Analysis of Occupational Safety and Health Risks in Scaffolding Work Using HIRADC and JSA Methods at PT. XYZ

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ABSTRACT

This study aims to analyze occupational safety and health (K3) risks in scaffolding work at PT. XYZ is using the Hazard Identification, Risk Assessment, and Determining Control (HIRADC) and Job Safety Analysis (JSA) methods. The study used a quantitative descriptive approach with field observation methods, structured interviews, and documentation of 11 respondents during the period August to December 2025. The results of the hazard identification showed that there were 17 potential hazards classified into 13 risk items. Risk assessment using a risk matrix of 5×5 showed that there were 2 high risks (R=15) and 11 moderate risks. The highest risk comes from work at height on the installation and painting of scaffolding. After the implementation of hierarchical-based controls, all high risks were successfully downgraded to medium risk, with an average reduction in risk values by 40%. The JSA analysis produced 37 safe work steps that can be used as the basis for the preparation of SOPs and safety briefings in the field. The results of the study show that the integration of HIRADC and JSA methods is able to increase the effectiveness of comprehensive risk identification and control in construction work.

1. Introduction

The construction industry is one of the sectors with a high level of risk of work accidents. Construction activities often involve complex work, the use of heavy equipment, work at heights, and interactions with various hazardous materials [1]. In the context of construction management, it is emphasized that the success of a project is largely determined by the integration between project planning, implementation, and control, including aspects of occupational safety [2]. Occupational Safety and Health (K3) is a basic right for the workforce, where one of the goals of occupational safety and health is to prevent work accidents [3]. Work accidents in construction are not caused by just one single factor, but a combination of factors of workers, workplace, materials, equipment, organization, and work environment [4]. The highest risk to workers is the high potential for accidents when performing some activities, especially in construction work [5].

Therefore, the implementation of the Occupational Safety and Health Management System (SMK3) is crucial to prevent occupational accidents and occupational diseases, so that the company's operations can run efficiently and effectively[6]. According to Heinrich's theory, 88% of work accidents are caused by *unsafe action*, 10% by *unsafe conditions*, and 2% by natural factors [7]. One of the riskiest activities is work at height using scaffolding, which has the potential to lead to falling from height, being hit by materials, and even scaffolding structural failure [8].

PT. XYZ is a construction, fabrication, trading, and logistics company that actively runs civil construction projects, PT. XYZ faces challenges in systematically managing occupational safety risks. There is a gap between safety conditions in the field and the need for a comprehensive risk analysis, so potential hazards can develop into a greater risk of accidents if not addressed through a structured and sustainable approach. In 2025, there will be 10 cases of work accidents, with 7 cases due to unsafe conditions (imposed by materials) and 3 cases due to unsafe actions (Unsafe Action), such as not wearing PPE. This condition shows that there is a gap between the implementation of occupational safety in the field and the need for comprehensive risk analysis. Judging from the fact that there were work accidents at PT XYZ, the use of HIRADC as a single method has limitations in describing the risks per work step in detail, so a combination with the JSA method is needed to group risk variables and determine control.

Previous research on the [9] construction of a multi-story hospital building in Langsa, Aceh has successfully demonstrated the effectiveness of using the integrated HIRADC and JSA approaches in analyzing occupational safety and health risks. The study identified that several work activities in the multi-story building construction project carry significant risk levels, with hazards such as falling from heights and being struck by materials being the primary concerns. The study also highlighted that risk control using the hierarchical approach was effective in reducing risk levels across all work stages, underscoring the importance of systematic K3 management in multi-story construction projects. Previous research [10] has analyzed the potential risks of K3 in the Tondano Lake Revitalization Project Phase I using a combination of HIRADC and JSA methods. The study identified hundreds of risks, some of which were in the high category, and highlighted the importance of strict supervision and discipline of K3. This study serves as a methodological and contextual basis for research that focuses on the integration of risk analysis methods and K3 compliance challenges in the construction/infrastructure sector. has analyzed K3 risks in ship repair activities[11] at PT. NF, integrating the HIRADC method for general risk assessment and JSA for the details of high-risk work. The study identified three major high-risk and six extreme risk occupations, and proposed improvements to the K3. This research is an important reference in the application of integrated risk analysis methods in the shipping industry, especially in identifying specific hazards and formulating relevant control measures.

