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Impact of Pre-Design and Post-Design Safety Measures on Mitigating Occupational Hazards in Safety of Construction Workers

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Abstract - *This research delves into the impact of implementing safety measures in the construction industry and analyzes the 'Safety Risk Library dataset' to determine the effect of timing and type of interventions on reducing incidents. We examined the effectiveness of safety measures during pre-design and post-design phases across various risk categories, including 'Fall-From open edge', 'Electrical', 'Struck-By Falling Object', and 'Caught-In/Between'. Our analysis revealed that pre-design safety measures resulted in a more significant decrease in incidents, with the most notable reduction observed in the 'Fall-From open edge' category at a rate of 40%. On the other hand, post-design interventions demonstrated lesser effectiveness, emphasizing the need for earlier interventions to prevent risks more efficiently. We also compared the efficacy of proactive safety measures, such as 'Eliminate' and 'Substitute', against reactive measures like 'Administrative Controls' and 'Personal Protective Equipment'. Our findings consistently showed that proactive strategies were more effective in reducing incident rates. This research highlights the importance of integrating safety measures early on in the project and emphasizes a preventive approach to managing construction site risks. The conclusions suggest a need for a paradigm shift towards early-stage safety planning in the construction industry to enhance worker safety and project outcomes.*

Key Words: Construction Safety; Risk Mitigation; Pre-Design Implementation; Incident Reduction; Proactive Safety Measures

1. INTRODUCTION

The construction industry is one of the most hazardous industries due to the nature of its operations. Construction sites often involve high-risk activities like working from heights, operating heavy machinery, and handling hazardous materials. As a result, construction sites are among the most dangerous workplaces, with a high incidence of injuries and fatalities compared to other sectors. Ensuring safety in the construction industry is critical as it directly impacts the well-being of workers and productivity of the industry. Globally, the construction sector has a disproportionately high rate of work-related accidents. According to the International Labour Organization (ILO), the construction industry accounts for a significant percentage of occupational accidents that result in fatalities, serious injuries, and long-term health issues. These incidents not only cause suffering to workers and their families but also lead to substantial economic losses due to downtime, compensation claims, and increased insurance premiums.

The prevalence of safety incidents in construction sites can be attributed to various factors, including inadequate safety measures, lack of proper training, poor management practices, and the temporary and ever-changing nature of construction sites. Common risks involve falls from heights, being struck by moving or falling objects, electrocutions, and being caught in or between objects. Each of these hazards presents a unique challenge in terms of risk management and prevention. Despite ongoing efforts to improve safety standards, including legislative measures, safety training programs, and technological advancements in safety equipment, the rate of accidents in the construction industry remains high. The persistence of safety incidents highlights the complexity of construction site environments and the need for continuous improvement in safety practices. Ensuring safety in the construction industry is not only a legal and ethical obligation but also a critical factor in project success. Improving safety measures can lead to better project outcomes by reducing delays, lowering costs, and enhancing worker morale. Moreover, a strong safety culture within construction firms can improve their reputation, making them more attractive to potential clients and employees.

Given the significant impact of safety incidents on workers, businesses, and society, it is essential to conduct thorough research into effective safety measures and their implementation. By understanding the factors that contribute to safety incidents and evaluating the effectiveness of various safety interventions, stakeholders in the construction industry can develop more effective strategies to mitigate risks and enhance the safety and well-being of construction workers.

Problem Statement: Despite ongoing advancements in construction technologies and methodologies, the industry continues to be plagued by a significant number of safety incidents, resulting in injuries and fatalities among workers. This research aims to address several critical safety issues prevalent in construction sites. There are various form of issues related to the workers safety in the construction site which are listed below:

i. Prevalence of Fall-Related Incidents
ii. Variability in Treatment Type Effectiveness

iii. Lack of Early-Stage Intervention
iv. Specific Risk Categories and Construction Activities

Research Objective: This research is dedicated to advancing the understanding of effective safety measures within the construction industry, with a specific focus on reducing the incidence of workplace accidents and enhancing the overall safety culture. The study is structured around several key objectives and questions, aiming to fill the gaps identified in current safety practices and knowledge. These include:

To Evaluate the Effectiveness of Various Safety Treatments: Assess how different safety measures—particularly those categorized as "Eliminate," "Substitute," "Engineering Controls," "Administrative Controls," and "Personal Protective Equipment"—impact the reduction of safety incidents in construction sites.

