex operational demands and strict international safety standards. Unlike previous studies that tend to assess fire safety generically, this research integrates field-based analysis with the Fire Risk Reduction and Control (ILO, 2021) framework and compliance with national Indonesian regulations. This offers a practical and comprehensive perspective that is rarely addressed in existing literature.

The main objective of this research is to evaluate the effectiveness of fire safety management systems implemented in a construction project at I Gusti Ngurah Rai International Airport in Bali, and to identify key weaknesses and potential areas for improvement. Additionally, this study aims to assess the extent of compliance with both national regulations and international standards related to fire safety.

Theoretically, this research contributes to the literature on fire risk management in the construction sector, particularly in sensitive environments such as airports. Practically, the findings are expected to provide actionable recommendations for contractors, project owners, and regulatory bodies to enhance fire safety systems that are more effective and sustainable. The study's outcomes may also serve as a reference for developing data-driven construction safety policies in Indonesia.

METHOD

This study uses a descriptive qualitative approach with a case study method on a construction project at I Gusti Ngurah Rai Airport Bali. The data collection technique was carried out through observation of primary data, in-depth interviews with the project work safety supervisor, and document analysis related to fire safety procedures. The data obtained was analyzed using the triangulation method to increase the validity of the results. The framework of the research concept (Figure 1), starting from observation, interviews and access to field data to obtain inputs using *the approach of The five steps to undertake a fire risk assessment* (HSE, 2010) namely; control of flammable materials, reduce the potential for ignition of fires, identification and rapid notification of the presence of fire or smoke, effective emergency provision and procedures, fire control, as well as fire risk management, information, training and education. In addition, the fulfillment of regulations related to fire safety in the workplace that apply in Indonesia is also used as input.

From this data, for the process, the author analyzes using *the Fire Risk Reduction and Control* (HSE, 2010) approach , namely; control of flammable materials, control of fire ignition potential, identification and rapid notification of fire or smoke, availability of emergency procedures, fire control, fire risk management, as well as information, training and education on fire safety. Furthermore, based on the analysis, the findings of conformity and non-conformity can be described as practical recommendations to construction project management for the improvement of fire safety management in other construction projects in the future.

RESULTS AND DISCUSSION

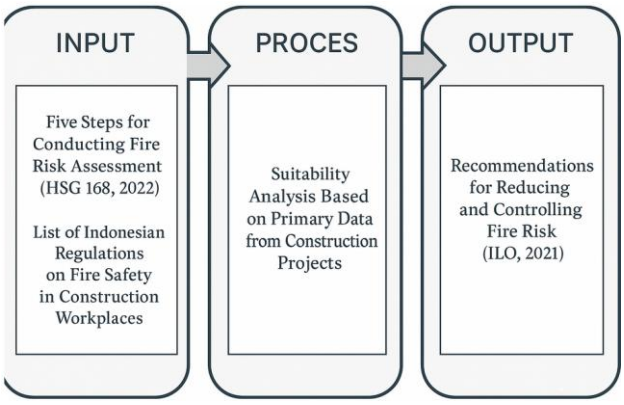


Figure 1. Research Concept Framework

The results of field observation using the approach *The five steps to undertake a fire risk assessment* (HSE, 2010) are; First, construction management has identified fire hazards such as the identification of heat and fire sources, potential fuel sources, and oxygen sources (Ferreira, 2022) as evidenced by the *hazard identification risk assessment and determining control* (HIRADC) documents that have been available. Second; Construction management has identified anyone who may be harmed by the fire, but there is no record of the number of people at the work site so there is no risk of being left behind at the job site in the event of a fire emergency. In addition, construction management has provided emergency access for everyone on the job site, but advanced risks are not yet fully controlled, such as the

unavailability of handrails on temporary emergency stairs (Figure 2) which may give rise to further risks such as falling.