Based on the study of previous research, three research gaps emerge that underpin the novelty of this study. First, previous studies applying integrated HIRADC and JSA were predominantly conducted in large-scale or government-funded construction projects, whereas medium-scale construction, fabrication, and logistics companies, which constitute the majority of the Indonesian construction sector, remain under-researched, particularly regarding their resource constraints and safety management capacity. Second, existing studies have seldom provided a sequential and comprehensive analysis covering all six stages of scaffolding work from mobilization through housekeeping within a single unified risk document. Third, this study introduces a quantitative measurement of residual risk (Residual R = L’ × S’ post-control) as an objective indicator of hierarchical control effectiveness, an approach rarely operationalized in Indonesian construction safety literature. This residual risk matrix allows direct comparison between initial and post-control risk values, enabling evidence-based prioritization of remaining risks and producing JSA documents that are immediately deployable as SMK3 field operational instruments.

Job Safety Analysis (JSA) is a systematic method that identifies potential hazards in each step of the implementation of a job, then determines the appropriate control measures for each step[8]. If HIRADC excels in comprehensive quantitative risk assessment using a risk matrix, then JSA excels in risk mapping based on work sequences that are operational and easy to understand by workers in the field. The combination of these two methods creates a risk analysis approach that is complementary, comprehensive, and practically implementable in a construction project environment[12].

Based on the description above, this study aims to: (1) identify the potential for scaffolding work in PT. XYZ and JSA in an integrated manner; (2) assess the level of risk of construction work accidents quantitatively through Risk Matrix 5×5; and (3) evaluate the effectiveness of hierarchical-based risk control measures in reducing the rate of work accidents.

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2. Methods

This study uses a quantitative descriptive approach with an observational design. Data was collected through direct field observation, structured interviews, and documentation of real working conditions in the civil construction project area at PT. XYZ during the period August to December 2025.

The subject of the study is all scaffolding work activities (installation, use, and dismantling of scaffolding) in building repair service projects and civil works at PT. XYZ, Indonesia. The selection of 11 respondents, consisting of 9 experienced civil workers and 2 field supervisors, represents the entire population (total sampling) directly involved in the specialized scaffolding operations at PT. XYZ. In qualitative-quantitative risk assessments like HIRADC, the expertise and direct exposure of the respondents to the hazard are more critical than the statistical sample size, ensuring high contextual validity of the scoring.

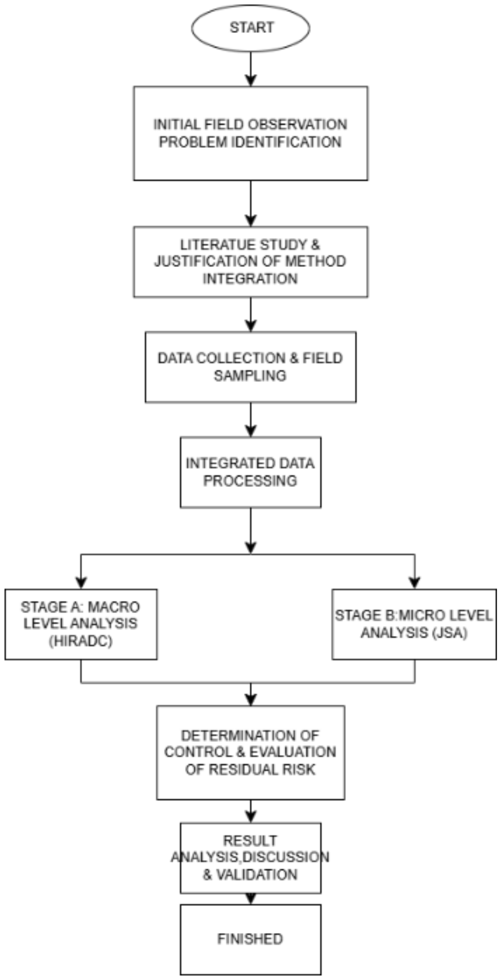

Figure 1. Research Flowchart

Data was collected through three techniques: (1) Comprehensive field observation for three months to record real working conditions and the order of work stages (2) In-depth interviews with workers and field supervisors using structured questionnaires to obtain information on potential hazards and work actions, and (3) Documentation in the form of photographs, field notes, and recordings of work area conditions as supporting evidence for the analysis.

