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Case study article

Safety improvement through root cause analysis and hazard control in lift installation

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ABSTRACT

The performance of construction projects is evaluated based on the effectiveness and efficiency of project completion, considering cost, schedule, quality, and safety. Elevator installation work is classified as high-risk and poses a potential for fatalities if safety protocols are not followed. To address these critical safety challenges, this research aims to control hazards and propose solutions using the Root Cause Analysis and Hazard Control approach. This approach involves identifying the hazard, assessing its source, and implementing interventions and controls to enhance work safety. Based on the analysis of alternative solutions, administrative controls and personal protective equipment (PPE) are prioritized, accounting for 31.8% of the measures to improve work safety. However, elimination and substitution measures, at 18.2%, are also critical to achieving higher safety standards. This research has limitations, including project delays during the research process, which necessitate further development to identify unaddressed risks.

1. Introduction

Occupational Safety and Health (OHS) aims to prevent workplace accidents by eliminating or reducing risks to achieve optimal productivity [1]. Although OHS has been implemented across various sectors, including construction, manufacturing, mining, offices, and healthcare, workplace accidents remain frequent, particularly in the construction sector, which has the highest risk level [2].

Construction project performance refers to the effectiveness and efficiency of completing construction projects, measured through key indicators such as cost, schedule, quality, and safety [1]. Many industries delay action until situations become uncontrollable [3], posing a significant threat to a company's survival. A primary issue in construction projects is the high incidence of workplace accidents caused by human error, such as non-compliance with work procedures, negligence, and fatigue due to extended working hours [4], [5]. This issue is particularly evident in elevator installation and maintenance, which is often associated with fatal accidents, including falls from heights, being crushed by materials, or electrocution [6]. Non-compliance with Personal Protective Equipment (PPE) use, low safety awareness, and poor coordination between workers and supervisors significantly contribute to these accidents [7]. Additionally, various occupational hazards—chemical, physical, biological, mechanical, and electrical—remain inadequately controlled [8]. These hazards not only reduce productivity but also endanger workers' lives [9].

While existing studies have explored occupational safety in construction, few have specifically investigated the interplay of safety protocol compliance, effective supervisory interventions, and safety leadership in the context of elevator installation. Most research focuses on general construction hazards or broad OHS frameworks, overlooking the unique risks associated with high-risk tasks like elevator installation and specific barriers to implementing safety measures, such as worker discipline and real-time

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supervisory oversight. This gap underscores the need for targeted research to develop tailored interventions that enhance safety compliance and reduce accident rates in the construction sector.

This research employs Root Cause Analysis and Hazard Control approaches. These methods were chosen because Root Cause Analysis identifies and addresses the root causes of issues to prevent recurrence [10], while Hazard Control provides interventions to enhance workplace safety [11]. These methods aim to optimize resources, reduce errors in work activities, improve efficiency [12], and provide deeper insights into error occurrence [13]. The initial stage involves the ILO Ergonomic Checklist, which identifies and corrects deviations in work activities within the work environment [14].

The advantages of the ILO Ergonomic Checklist include assessing workers' skills and experience and identifying factors related to the issue [15]. The HAZID Worksheet method is used to identify hazard sources, assess consequences, evaluate likelihood and severity, and categorize risk levels associated with workplace accidents. The HAZID Worksheet effectively identifies and evaluates occupational hazards from work processes [16]. Likelihood refers to the frequency of workplace accidents, while Severity indicates their seriousness [17]. Furthermore, the process explores alternative solutions using the Hierarchy of Controls, a structured approach to risk management where higher levels are more effective at reducing hazards and lower levels are less effective [18].