Figure 3. *Handrail* on emergency access not yet installed



Figure 2. Sparks at Iron Cutting Work Have Not Been Controlled

Third; construction management has evaluated, eliminated, reduced, and protected from fire hazards and risks, but has not been consistent in supervision such as the discovery of effectively uncontrolled sparks from the iron cutting work (figure 3), the lack of special smoking site arrangements, and improper storage of heavy equipment diesel fuel, emergency lighting is not available at the evacuation access route, and project-specific emergency siren systems are not yet available. Fourth; construction management has planned, provided information (Zhao, 2024) instructed, provided training, and recorded all activities in an effort to reduce fire risk in the project, but the number of competent firefighters available is still considered insufficient to protect the overall number of workers (Hulse et al., 2022). Fifth, construction management has carried out a review of the implementation of the fire emergency response plan by involving work supervisory consultants from the project's internal parties, but from external parties (consultants) who have special expertise have not been involved, such as the implementation of a special external audit of fire emergency preparedness (Grover et al., 2023) The external audit in question is not mandatory, it will only increase opportunities for continuous improvement.

The results of the analysis of the fulfillment of regulations related to fire safety in the workplace that apply in Indonesia are considered to have been met, but there are still some findings of non-conformity such as the lack of handrails not being installed on emergency stairs, lack of risk control in welding work, and improper storage of heavy equipment diesel fuel.

Table 1. List of Indonesian Regulations Regarding Fire Safety in Construction Workplaces

No.	Regulation	Description of the Regulations	Fulfillment Status
1	Law No. 1 of 1970	Occupational Safety	Fulfilled
2	Law No. 8 of 2002	Building	Fulfilled
3	Law No. 31 of 2009	Firefighter	Fulfilled
4	Law No. 2 of 2017	Construction Services	Fulfilled

5	Law No. 17 of 2023	Health	Fulfilled
6	Law No. 6 of 2023	Enactment of Government Regulation in Lieu of Law Number 2 of 2022 concerning Job Creation into Law	Fulfilled
7	Government Regulation No. 7 of 2011	Implementation of Fire Management	Fulfilled
8	Government Regulation No. 50 of 2012	Occupational Safety and Health Management System	Fulfilled
9	Government Regulation No. 16 of 2021	Implementing Regulation of Law No. 28 of 2002 concerning Buildings	Fulfilled
10	Government Regulation No. 28 of 2024	Regulations for the Implementation of Law No. 17 of 2023 concerning Health	Fulfilled
11	Ministry of Manpower Regulation No. 186 of 1999	Workplace Fire Suppression	Filled with notes
12	Ministry of Manpower Regulation No. 4 of 1980	Installation and Maintenance Requirements for Light Fire Extinguishers	Fulfilled
13	Ministry of Manpower Regulation No. 2 of 1983	Automatic Fire Alarm Installation	Fulfilled
14	Ministry of Public Works and Public Housing Regulation No. 26/PRT/M/2008 of 2008	Technical Requirements for Fire Protection Systems in Buildings and Environments	Filled with notes
15	Ministry of Manpower Regulation No. 5 of 2018	Occupational Safety and Health of the Work Environment	Fulfilled
16	Ministry of Public Works and Public Housing Regulation No. 10 of 2021	Construction Safety Management System Guidelines	Fulfilled
17	Ministry of Manpower Decision No. 186 of 1999	Workplace Fire Suppression Unit	Filled with notes
18	KB. Minister of Manpower and Public Works Decree No. 147 of 1986	Occupational Safety and Health at Construction Sites	Fulfilled

From the two analysis inputs mentioned above (Figure 1), the construction project management ability of PT. The X in the application of fire safety management in the workplace can be described as follows. First, project management ensures that all workers have received information, instructions, and training on how to work safely when handling/storing/using flammable materials, this is evidenced by the presence of attendance list documents and photo evidence of implementation. Highly flammable liquids and gas bottles have been stored safely and labeled (Makeenkov et al., 2015) Flammable materials such as paper, fabric, wood, plastic, packaging materials, chemicals, etc. are not allowed to be stored under stairs or near sources of ignitors such as; heating equipment, cabinets or electrical appliances, places where hot work is taking place such as welding, and smoking places (Hassanain et al., 2022). All flammable materials and liquids have been adequately labeled and stored in appropriate refractory containers where chemical warning signs, classifications and labelling are affixed.