2.1. HIRADC

The HIRADC *(Hazard Identification, Risk Assessment, and Determining Control)* method is a systematic approach to identifying hazards, assessing risks, and determining appropriate control measures. This process involves identifying potential hazards in the work environment, assessing the level of risk posed, and developing strategies to reduce or eliminate those risks. By applying this method, companies can be more proactive in managing K3 risks, so that they can protect their workforce and patients from potential hazards [13]. According to the Regulation of the Minister of Manpower and Transmigration of the Republic of Indonesia No. PER.05/MEN/1996, the stages of *HIRADC* include:

a. Hazard *Identification*: Includes the collection of information about work activities, equipment, chemicals, and work environments that can pose hazards.
b. Risk Assessment: Carried out by analyzing potential hazards based on frequency (likelihood of occurrence) and severity (severity).
c. *Determining Control*: Control is carried out with the principle of a control hierarchy, namely elimination, substitution, technical engineering, administration, and personal protective equipment (PPE).

a. Hazard Identification

Hazard identification is an effort to discover hazards in work activities. The hazard identification process needs to be carried out comprehensively to minimize the possibility of undetected risks.[14]

b. Risk Assessment

According to the following, an assessment of the potential hazards that have been identified is carried out to determine the level of risk of the hazard. Risk assessment was carried out quantitatively using Risk Matrix 5×5. The risk value is obtained from the multiplication of two parameters:

$$R = L \; x \; S$$

where R = *Risk*, L = *Likelihood* (likelihood of hazard), and S = *Severity* (severity of impact). This assessment is in line with the ISO 31000 standard, which uses risk matrix techniques to rank and prioritize Risk.

Table 1. Risk Matrix

Scale	**Impact**				
	Insignificant	**Minor**	**Moderate**	**Major**	**Catastrophic**
Likelihood	**1**	**2**	**3**	**4**	**5**
Rare	1	2	3	4	5
Unlikely	2	4	6	8	10
Moderate	3	6	9	12	15
Likely	4	8	12	16	20
Certain	5	10	15	20	25

Very High Risk
High Risk
Medium Risk
Low Risk

c. Determination of Controls (*Determining Control*)

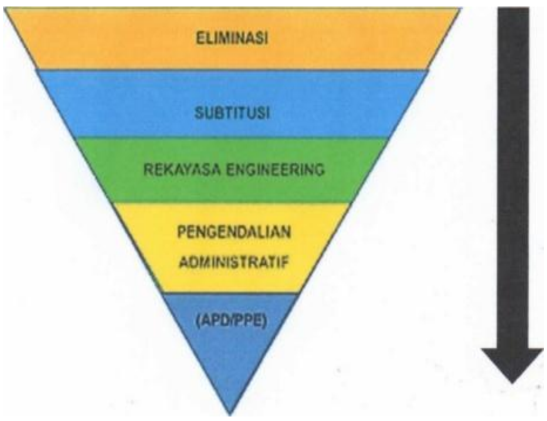

Figure 2. Hierarchy of control

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Risk control is carried out based on the control hierarchy according to the ISO 45001 standard which consists of five levels, from the most effective to the lowest: (1) Elimination, which involves eliminating the source of the hazard completely; (2) Substitution, which involves replacing hazardous materials or equipment with safer ones; (3) Technical Engineering, referring to modification of equipment or work area; (4) Administrative Control, encompassing procedures, SOPs, safety briefings, and work rotations; and (5) PPE, Referring to the use of Personal Protective Equipment according to the type of work.[15]

2.2. JSA (*Job Safety Analysis*)

Job Safety Analysis is a technique used to determine hazards in each stage of work activities as an effort to prevent work accidents and control hazards. It is usually done by studying and making reports of each step of the work, analyzing potential occupational hazards and existing hazards, and then determining the best solution to reduce or eliminate hazards in the workplace.[16]

The steps in the Job Safety Analysis method are as follows:

a. Selecting work to be analyzed. At this stage, location determination, initial observation, and interviews are carried out to determine hazards and risks related to the work to be analyzed.
b. Determining the order and work steps. At this stage, the determination of the steps and order of the implementation of previous work activities is carried out. based on observation
c. Recognizing and Analyzing Hazards for Each Work Step. At this stage, identification is carried out related to hazards that may occur in the activities carried out.
d. Determine the best solution to carry out each step of work safely. At this stage, the solution of each hazard identified in work activities is determined.

Table 2. Hazard identification by stage of work

Stages of work	Identify potential hazards
Appointment of a manual	Non-ergonomic lifting position, sudden fall/pulled load, tripping
Mobilization of equipment & materials	Exposure to B3 materials, scattered materials, vehicle traffic, slippery and dusty areas
Installation & disassembly of scaffolding	Falling from height, falling material from above, or hitting scaffolding components
Frame & roof dismantling	Hit by dismantling materials, sharp materials, exposure to dust, and electric shock
Installation of construction raw materials	Hit by material, falling from height, slipped due to cement dust, and non-ergonomic lifting position
housekeeping	Dusty and slippery working area, non-ergonomic working position, sharp and scattered material, poor material handling

3. Results and discussion

Data collection was carried out at PT. XYZ in the period from October 13, 2025, to January 20, 2026. Primary data was obtained through field observation, structured interviews, and the distribution of questionnaires to 11 respondents, consisting of 8 field workers, 1 safety officer, and 2 field supervisors. In 2025, at PT. XYZ recorded 10 cases of work accidents distributed as shown in Table 3.