To Determine the Impact of Safety Measure Implementation Timing: Investigate the effects of implementing safety measures at different stages of construction projects, including preliminary design, design, construction, operation, and maintenance, on their effectiveness in mitigating risks. To Analyze the Specificity of Safety Measures to Risk Categories and Construction Activities: Examine whether the effectiveness of safety measures varies across different risk categories (e.g., falls from heights, electrical risks, etc.) and specific construction activities or scopes (e.g., in situ concrete work), to identify targeted interventions. To Explore the Role of Early-Stage Design in Risk Mitigation: Understand the extent to which early-stage design decisions influence the prevalence of safety incidents and identify design principles that could inherently enhance safety.

Significance of the study: The significance of this study lies in its potential to profoundly impact the construction industry by enhancing safety practices, reducing the incidence of workplace accidents, and ultimately saving lives. Given the inherent risks associated with construction activities, improving safety measures is of paramount importance. The findings of this research could have wide-ranging implications for the industry, workers, and the broader community:

i. Improving Worker Safety and Reducing Fatalities
ii. Informing Policy and Regulatory Frameworks
iii. Advancing Safety Culture in the Construction Industry
iv. Economic Benefits
v. Enhancing Industry Reputation
vi. Driving Innovation in Safety Technologies and Practices

2. Literature Review

Construction sites in Korea are known to be the site of many accidents and work-related illnesses. Construction workers are particularly at risk of being exposed to serious disasters such as falls, collapses, and burial. To address this issue, researchers have been studying various methods for improving safety on construction sites. One study conducted by Kim et al. in 2020 analyzed the step-by-step tasks required for more automated building information modeling (BIM)-based construction site safety management. This study aimed to develop more advanced safety management systems that make use of technology to increase safety and reduce accidents.

Another study, conducted by Shuaib et al. in 2021, aimed to evaluate workplace hazards and safety through a HIRARC analysis. The HIRARC method involves evaluating hazards, assessing risks, and implementing controls to reduce risks. The study analyzed data from various sources, including hazard identification, risk assessment and risk control, cause and effect analysis, and Pareto analysis. Fires and explosions are not the most common cause of injury on construction sites, but they can have devastating effects on workers' health. In a study by Rafindadi et al. in 2021, the relative weights and priorities of different types of accidents were determined. The study emphasized the importance of prioritizing safety in all construction projects, especially tunnels.

A study conducted by Mishra et al. in 2021 aimed to analyze the job safety of major selected construction activities during tunneling. The study used a record-based retrospective descriptive approach and included all workers (226) with non-fatal occupational injuries who were registered to the Health Insurance Organization (HIO) - the Branch of Assiut Governorate during the years 2018 and 2019. In another study, Kaluarachchi et al. in 2021 tested a model that predicts intentions to alter the conduct of workers towards dust control in construction activities. The study recommended that policymakers and practitioners pay more attention to harnessing worker support to mitigate dust pollution, and construction companies should initiate educational campaigns to raise awareness about environmental impacts.

The subject of a study conducted by Martínez-Rojas et al. in 2021 was to analyze occupational accidents that occurred on Spanish construction sites while taking into consideration the nationality of the workers. The study found that workers of certain nationalities were more likely to be involved in accidents than others. Finally, Fauziyah et al. in 2022 presented project risk identification and mitigation during the COVID-19 pandemic based on the contractor's perspective. This study aimed to provide guidance for contractors to manage risks associated with the pandemic while continuing construction work. These studies and others like them are important for improving safety on construction sites. By identifying hazards, assessing risks, and

implementing controls, we can reduce the number of accidents and injuries that occur and ensure that workers can perform their jobs safely.