This study contributes to occupational safety and health by addressing the specific challenges of safety compliance and supervisory oversight in elevator installation within construction projects. Theoretically, it fills the research gap by analyzing the interplay of worker discipline, safety leadership, and real-time supervision, offering a framework for mitigating high-risk hazards in specialized construction tasks. Practically, it provides actionable recommendations for improving PPE compliance, enhancing supervisory interventions, and implementing the Hierarchy of Controls to reduce workplace accidents. By combining Root Cause Analysis, the ILO Ergonomic Checklist, and the HAZID Worksheet, this research offers a comprehensive methodology for identifying and controlling hazards, adaptable to other high-risk construction activities. These contributions aim to enhance worker safety, improve project performance, and support construction companies in achieving sustainable safety practices.

2. Material and method

2.1. Root cause analysis

The method is used to identify the causes of deviations in work activities and correct them. There are steps in Root Cause Analysis (RCA) that can be taken, namely identifying the occurrence risk, finding the root cause of the occurrence risk, and providing corrective solutions for the occurrence risk [19]. The use of this method is based on the data obtained, thus making it more effective [20].

2.2. ILO ergonomic checkpoints

International Labor Organization, Ergonomic Checkpoints are carried out to determine the work area to be inspected, an initial survey is conducted, the inspection results are recorded, priorities are set, and group discussions about the inspection results are held [14]. These safety hazards include heights, inappropriate machinery or tools, slippery walking surfaces, and working close to flammable materials, chemicals, and others [8].

Hierarchical Task Analysis (HTA) is a technique used to describe all complex activities on several levels [21]. Applications of this technique can include interface evaluation, error prediction, and workload assessment [22]. The advantages of using HTA are that it is systematic in task organization, helps detect tendencies for errors in the tasks being performed, and is a good tool for providing interventions in the functions being carried out [23].

2.3. Occupational Safety and Health (OSH)

Occupational Safety and Health is an effort to prevent work accidents by eliminating and reducing the risk of work accidents to achieve targets/productivity. Work environments that do not meet occupational safety and health requirements [24], unsafe work processes, and increasingly complex and modern work systems can be a risk to worker safety and health [25], [26].

2.4. Hazard Identification, Risk Assessment, and Risk Control (HIRARC)

Hazard Identification, Risk Assessment, and Risk Control (HIRARC) is the process of determining work activities and identifying risks, conducting risk assessments to classify risk levels, and providing risk control to minimize work accidents in the work environment.

2.5. Likelihood, severity, and risk matrix

Likelihood refers to the frequency of workplace accidents [26]. This likelihood is assessed using a scale from 1 to 5, as shown in Table 1. Severity indicates the seriousness of workplace accidents [26]. This severity is also evaluated on a scale from 1 to 5, as presented in Table 2. This stage assesses the level of occupational hazards in the workplace. The Risk Assessment Matrix Table, which combines Likelihood and Severity values, determines the risk level. For example, in the Risk Assessment Matrix Table, a value of 10 may be categorized as High or Extreme.

Table 1
Likelihood

Level	Description	Description
1	Rare	Almost never happens
2	Unlikely	Rarely occurs
3	Prosibble	It happens once in a while
4	Likely	Happens often
5	Almost Certain	Happens every time

Table 2
Severity.

Level	Description	Description
1	Insignificant	No injury, slight financial loss
2	Minor	Minor injury, minor financial loss
3	Moderate	Moderate injury requiring medical treatment, substantial financial loss
4	Major	Severe injury to 1 or more persons, substantial loss, and disruption of work
5	Catastropic	Deaths of 1 or more people, very large losses, disruption of work, and widespread and comprehensive impact

Table 3
Risk matrix.

Likelihood	Severity				
	a	b	c	d	e
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Note: a (insignificant), b (minor), c (moderate), d (major), e (catasthropic)

Table 4
Indication of risk level

Indicator	Description
Low	No need for additional controls
Medium	Risk is acceptable, monitoring is done by site staff.
High	Unacceptable risk involves work units.
Extreme	Disaster need leadership involvement.