Table 3. Hazard identification using the HIRADC method

No	Types of accidents	Main causes	Number of cases	Category
1	Hit by demolition material	Unsafe Condition (no barrier)	7 cases (70%)	Unsafe conditions
2	Not wearing PPE while working	Unsafe action	3 cases (30%)	Unsafe actions

Total	10 cases

The scope of observation includes 6 stages of scaffolding work: (1) mobilization of equipment and materials; (2) scaffolding installation; (3) dismantling of the frame and roof; (4) painting at height; (5) scaffolding dismantling; and (6) housekeeping. All stages of the work are carried out under routine operating conditions every day during the project, so that potential risk exposure is repetitive and continuous.

3.1. Hazard identification

Hazard identification aims to comprehensively recognize all potentials at each stage of construction work. This process was carried out through a combination of field observation and structured interviews with respondents. The results of the identification found 17 potential hazards distributed in 9 types of Risks.

Table 4. Hazard identification using the HIRADC method

No	Work steps	Source of danger	Potential hazards	Operating conditions	K3 Risk/ Environmental Impact
1	Mobilization of equipment & materials	Slippery & dusty areas	Slip	Routine	Moderate injury/light dust pollution
		The lifting position is not ergonomic	Manual handling does not meet ergonomic standards	Routine	Low back pain/insignificant injury
		Operational vehicles	Workers and vehicles on the same track	Routine	Serious injury/facility damage
2	Scaffolding installation	Working at height	Falling from a height	Routine	Severe/fatal injury, minor environmental impact
		Material from above	Stuck by falling material	Routine	Head injury/minor environmental impact
		Unstable structure	Scaffolding collapsed	Routine	Fatal/ serious injuries, minor environmental impact
3	Frame & roof dismantling	Building structure	Struck by/cut by falling materials	Routine	Serious injury, respiratory distress
		Sharp material	Scratched/cut	Routine	Open wounds, solid waste
		Dust & Electrical Installation	Exposure to dust, electric shock	Routine	Respiratory disorders
4	Installation of construction raw materials	Building materials & height	Hit by a slipper, fall	Routine	Severe/minor injuries, environmental impact
5	Scaffolding dismantling	Work tools/components	Hit by components	Routine	Severe/insignificant injuries
6	Housekeeping	Sharp & heavy material	Scratched/ crushed	Routine	Lacerations/facility damage(minor)
		Dusty slippery areas	Slipped/ Fallen	Routine	Mild to moderate injury/dust pollution

3.2. Risk assessment

Risk assessment was carried out quantitatively using a 5x5 risk matrix with the formula R = L x S. Likelihood (L) and severity (S) values were obtained from the answer mode values of 11 respondents on the structured questionnaire. The following table presents the results of the risk assessment, including control measures and residual risk values for all 13 risk items identified in Table 3. To ensure scoring transparency and reproducibility, this study adopts descriptive anchor criteria following the AS/NZS 4360:2004 risk standard. Likelihood (L) criteria: L=1 (Rare) the event has never occurred in the company and requires highly exceptional circumstances; L=2 (Unlikely) the event has occurred at least once in the industry but is not expected in this project cycle; L=3 (Possible) the event could plausibly occur and has been documented in similar Indonesian construction activities; L=4 (Likely) the event is expected to occur at least once during the project given current working conditions; L=5 (Almost Certain) the event is expected to occur repeatedly or is already observable in daily operations. Severity (S) criteria: S=1 (Insignificant) no injury or first-aid only, no lost time; S=2 (Minor) minor injury requiring first aid, no lost workday; S=3 (Moderate) medical treatment required, temporary incapacity, reversible health impact; S=4 (Major) serious injury, permanent partial disability, or significant property damage; S=5 (Catastrophic) fatality, permanent total disability, or mass injury. The mode of 11 respondents' scores was used as the final L and S value for each hazard, minimizing outlier influence and reflecting collective expert field judgment, consistent with established practice in construction risk assessment [17]. This approach also allows capture of field-level knowledge about fall-from-height hazards, which Abdul Halim et al. [18]demonstrated through structural equation modelling to be the single most significant risk factor in construction sites across the Southeast Asian region, with Severity consistently rated at the catastrophic level (S=5).