Second, the existence of a heat source or ignition of a fire either related to the location of flammable materials can be easily controlled (Hsiao & Hsieh, 2023) The measures implemented for this control have been contained in the construction work safety management plan (Park & Kim, 2013) namely; no smoking in the workplace, except in places with a dedicated area for smoking, safe access to minimize the potential for fire, a good hygiene program for the hot work area (welding/grinding), then after the work is completed, there is a regular inspection in the work area to ensure the material does not burn, and effective electrical maintenance and inspection. From field observations, to minimize the potential for static electricity that causes sparks, control has been carried out using the grounded method, the electrical circuit has a fuse.

Third, automatic alarms and warning systems are available as early warnings of fire (Ji, Li, & Zhu, 2022) Alara is able to reach up to the area of the building where flammable materials or flammable liquids are stored (Ji, Li, & Lou, 2022) However, because the building is still in the construction stage, heat and smoke treatment has not been installed using the regular work site monitoring method with a duration of time every 2 hours to all work areas. Regarding the need for evacuation routes, project management already has one qualified main access route (sign, lighting) that can be multifunctional and one emergency route on the other side that can only be opened in the event of an emergency (Daamena & Hoogendoorn, 2010) The project management was also able to prove through the fire evacuation simulation report that the workers had been given self-rescue training.

Fourth, a Light Fire Extinguisher (APAR) has been available, adjusted to the type of fire (Daamena & Hoogendoorn, 2010)given a triangle symbol, and a red tube. The fire extinguishers are placed in such a way that they are separated from obstructing objects and hung on the wall between 15 cm – 120 cm from the floor surface so that it is easily accessible to all people in the project.

Fifth, efforts to control fires, project management appoints 4 employees who have a class D firefighting license and 1 person with a class C firefighting license for a total of 85 active workers every day, each employee who is a member of the emergency response organization structure is equipped with a radio communication device (HT) as a medium of communication speed. The number of workers and visitors in the construction work area is recorded and controlled where everyone entering the construction project is required to have proof of a sticker that has received a safety induction in which they are instructed on evacuation procedures. Project management has a fire emergency procedure as a standard reference for

project firefighters who are given the additional task of inspecting the work area, arranging, and reporting project conditions regularly to the person in charge of occupational safety. In this procedure, when evacuation is carried out, everyone is directed to the gathering point and remains there until the emergency status is lifted (Vespaziani, 2019) An external assistance route (Adesina, 2021) has been prepared through the main access of project vehicles (as opposed to worker access) so that it facilitates access for emergency services to the construction site in the event of a fire.

Sixth, emergency procedures are available on the K3 information board as a continuous reminder (socialization) to all workers. Furthermore, some workers have been given formal training (Andrew and Muckett, 2007) on handling fire emergencies. Then several other representatives took turns receiving refresher training on a regular basis. Especially for guests, they were given instructions and information about the fire alarm warning system, evacuation routes, and fire gathering points in the form of leaflets for easy understanding.

Discussion

This study shows that PT X's project management on the construction work at I Gusti Ngurah Rai Airport Bali has implemented most of the fire safety principles recommended by international and national standards, as outlined in NFPA 241 and ICAO Annex 14. One of the main strengths found is the existence of a training program and occupational safety socialization for workers, including training in the use of light fire extinguishers (APAR) and emergency evacuation procedures. This is in line with research (Chow et al., 2013) which states that regular training can improve a quick and effective response to fire incidents on construction sites. However, there are still some significant mismatches that need to be corrected to minimize the potential risk of fire.