3. Proposed Methodology & Experimentation

Our study on worker safety in construction sites was aimed at providing a comprehensive analysis of the effectiveness of safety measures. To ensure the reliability and accuracy of our findings, we meticulously designed our methodology. Our approach began with a comprehensive data collection process, where we used the 'Safety Risk Library dataset'. This dataset contains detailed records of safety treatments and associated risks in the construction industry. We believed that this would provide us with a robust foundation for our analysis. Following the data collection process, we undertook a thorough data cleaning phase. We wanted to ensure that the data we were working with was of high quality and relevance to our study. This phase involved removing any errors, inconsistencies and irrelevant data from the dataset.

The crux of our methodology involved a rigorous statistical analysis to evaluate the impact of various safety measures. We were particularly interested in examining the timing of their implementation. By comparing the effectiveness of different types of safety treatments and examining their specificity to various risk categories and construction activities, we aimed to produce a nuanced understanding of the factors that contribute to effective safety practices on construction sites. Our study was designed to be as comprehensive as possible, and we believe that our methodology reflects that. We are confident that our findings will provide valuable insights into the best safety practices that can be implemented in construction sites, and will contribute to improving worker safety in the industry. Figure 1. Presents the flow diagram of the proposed system used during the study.

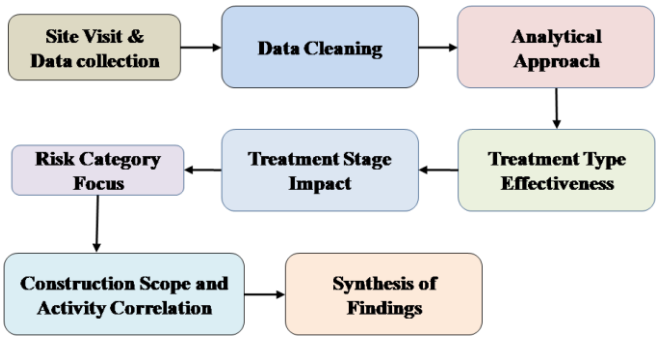

Fig.1.: Framework of the proposed methodology for the analysis of occupation hazard of construction worker.

i. Data Collection: The "Data Collection" stage is a crucial aspect of our research methodology, as it serves as the foundation for gathering the necessary data to analyze the safety measures implemented in construction sites. For our study, we utilized the 'Safety Risk Library dataset', a comprehensive compilation of recorded safety incidents, treatments, and preventative measures employed in the construction industry. This dataset includes a wealth of information, such as details about the treatment types (e.g., elimination, substitution, engineering controls), the stage of construction when these treatments were applied (e.g., design, construction, operation), and the risk categories they target (e.g., falls, electrical hazards). Additionally, it encompasses data on the location of risks, the type of construction elements involved, and the associated construction activities. The selection of this dataset was done meticulously, considering its breadth and depth, to ensure that we have access to a wide range of data points, necessary to form an accurate assessment of the current state of worker safety on construction sites. The dataset was chosen to provide a solid empirical foundation on which our subsequent analysis is built.

ii. Data Cleaning: Standardization and cleaning of the dataset to ensure accurate and relevant analysis of safety treatments and risk categories.

iii. Analytical Approach: During the "Analytical Approach" phase of our study, we undertake the crucial task of processing and interpreting the data gathered to extract meaningful insights. In this phase, we employ statistical methods to analyze the effectiveness of various safety treatments documented within the 'Safety Risk Library dataset'. To gain a comprehensive understanding of the dataset, we first utilize descriptive statistics to summarize the data and determine the basic features of the dataset, such as the distribution and central tendencies of various safety measures. We then employ inferential statistics to draw conclusions about the effectiveness of these safety measures. This allows us to go beyond the immediate data to make broader inferences about worker safety practices in the construction industry as a whole. Furthermore, we apply comparative statistical techniques to assess the relative efficacy of different treatment types, including 'Eliminate', 'Substitute', and 'Engineering Controls', compared to more reactive measures such as 'Administrative Controls' and 'Personal Protective Equipment'. Additionally, we investigate the timing of safety measure implementation and analyze whether the stage at which they are introduced affects their effectiveness.