Table 5. Results of HIRADC risk assessment (risk matrix 5x5)

No	Activities	Hazard identification	Risks	L	S	R	Category
1	Equipment mobilization	Slippery, dusty work area	Slip	3	3	9	Medium
2	Equipment mobilization	Manual handling is not ergonomic	Muscle injury/ LBP	3	3	9	Medium
3	Equipment mobilization	Vehicle traffic	Hit by a vehicle	2	5	10	Medium
4	Scaffolding installation	Working at height	Falling from a high	3	5	15	High
5	Scaffolding installation	Scaffolding is not sturdy	Scaffolding collapse safety	2	5	10	Medium
6	Frame disassembly	Material from above	Struck by falling material	3	4	12	Medium
7	Frame disassembly	Sharp Materials	Cut/tear wounds	3	3	9	Medium
8	Frame disassembly	Active Electrical Equipment	Electrocution	2	5	10	Medium
9	Painting at height	Exposure to paint chemicals	Breath disturbances/irritation	3	3	9	Medium
10	Painting at height	Working at height	Falling from a high	3	5	15	Height
11	Scaffolding dismantling	Falling scaffolding components	Struck by falling scaffolding components	3	4	12	Medium

12	Housekeeping	Sharp & heavy material	Lacer/compressed wounds	3	3	9	Medium
13	Housekeeping	Slippery work area	Slip	3	2	6	Medium

Of the 13 risk items assessed, 2 items were found in the High category (R=15), namely falling from height in the installation of scaffolding and painting at height, and 11 items in the medium category (R=6 to 12); no low risk was found before control. This condition implies that all civil construction activities at PT. XYZ requires planned and structured control.

3.3. Determining control

Control is determined based on the OHSAS 18001 control hierarchy: elimination, substitution, technical engineering, administrative control, and PPE. The following details of the control and residual risk value are presented in Table 6.

Table 6. Risk control and residual risk

No	Activities	Hazards/risks	Initial R	Risk control (*hierarchy*)	L Residual	S Residual	Residual R
1	Equipment mobilization	Slippery & dusty/ Slipped areas	**9**	Adm+APD: Housekeeping routine, safety sign, safety shoes & dust mask	2	3	**6**
2	Equipment mobilization	Manual handling/ Muscle injuries	**9**	Engineering+Adm: Ergonomic engineering, min. 2 people, safety briefing	2	3	**6**
3	Equipment mobilization	Vehicle traffic/ Hit	**10**	Adm: Gate pass, speed bump, traffic sign, SIM verification	1	5	**5**
4	Scaffolding installation	Working at height/Falling	**15**	Engineering+APD: Full body harness double hook, lifeline, certified scaffolder, tagging scaffolding	2	5	**10**
5	Scaffolding installation	Scaffolding is not sturdy/collapses	**10**	Engineering+Adm: Periodic inspection, tagging, safety inspector, standard components	1	5	**5**
6	Frame disassembly	Material from above/ Overwritten	**12**	Engineering+PPE: Limit the bottom area, safety helmet, gradual disassembly method	2	4	**8**
7	Frame disassembly	Sharp Material/Cut Wound	**9**	APD+Adm: Standard gloves, SOP enforcement of tools	2	3	**6**
8	Frame disassembly	Electrical shock/ Electrocution	**10**	Engineering+Adm: Routine wiring check, perfect insulation, tool feasibility verification	1	5	**5**
9	Painting at height	Chemicals/ Respiratory disorders	**9**	PPE+Adm: Respirator mask, adequate ventilation, provide MSDS	2	3	**6**

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No	Activities	Hazards/risks	Initial R	Risk control (*hierarchy*)	L Residual	S Residual	Residual R
10	Painting at height	Working at height/Falling	**15**	Engineering+APD: Full body harness, lifeline, scaffolding tagged safe	2	5	**10**
11	Scaffolding dismantling	Dropped/Overwritten components	**12**	Engineering+Adm: Gradual dismantling, safe zone, competent workers	2	4	**8**
12	Housekeeping	Sharp material/Tear wound	**9**	APD+Adm: Protective gloves, correct handling technique	2	3	**6**
13	Housekeeping	Slippery/ Slippery Area	**6**	Adm: 3x/day cleaning schedule, anti-slip mat	1	2	**2**

Table 5 shows that after the implementation of controls, all 2 high-risk items (R=15) were successfully downgraded to the medium category (R=10). The risk distribution shifted from 2 high + 11 medium to 0 high + 10 medium + 3 low. The average decrease in risk value reached 40%, with the largest decrease in the risk of slipping during housekeeping from R=6 to R=2 (down 67%).

a. Data Processing of the JSA (Job Safety Analysis) Method

At this stage, JSA is carried out to complement HIRADC by describing the risks in detail per work step. The JSA analysis is presented for five main activities that have a significant level of risk based on the HIRADC results. The JSA format includes sections on work steps, potential hazards, possible consequences, and operational control recommendations.

b. JSA installation and disassembly of scaffolding

Scaffolding installation and dismantling activities are jobs with the two highest risk items (R=15). The JSA for this activity is presented in Table 7.