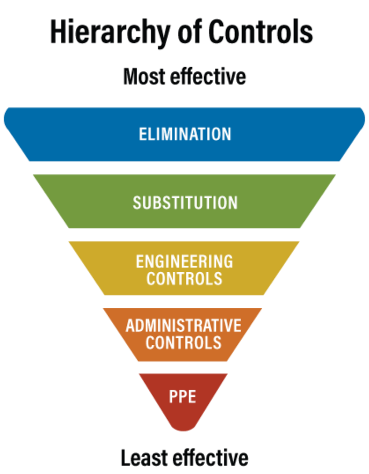

Fig. 1. Risk control hierarchy.

A High category value of 10 results from a Likelihood score of 5 and a Severity score of 2, indicating frequent accidents with minor injuries and small financial losses. Conversely, an Extreme category value of 10 results from a Likelihood score of 2 and a Severity score of 5, indicating rare but highly severe accidents. Therefore, both Likelihood and Severity must be considered together when assessing risk, as evaluating only one aspect (e.g., Likelihood or Severity alone) is insufficient. To evaluate workplace hazard levels, refer to the Risk Assessment Matrix Table in Table 3 and the Indication of Risk Level Table in Table 4.

Risk control is carried out to reduce or avoid the risks workers face. Risk control can be done using the risk control hierarchy. A picture of the risk control hierarchy is presented in Fig. 1 [29].

2.6. Factors of occupational accidents and types of hazard

Work accidents can occur due to three aspects: work equipment, the work environment, and the workers involved. Factors that can cause work accidents are an uncomfortable work environment, working without Standard Operating Procedures (SOP), working without Personal Protective Equipment (PPE), unsafe working conditions, and others [30]. According to [31], the types of hazards in work accidents include.

1. Mechanical Hazards. These hazards originate from mechanical equipment or moving objects, whether manually or propelled. The risk of these hazards can cause injury or damage, such as cuts, pinches, cuts, or chips.
2. Electrical Hazards. This hazard is caused by electrical energy. The risk of this hazard includes the potential for fire, electric shock, and short circuits.
3. Chemical Hazards. This hazard is caused by chemicals with potential hazards due to their inherent nature and composition. The risk of this hazard can lead to toxic poisoning, irritation, fire, explosion, pollution, and environmental degradation. Symptoms of skin irritation can be characterized by the appearance of a reddish rash, itchy skin, dry skin, hot skin, swollen skin, and painful skin when pressed [32].
4. Physical Hazards. This hazard is caused by physical factors: noise, vibration, hot/cold temperatures, light or lighting, radiation from radioactive materials, and ultraviolet or infrared rays.
5. Biological Hazards. This hazard is caused by biological elements such as flora and fauna found in the work environment. This hazard factor is found in the food, pharmaceutical, agricultural, chemical, mining, oil and gas processing industries.

2.7. Lean

Lean is a change initiative that focuses on solutions involving social and behavioral processes. It is an approach that emphasizes minimizing waste. Process flow and efforts are made to meet needs through continuous improvement. The advantages and benefits of lean include higher quality improvement, greater productivity, higher customer satisfaction, enhanced safety, better risk management, and cost reductions [33].

2.8. Research framework

The research novelty is researching the process flow that adds value and differs from previous research. Adaptation for specific industries in RCA can be tailored to the needs of industries, such as lift installation. Innovations in RCA can emerge in the form of more specific methods to identify mechanical, electronic, or managerial hazards relevant to lift installation. The RCA approach in this study can be compared with other similar studies as a basis for recommendations and improvements, forms a deeper understanding of the methods used, and provides an overall perspective [34], [35].

The research framework is a structure that provides a research process between previous research and current research. The previous research consisted of general research stages, ergonomic checkpoints, HIRARC, HAZOP, HAZID Worksheet, and Job Safety Analysis. The current research consists of Root Cause Analysis, Ergonomic Checkpoints, Modified HAZID Worksheet, and Hierarchy of Control. Root Cause Analysis (RCA) is a stage to identify the risk of occurrence, find the root cause of the risk of occurrence, and provide an improvement solution to the risk of occurrence [36]. Ergonomic Checkpoints are carried out to determine the work area to be inspected, initial surveys, recording the inspection results, setting priorities, and group discussions about the inspection results [37].