The appropriate placement of fire extinguishers, safe storage of flammable materials, and available heat work procedures demonstrate the application of good fire risk control principles (Jaafar et al., 2018) However, some weaknesses are still found, such as the unavailability of handrails on temporary emergency ladders, storage of diesel fuel that is not up to standard, and spark control from metal cutting work that is not optimal. These findings are in line with a report by Divya (Patel, 2017)which asserts that a major challenge in public construction projects, particularly in airport areas, is the lack of consistency in the supervision and implementation of daily fire safety standards. Another aspect that needs to be considered is the unavailability of automatic early detection systems such as smoke detectors during the construction period. In fact, according to research (Barua et al., 2024) early detection systems play a crucial role in reducing response time to fires and minimizing losses. In this context, the bi-hourly manual monitoring implemented by PT X can be categorized as a temporary solution, but it cannot replace the effectiveness of automated systems.

The external involvement of safety auditors is also one of the areas that has been underpaid. External audits by independent third parties have proven to be effective in improving compliance with safety standards and encouraging continuous improvement (Barua et al., 2024) By engaging certified professional auditors, construction projects in sensitive areas such as airports will be better able to anticipate and proactively manage fire risks. In the context of risk management in general, PT X's approach is quite in line with the Fire Risk Reduction and Control (ILO, 2021) model, but needs to be strengthened on administrative and technical

control aspects, such as stricter segregation of smoking areas and risk labeling in fuel storage areas.

Overall, the results of this study reinforce the importance of full integration between fire safety planning and the active construction stages, as suggested by Zheng (Zheng et al., 2022) where safety is not only seen as an administrative requirement, but rather as an integral part of every technical and managerial decision in a project. The implementation of this recommendation not only improves the safety of airport workers and users, but also maintains the reputation of contractor companies and airport operators in meeting national and international occupational safety standards.

CONCLUSION

This study shows that the fire safety management in the construction project at I Gusti Ngurah Rai Airport Bali by PT X has generally met national and international fire safety standards. Practices such as routine safety training, appropriate storage of hazardous materials, and provision of emergency evacuation access have been implemented quite well. However, there are several critical areas that still need to be improved, including inconsistent supervision of high-risk work (such as welding), suboptimal fuel storage, and limitations in early detection of fires due to the lack of automatic alarm systems. These findings underscore the importance of strengthening internal and external control systems, as well as the need to integrate fire safety into every operational aspect of construction projects in sensitive public areas such as airports. Considering the importance of airport operational continuity and the safety of service users, fire risk management in construction projects should be an integral part of project planning and execution.

Based on the results of the analysis and discussion, some suggestions for improvement that can be given include; The installation of temporary smoke and heat detection systems during the construction phase needs to be prioritized to speed up the response to fire incidents, Immediately equip evacuation access facilities, such as the installation of handrails on emergency stairs and the provision of evacuation path lighting, to reduce the risk of falls and smooth the evacuation process. Supervision of high-risk activities such as heat work should be carried out more strictly and continuously, including providing dedicated smoking areas that meet safety standards. Engage certified external auditors to conduct periodic fire safety audits to enhance evaluation objectivity and encourage continuous improvement.

Increase the ratio of certified firefighters to active workers, in accordance with best practices in construction safety in high-risk areas. Conducting regular fire safety training refresher programs for all workers, subcontractors, and project visitors, so that the work safety culture is maintained consistently. The implementation of these suggestions is expected to improve fire safety management in construction projects, reduce the potential for incidents, and improve the safety and reliability of airport operations in the long term.

For future development, it is recommended to conduct several experiments, including simulations of small-scale fires in construction areas to test the effectiveness of evacuation procedures and extinguishing response, as well as evaluation of the use of portable smoke detection systems to improve early detection in sites without permanent protection. In addition, it is necessary to conduct experiments comparing the effectiveness of standard fire response training with virtual reality (VR) simulation-based training, as well as studies on the use of alternative building materials that are more resistant to fire to reduce potential fire risk. It is

also recommended to test the integration of temporary fire protection systems such as portable sprinklers, as well as analyse the relationship between the level of mobility in the project area and the increased risk of fire, so that in the future mitigation measures can be more data-based.

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