Table 7. Job safety analysis of scaffolding installation and dismantling stages

No	Work step	Hazard	Consequence	Control measure (hierarchy)
1	Component inspection	Rusty/deformed parts	Structural failure	100% visual inspection; red-tag rejected parts; use SNI-certified components
2	Transport components to the work area	Heavy/unbalanced load	Musculoskeletal injury; dropped component	Max. 25 kg/person; 2 workers for long items; gloves & safety shoes
3	Base plate & lower scaffold installation (0–2 m)	Uneven/soft ground	Scaffold tilt or collapse	Install on a hard surface; mudsill on soft soil; secure with a safety pin
4	Scaffold assembly at height (>2 m)	No harness/PPE	Fatal fall from height	Full body harness double-hook + lifeline MANDATORY; certified scaffolder; never work alone; install safety net
5	Guardrail & toeboard installation	Guardrail absent during work	Workers/materials fall from the platform edge	Guardrail min. 0.9 m; toeboard min. 15 cm; green tag after full installation
6	Material lifting to the platform	Rope failure/tossed materials	Struck by a falling object; head injury/fatal	Certified lifting ropes; hazard signs below the lift zone; helmet mandatory

7	Platform use (work activities)	Platform overload	Scaffold collapse	Do not exceed max. load; prohibit excess material accumulation on the platform
8	Scaffold dismantling (top to bottom)	Careless component removal	Component falls on workers below; fatal	3 m safe zone; safety strap on removed components; sequential top-down dismantling
9	Component collection & storage	Scattered materials	Tripping/slipping	Immediately arrange after disassembly; label & store in designated area

c. JSA Painting at high altitude

Painting at height is the second high-risk activity (R=15) and has two types of hazards at the same time, including falling from height and exposure to chemicals

Table 8. Painting at height

No	Work steps	Hazards	Consequences	Control measure (Hierarchy)
1	Prepare paint & solvent	Chemical spills/splashes	Eye/skin irritation; environmental pollution	Protective goggles + nitrile gloves; prepare MSDS; work in a ventilated area
2	Access scaffold platform	Fall while climbing stairs	Moderate to fatal injury	Full body harness MANDATORY; check stair condition; 3-point contact rule
3	Stir & pour paint	Solvent vapour splash	Respiratory distress/mild poisoning	Organic respirator mask; open/ventilated workspace; keep away from ignition sources
4	Paint vertical & horizontal surfaces	Loss of balance when reaching difficult areas	Fall from height; potentially fatal	Lifeline installed; body must not extend beyond arm's reach; use long brush/roller
5	Paint the corner & edge areas	Unstable posture at the platform edge	Fall from scaffold edge	Guardrail installed; harness attached to a solid structure; never work alone
6	Clean painting equipment	Solvent/thinner exposure	Skin & airway irritation	Nitrile gloves + organic mask; dispose of paint waste per B3 procedure
7	Descend from the platform	Fall while descending with equipment	Fall/trip on stairs	Lower equipment by rope first; descend with both hands free; 3-point contact mandatory

d. JSA dismantling of the frame and roof of the building

The dismantling of the frame and roof contains three significant hazards: being hit by material (R=12), being electrocuted (R=10), and being exposed to sharp materials (R=9).

Table 9. Dismantling of the frame and roof of the building

No	Work step	Hazards	Consequence	Control measure (Hierarchy)
1	Pre-demolition structural survey	Unstable/unidentified structure	Sudden collapse of workers	Expert structural inspection; written demolition plan; identify critical points
2	Electrical isolation	Unidentified live cable	Electrocution; serious/fatal injury	Contact PLN/technician to cut power; voltage tester check; Lockout/Tagout procedure
3	Scaffold access to the roof	Fall while mounting at height	Serious/fatal injury	Full body harness + lifeline; certified scaffolder; scaffold inspection before boarding