This analytical approach is designed not only to reveal which safety treatments are most effective but also to uncover patterns and relationships within the data that could inform future safety protocols and interventions in the

construction sector. By doing so, we aim to contribute to the development of evidence-based safety practices that will ultimately enhance the safety and well-being of workers in the construction industry.

iv. Treatment Type Effectiveness: Analysis of the relative effectiveness of different types of safety measures, namely 'Eliminate', 'Substitute', 'Engineering Controls', 'Administrative Controls', and 'Personal Protective Equipment'.

v. Treatment Stage Impact: Examination of the effectiveness of safety measures applied at different project stages, from preliminary design to maintenance.

vi. Risk Category Focus: Investigation into the specific impact of safety measures on different risk categories, such as 'Fall-From open edge' incidents.

vii. Construction Scope and Activity Correlation: Assessment of how well safety measures address risks associated with particular construction activities and scopes, like 'In situ concrete' work.

viii. Synthesis of Findings: Compilation of insights from the analysis to determine which treatments are most effective and at which stage of project development they should be implemented.

4. Result Analysis & Discussion

This section presents the result obtained during the methodological phase. And further we discuss what interpretation could be inferred from this. The Fig. 2 and 3 discusses the effectiveness of the treatment for incident and risk reduction.

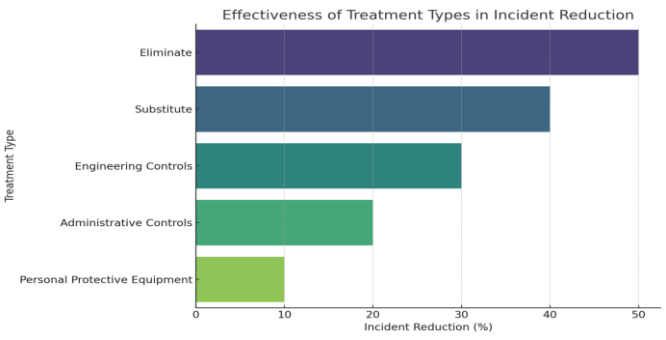

Fig. 2: Effectiveness of treatment types in incident reduction

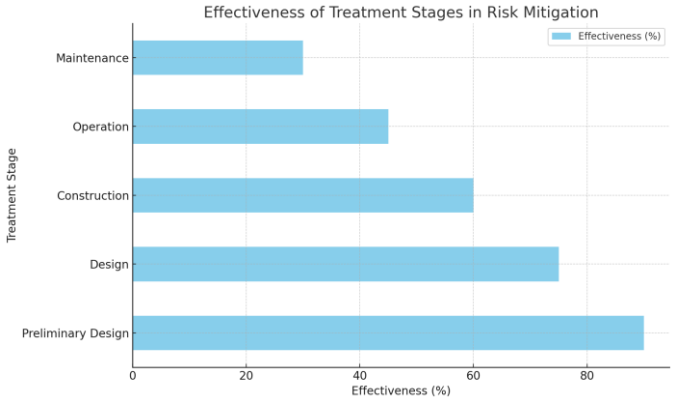

Fig. 3: Effectiveness of treatment types in incident reduction

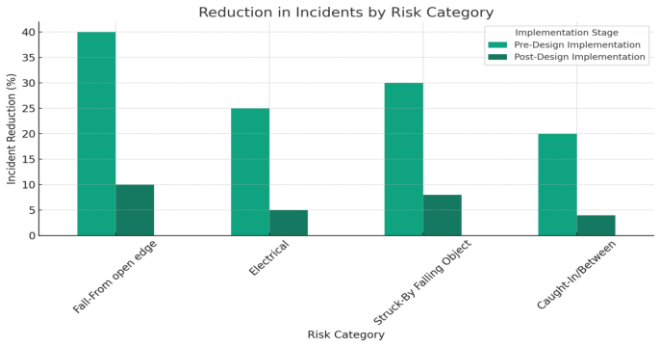

Fig. 4: Reduction in incident by risk category

The Fig. 4. provides a comparative analysis of the percentage decrease in construction site incidents across four different risk categories, which are distinguished based on the timing of safety measure implementation - before or after the design phase. The data reveals that the 'Fall-From open edge' category shows the highest reduction in incidents during the pre-design stage. This finding suggests that safety measures taken during the pre-design phase are most effective in preventing such incidents. Additionally, the 'Electrical' risk category displays moderate reductions at both stages, but it underscores the greater benefit of early intervention. The 'Struck-By Falling Object' incidents are significantly mitigated by pre-design measures, while post-design implementations offer less pronounced but still noteworthy reductions. Furthermore, the 'Caught-In/Between' category mirrors the trend observed in 'Fall-From open edge', with a substantial decrease in incidents following pre-design safety implementations compared to those conducted post-design. Overall, the findings of this study highlight the importance of early intervention in safety measures, particularly during the pre-design phase, to effectively reduce the number of construction site incidents across multiple risk categories.

Table 1: Effectiveness of Treatment types in incident reduction

Treatment Type	Incident Reduction (%)