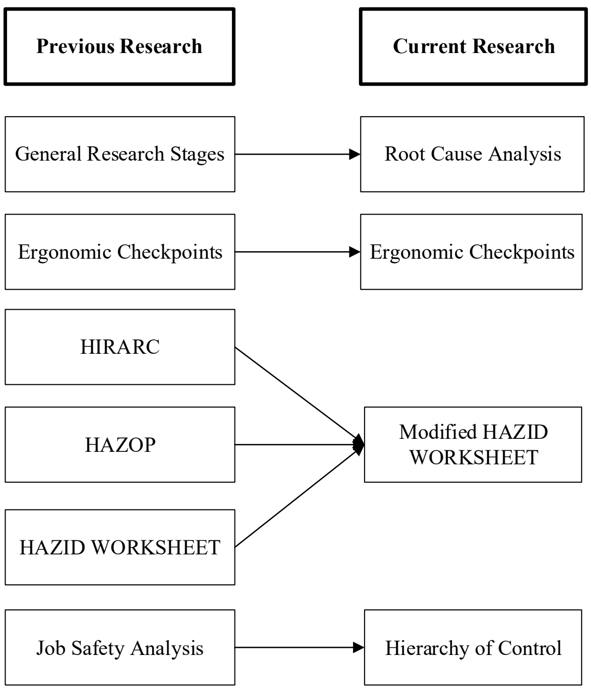

Fig. 2. Research framework.

Table 5
Aspect of ILO ergonomic checkpoints

Aspects	Points
Material Storage and Handling	17 Point
Hand Tools	14 Point
Machine Safety	19 Point
Workstation Design	13 Point
Lighting	9 Point
Workspace	12 Point
Hazard Sources	10 Point
Public Facilities	11 Point
Work Organization	27 Point
Total	132 Point

Table 6
Ergonomic checkpoints observation data recapitulation

Aspects	Sub-Aspects (Points)	Assessment		NF
		G	NG	
Material Storage and Handling	17	7	6	4
Hand Tools	14	9	5	0
Machine Safety	19	17	0	2
Workstation Design	13	6	2	5
Lighting	9	1	3	5
Workspace	12	8	1	3
Hazard Sources	10	7	3	0
Public Facilities	11	9	2	0
Work Organization	27	18	3	6
Total	132	82	25	25

Modified HAZID Worksheet is a combined table between HIRARC, HAZOP, and HAZID Worksheet whose contents become more detailed. The table contains no task, no sub-task, work area, hazard source, consequence, and risk assessment (Likelihood, Severity, Risk Assessment, and Risk Level). Hierarchy of Controls is a sequence in risk control consisting of several levels. The higher the level of the hierarchy, the more effective the method is to reduce the level of danger that occurs, otherwise the lower the level of the hierarchy, the less effective it will be to reduce the level of danger that can occur [18]. The Research Framework is presented Fig. 2.

3. Results and discussion

3.1. ILO ergonomic checkpoints

The first stage in this data processing is the Root Cause Analysis (RCA) stage, which involves defining the problem [38]. At this stage, the problem is identified using the ILO Ergonomic Checkpoints. The Ergonomic Checkpoints form is a practical tool that facilitates improvements in occupational safety and health. It includes nine aspects that need to be considered. The Ergonomic Checkpoints form is completed by researchers through observation and assessment of the work area. The ILO Ergonomic Checkpoints Aspect Table is presented in Table 5. Of the nine aspects and 132 points, 82 points met the Ergonomic Checkpoints criteria, 25 points did not meet the criteria, and 25 points were not applicable to the work environment. Aspects with high scores in the "Not Good" category include material storage and handling and hand tools. The recapitulation table of observation data using Ergonomic Checkpoints is shown in Table 6. Based on Table 6, the aspects with the highest unfavorable assessment points are material storage and handling and hand tools, with 6 and 5 points, respectively. These findings are used in the Hazard Identification Worksheet stage to identify hazard sources in the work environment.