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No	Work step	Hazards	Consequence	Control measure (Hierarchy)
4	Roof material removal (tile/zinc)	Falling roof materials	Struck by demolition material; head injury	Barrier & safety net below; helmets mandatory; dismantle edge to center
5	Steel/wood frame cutting	Debris & sparks	Eye wounds/burns	Protective glasses + face shield; ensure no flammable materials nearby
6	Lower dismantled materials	Loose rope/uncontrolled sliding material	Material falls on workers below	Rated-capacity strap; 5 m clearance zone; radio/signal coordination
7	Post-dismantling cleanup	Scattered sharp materials	Cuts/punctures from nails/iron	Thick gloves + safety boots; use tools to lift (not bare hands); segregate sharp waste

e. JSA Mobilization of equipment and materials

Table 10. Mobilization of equipment and materials

No	Work steps	Hazards	Consequences	Control Measure (Hierarchy)
1	Receive materials from the vehicle	Vehicles in the workers' area	Struck by a vehicle; severe/fatal injury	Separate vehicle lanes; gate pass + speed bumps mandatory; drivers must hold a valid license
2	Unload cargo from trucks	Heavy load falls during lowering	Struck by material; serious injury	Forklift/crane for >50 kg; workers must not stand under suspended load
3	Manual lifting of light materials	Non-ergonomic lifting posture	Lower back injury (LBP)	Correct technique: straight back, bent knees; max. 25 kg; use lifting aids when available
4	Transport materials to storage	Slippery/dusty path	Slip/fall; mild to moderate injury	Clear path before mobilization; safety signs; safety shoes mandatory; anti-slip base on the main path
5	Arrange & store materials	Unstable/disorganized stacking	Collapsed pile strikes workers	FIFO stacking; max. height 1.5 m; bind long materials; install buffer/barrier

f. JSA *Housekeeping*

Table 11. Housekeeping

No	Work steps	Hazards	Consequence	Control Measure (Hierarchy)
1	Collect waste & construction debris	Sharp materials (nails, iron, glass)	Cuts/punctures; open wound	Thick gloves + collecting tools (shovel/tongs); thick-soled safety shoes
2	Clean dust from surfaces	Silica dust exposure	Long-term respiratory disorder/silicosis	N95 mask mandatory when sweeping; spray water to suppress dust; ensure area ventilation
3	Clean floors & traffic lanes	Slippery surfaces (oil/water/cement)	Slip/fall; mild to moderate injury	Cleaning schedule 3×/day; mop + cleaning liquid; floor signage; anti-slip mat
4	Transport & dispose of heavy waste	Overload/non-ergonomic lifting	Muscle injury/material fall	Max. 25 kg lift; use trolley for heavy items; minimum 2 persons for team lifting
5	Arrange & store work tools	Tools scattered in traffic lanes	Tripping/slipping	Store tools in designated area; label equipment; verify lane is clear after work

3.4. Analysis and discussion

a. Analysis of HIRADC Risk Assessment Results

Based on the results of the HIRADC analysis, work-related activities such as scaffolding installation and painting include the most risky sources, with a maximum risk of R=15 and a severity level of 5 (catastrophic). The aforementioned severity levels cannot be eliminated during work at height; the focus of control can only be on reducing the likelihood of accidents. This indicates that the primary concern in scaffolding work is the risk of remaining high. Following the implementation of controls based on the control hierarchy, the risk of success is distributed in a way that is more secure. Compared to using personal protective equipment (PPE) in various construction activities, control via technique and administration is more effective in lowering risk levels. In addition, quantitative residual risk measurement in this study resulted in a Residual R value of 10 for both work-at-height activities, thus serving as an objective benchmark for management in monitoring ongoing risk exposure. This capability is not possessed by conventional JSAs, because according to Kwon et al. [19], stand-alone JSAs have a limited scope due to their focus only on the tasks performed without being able to identify hazards arising from interactions between tasks or between work stages. The integration of the HIRADC and JSA methods in this study was able to overcome this limitation through the analysis of six stages of scaffolding work as a sequential system. Residual risk values ranging from Residual R = 2 to 10 for all 13 items indicate that the implementation of hierarchical controls successfully reduced the average risk level by 40%. However, the two activities involving work-at-height still maintained a residual severity level of 5 (catastrophic), thus requiring engineering controls and ongoing behavioral monitoring. This quantitative documentation of post-control risks is an important contribution to construction safety studies. In addition, the finding that 30% of accidents at PT XYZ were caused by unsafe actions is also in line with research by Wang et al. [20], which shows that unsafe worker behavior is the main factor causing various construction accidents, such as falls, collapses, and incidents of being hit by objects.