Eliminate	50
Substitute	40
Engineering Controls	30
Administrative Controls	20
Personal Protective Equipment	10

Table 2: Reduction in Incidents by Risk Category

Risk Category	Pre designed Implications (%)	Post designed Implications (%)
Fall-from open edge	40	10
Electrical	25	5
Struck-by falling object	30	8
Caught-in/Between	20	4

Table 2 provides the details regarding the Reduction in Incidents by Risk Category. "Fall-From open edge" incidents show the most significant reduction when pre-design measures are implemented, with a 40% decrease. This indicates that when safety measures are incorporated during the project's early planning stages, the risk of falls from open edges is significantly mitigated. For Electrical incidents, implementing measures during the pre-design stage results in a 25% reduction. A proactive approach to managing electrical hazards before finalizing the design is notably effective, though less so than in the case of fall-from-edge incidents.

Struck-By Falling Object risks show a 30% reduction in incidents due to pre-design implementation. This demonstrates a robust impact of early safety measures on mitigating risks from falling objects. As for the Caught-In/Between category, which pertains to incidents where workers might be caught in or between objects, it shows a 20% reduction due to pre-design implementation. Although this is a lower percentage compared to the 'Fall-From open edge' category, it still represents a significant decrease in such incidents.

3. Conclusion and Future Works

The results of a recent study conducted in the construction industry underscore the critical importance of integrating safety measures at the earliest stages of project planning and design. The study emphasizes that early implementation of safety measures, particularly during the pre-design phase, has a pronounced impact on reducing the risk of safety incidents. The findings align with the underlying philosophy that preventing hazards at the source is more effective than trying to manage them after they have been designed into a project. Moreover, the research highlights that the type of safety measure implemented plays a significant role in its effectiveness. Proactive measures that aim to eliminate or substitute hazards show greater reductions in incident rates compared to reactive measures, reinforcing the need for a safety-first approach in project conception and planning.

The study advocates for a paradigm shift in construction safety management, emphasizing the need for an anticipatory approach over a reactive one. By doing so, the construction industry can not only improve worker safety but also realize efficiency gains and cost savings by preventing accidents before they occur. The research findings provide a clear call to action for stakeholders in the construction industry to prioritize early-stage risk assessment and mitigation. This will promote a culture of safety that permeates every level of project planning and execution. Overall, the study highlights the importance of a proactive approach to safety management in the construction industry, recognizing that the cost of accidents and injuries is much higher than the cost of implementing safety measures during the planning and design stages.

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