3.2. Hierarchical Task Analysis (HTA)

The second stage of data processing is the Root Cause Analysis (RCA) stage, referred to as "Understanding the Process" [38]. At this stage, the flow of the lift installation process is analyzed using Hierarchical Task Analysis (HTA). Hierarchical Task Analysis (HTA) is a technique used to describe complex activities across multiple levels [21]. The job task planning was derived from observations and interviews, making the HTA more structured and easier for readers to understand [39], [40]. Additionally, Hierarchical Task Analysis (HTA) is utilized in the Hazard Identification Worksheet stage to identify workplace accidents based on the work activities performed and to propose improvements to mitigate such accidents. The Hierarchical Task Analysis can be obtained from the corresponding author upon request.

3.3. Hazard identification worksheet

The third to fifth stages of data processing are derived from the Root Cause Analysis (RCA) stages: Identify Hazards as Possible Causes, Collect Data and Evidence, and Analyze the Risk Level [38]. These stages are conducted using the Hazard Identification (HAZID) Worksheet. The Hazard Identification Worksheet is a modified version of the HAZOP, HIRARC, and HAZID tables, providing more detailed information to identify workplace accidents compared to previous research. The worksheet is completed by observing sources of hazards in the tasks performed, assigning Likelihood and Severity values, and determining risk level categories [41]. The "Extreme" risk level category results from the Hazard Identification Worksheet are used to propose alternative solutions based on the Hierarchy of Control. The Hazard Identification Worksheet can be obtained from the corresponding author upon request.

3.4. Alternative solution with hierarchy of control

The sixth stage of data processing is derived from the Root Cause Analysis (RCA) stage, which involves developing alternative solutions based on the Hierarchy of Controls [38]. The Hierarchy of Controls is a multilevel approach to risk management, with each level varying in effectiveness. The implementation of alternative solutions follows the Hierarchy of Controls principle to enhance workplace safety. Higher levels in the hierarchy are more effective at reducing hazards, while lower levels are less effective [18].

Alternative solutions primarily target the "Extreme" risk level category due to its potential for catastrophic incidents and the need for leadership involvement. If solutions for the "Extreme" risk level are successfully implemented, further solutions can be developed for the "High" to "Low" risk level categories. The proposed alternative solutions, based on the Hierarchy of Controls, have been approved by an expert judgment, specifically the Project Supervisor, through interviews. The validation stages for the proposed improvements are illustrated in Fig. 3.

Implementing these alternative solutions serves as a mitigation strategy to prevent work-related accidents during the elevator installation process. In the long term, this mitigation contributes to increased productivity, time and cost efficiency, heightened safety awareness among workers, and advancements in occupational safety literature [25].

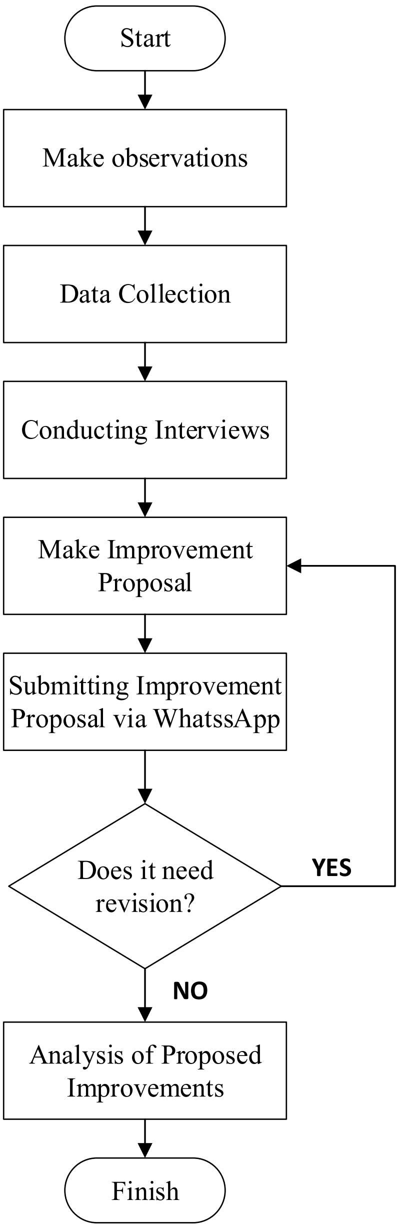

Fig. 3. Validation of proposed improvements.