b. Analysis of JSA results

The JSA analysis yielded 9 job tables with a total of 37 risky work steps equipped with specific operational control measures. JSA provides added value that cannot be obtained from HIRADC alone, namely: (1) a sequence of preventive measures that can be understood directly by workers in the field; (2) identification of hazards arising from the interaction between work steps (transition hazards); and (3) the basis for the preparation of SOPs and daily safety briefings. For example, the JSA of scaffolding installation (Table 6) identified that step 4 (assembly at a height of >2 m) and step 8 (disassembly from above) were critical points that required close supervision, something that could not be seen specifically from the HIRADC table.

c. Synergy of HIRADC and JSA methods

The integration of HIRADC and JSA addresses the inherent limitations of using either method in isolation. HIRADC operates at a macro-level, evaluating overall occupational fatigue and establishing control priorities across 13 risk items using a quantitative matrix. However, it fails to capture the operational transitions between tasks

Table 12. Contribution composition of HIRADC and JSA methods

Aspects	HIRADC	JSA
Scope of analysis	Occupational hazard scope (13 risk items)	Per step of work (37 steps)
Assessment Approach	Quantitative (*R= L x S,Matrix 5x5)*	Operational qualitative based on work order
Main output	Risk Value, Category, Control Priorities	Safe working procedures per step
Pros	Objectively and measurably rate risks	Easy to understand for field workers based on SOPs and briefings

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Limitations	Not outlining the risks between work steps in detail	Not providing a quantitative value of risk
The results at PT. XYZ	100% elimination of high risk, average reduction of 40%	37 documented safe work steps for 5 key activities
Uses for SMK3	Basic planning and priorities for K3 control	Training materials, safety briefing, and daily SOPs

Conversely, JSA functions at a micro-level, breaking down the activities into 37 sequential steps. In this study, the JSA successfully identified 8 critical transition hazards that were completely omitted by the HIRADC analysis, such as the hazard of workers descending from the scaffolding platform while manually carrying tools. Thus, HIRADC provides the safety strategy, while JSA provides the tactical, shop-floor execution standard.

d. Achievement recapitulation

Table 13. Recap of achievements in the application of HIRADC and JSA methods

Indicators of achievement	Before handling	After control
Total Potential Hazards Identified (HIRADC)	17 hazards (13 items rated)	0
Documented risky work steps (JSA)	0	37 steps of 5 main activities
High risk (**R ≥ 13)**	2 items (R=15)	0 items (100% elimination)
Medium Risk **(R 5–12)**	11 items	10 item
Low Risk **(R ≤ 4)**	0 items	3 items
Average decrease in risk value	0	40%
The biggest decline	0	Housekeeping slip risk R=6 dropped to R=2 (down 67%)
Safe work procedures (SOP based on JSA)	Not available	5 SOPs for the main activities are compiled

Table 13 shows that the integration of HIRADC and JSA provides a double achievement quantitatively, successfully eliminating all high risks and reducing the average risk value by 40%, and operationally resulting in 37 safe work steps that are documented as the basis of SOP and daily safety briefing. Two residual risks with residual R=10 (falling from height on scaffolding installation and painting) still require continuous disciplinary supervision because the severity=5 value cannot be lowered as long as the work at height is still being carried out.

4. Conclusion

This study successfully integrated the HIRADC and JSA methods to analyze occupational accident risks in scaffolding construction work at PT XYZ. Three main results were obtained. First, hazard identification using HIRADC identified 17 potential hazards across seven work stages, with the risk of falls from heights being the most dominant threat (R=15, catastrophic). Second, the risk assessment results indicated two high-risk items and 11 moderate-risk items at baseline. After implementing the hierarchy of controls, all high risks were eliminated with an average risk reduction of 40%, resulting in a final distribution of 0% high risk, 77% moderate risk, and 23% low risk. Third, the JSA analysis complemented HIRADC by developing 37 safe work steps across five key activities that can be used as the basis for operational SOPs and daily safety briefings. The integration of the HIRADC and JSA methods has been proven to provide a more comprehensive risk analysis than using either method alone. This research has several novel contributions, namely the integrated application of HIRADC-JSA to all stages of scaffolding work in medium-scale construction companies in Indonesia, the preparation of residual risk measurements as an indicator of control effectiveness, and the development of JSA documents that can be directly applied as operational instruments for SMK3. These findings also support previous research [21], which shows that the implementation of a comprehensive K3 management system in the construction sector can increase the effectiveness of work risk control. However, this study still has limitations because it was conducted on only one construction project with a relatively small number of respondents. Therefore, further research is needed on different project types and company scales with a larger number of respondents so that the results can be more broadly generalized.

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