Currently, the project under study is delayed, preventing the implementation of these solutions. However, they can be applied once the project resumes and have the potential for use in other projects to enhance worker safety during elevator installation. The Alternative Solutions Table, based on the Hierarchy of Controls, can be obtained from the corresponding author upon request.

Based on the Hierarchy of Control, the proposed improvements for workplace safety are distributed as follows: Elimination (18.2%), Substitution (18.2%), Administrative Controls (31.8%), and Personal Protective Equipment (PPE) (31.8%). These alternative solutions aim to help workers avoid workplace accidents. Key factors influencing the effectiveness of these solutions include workers' safety awareness, effective communication, and adherence to established Standard Operating Procedures (SOPs).

According to the risk control hierarchy, various strategies can be implemented, including elimination, substitution, engineering controls, administrative controls, and PPE. For example, to address the consequences of fractures, concussions, and fatalities, the lift shaft area should be cleaned routinely once a week. To mitigate the risk of electric shock, procedures for using electrical equipment should be reviewed, and toolbox meetings should be conducted before starting work. To prevent short circuits and explosions, the use of electrical insulation gloves should be inspected, and electrical grounding should be monitored.

This research was conducted using observational data, analyzed through Root Cause Analysis and Hazard Control. Root Cause Analysis systematically identifies the root causes of workplace accidents, while hazard control focuses on interventions and risk management to enhance workplace safety. The study results indicate that administrative controls and PPE are prioritized for improving safety. However, elimination and substitution solutions are essential for achieving higher safety standards.

This research has limitations, including project delays that restricted data collection in the field. Therefore, further research is recommended to identify unaddressed risks and develop more effective risk control measures for elevator installation.

4. Conclusions

In this study, the information provided is more detailed, as it utilizes a modified HAZID Worksheet, compared to previous studies. This study obtained seven consequences with a risk level of "Extreme", namely broken bones, concussion, death, unclear information delivery, electric shock, electrical short circuit, and explosion. The project that became the research location was delayed, so the implementation of alternative solutions can be done after the project is resumed and can be applied to other projects to improve worker safety during the elevator installation process.

Alternative solutions are proposed to enhance work safety, as determined through interviews with the Project Supervisor. Based on the Hierarchy of Control, various alternative solutions can be employed, including elimination, substitution, engineering controls, administrative controls, and personal protective equipment. Based on the results of the analysis of alternative solutions obtained, it is evident that Administrative Control and Personal Protective Equipment, at 31.8%, are priority measures to improve work safety. Although elimination and substitution percentages of 18.2% are effective solutions. The company can implement these alternative solutions so that workers can feel occupational safety and health during elevator installation, and can increase intense communication to motivate workers during elevator installation.

The methodology used in this study could be applied to other high-risk construction project such as steel structure installation or scaffolding to test the adaptability of the approach across various scenario. The future research could include the assessment of workers' perceptions, attitudes, and behaviors toward safety to complement the technical analysis. A safety climate survey and observation are also needed to provide a holistic mitigation.

Declaration statement

Valentino Bernardus Gurning: Conceptualization, Methodology, Data Collection, Formal Analysis, Writing-Original Draft. **Dian Mardi Safitri:** Assist in the writing process, reviewing the methodology and research framework, lead the validation process.

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The authors report that there are no competing interests to declare.

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article. Other data not within article can be obtained from the corresponding author upon request.

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