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## Risk Assessment of Occupational Health and Safety in Lifting Operations Using the HIRADC Method: A Case Study in Oil and Gas Construction

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### ABSTRACT

The complexity of lifting operations in oil and gas refinery construction presents significant occupational safety and health risks. This study aims to enhance the effectiveness of Hazard Identification, Risk Assessment, and Determining Control (HIRADC) by identifying existing hazards, assessing inherent and residual risks, and proposing improved mitigation measures. The initial HIRADC analysis revealed five work activities classified as high risk, with risk scores ranging from 12 to 15. After implementing additional control measures, such as the installation of hard barricades, pre-lifting inspections, and standardized signaling, the residual risk scores were reduced to a range of 6 to 9, corresponding to moderate-to-high categories, representing a risk reduction of up to 50%. Additionally, the novelty of this study lies in its data-driven refinement of the HIRADC framework, which incorporates previously unrecorded critical activities, such as job preparation and work method validation. It aligns risk evaluation with real-time field observations. This offers a replicable model for continuous safety improvement in high-risk industrial environments. The study concludes that improving the HIRADC process, supported by routine inspections, proper use of personal protective equipment (PPE), and the placement of HSSE signs, plays a crucial role in preventing workplace accidents caused by unsafe actions, mechanical hazards, and ergonomic issues during lifting operations.

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## 1. INTRODUCTION

The continuous increase in demand for fuel types such as Peralite, Pertamina, diesel, and aviation fuel (Avtur) has prompted the Indonesian government to launch several national strategic initiatives aimed at expanding and upgrading domestic oil refinery capacities. As a vital energy source, crude oil is refined into various fuels, power generation inputs, and lubricant raw materials (Suwanto & Hasan, 2018). In response to future challenges, the government has invested USD 48 billion to enhance the country's refining capabilities, targeting a production capacity of 1.8 million barrels per day by 2030 and adopting higher emission standards (Euro V). These refinery development efforts have been officially designated National Strategic Projects (Proyek Strategis Nasional/PSN) under Presidential Regulation No. 3 of 2016 and Presidential Instruction No. 1 of 2016. The primary goal is to improve refinery efficiency and profitability while strengthening national energy resilience and self-sufficiency.

The oil and gas refinery, which remains one of the most significant contributors to state revenue, is inherently high-risk due to its involvement with hazardous and flammable substances such as gas and crude oil. The sector is characterized by complex and large-scale operations, hazardous environments, and a substantial workforce, all elevating the likelihood of work-related accidents. As such, the responsibility to implement and

enforce occupational health and safety (OHS) standards is paramount. Operational and maintenance activities are often accompanied by various potential hazards, making it imperative for companies to prioritize the protection and safety of their workers (Prastiyo & Ashari, 2022).

Risk is commonly defined as the probability of an undesired outcome occurring within a process. Risk management, as outlined by Susihono & Rini (2013), typically comprises three key stages: risk identification, risk assessment, and risk control. These are often embedded within two significant components of OHS initiatives: the Occupational Health and Safety Management System (OHSMS) and technical operational programs. Risk control strategies should be prioritized based on a risk hierarchy, ranging from elimination and substitution to engineering controls, administrative procedures, and personal protective equipment (PPE) as recommended by Dankis & Mulyono (2015). Once hazards are identified, the severity and likelihood of potential incidents must be assessed to derive a risk level, using qualitative or quantitative scales to guide mitigation efforts.

According to Mangkunegara, as cited in Djatmiko (2016), OHS refers to a set of principles and efforts aimed at ensuring the physical and mental well-being of workers in particular and humans in general, as well as safeguarding the outcomes of their work and culture to support the development of a just and prosperous society. Meanwhile, Suma'mur (2014) defined OHS as safety measures related to machinery, tools, work equipment, materials, processing methods, workplace conditions, and the environment, including the manner in which tasks are performed.

Occupational Health and Safety Management Systems (OHSMS) are integral to a comprehensive management system. They encompass organizational structure, planning, responsibilities, implementation, procedures, and the necessary resources to develop, achieve, evaluate, and maintain occupational health and safety policies. The goal is to control the risks associated with workplace activities and to create a safe and comfortable working environment (OHSAS 18001, 2007). Every industry must comply with applicable regulations and implement an established system. Organizations that already have risk control measures in place are expected to follow standard procedures to prevent accidents.

Nevertheless, oil and gas refinery projects face increasing challenges in managing workplace safety, especially as workforce size and workload intensify. Between 2019 and 2024, 181 workplace incidents were recorded in national oil and gas refinery projects in Indonesia, including 78 near-miss cases and 42 instances of property damage. In this context, risk is defined as a combination of the probability of an event and the severity of the potential consequences it may cause (Damayanti & Nalhadi, 2017; Puspasari & Koesyanto, 2020). Meanwhile, a workplace accident is described as an unplanned and often unexpected event that results in losses—whether in time, assets, or even lives—during industrial processes or related activities (Ismail et al., 2022). These definitions align with Framulya's (2022) findings, which emphasize that occupational health and safety are critical in ensuring a safe work environment and protecting workers from accidents and potential hazards.

The HIRADC (Hazard Identification, Risk Assessment, and Determining Control) method is employed to address these safety challenges. It is a tool to systematically identify potential hazards, particularly in lifting operations, by calculating the Risk Priority Number (RPN) based on severity and occurrence ratings. Lazuardi et al. (2022) applied HIRADC in the electrical assembly department, while Windan et al. (2022) applied HIRA to potential hazards in chemical product processes. Pardede et al. (2025) applied HIRADC to risk management of hazardous and toxic materials in the sizing agent production process. At the same time, Pranata and Sukwika (2022) explored its use within the freight forwarding industry. However, these studies did not account for the dynamic nature of projects such as refinery construction, where rapid changes frequently occur.

Several empirical studies have implemented risk identification frameworks such as HIRA and HIRARC across diverse industrial settings. Efendi et al. (2018) applied the HIRA method in an LPG cylinder repair facility. They found that 22% of tasks, such as hand guard pressing and painting, were classified as high risk, necessitating prompt mitigation. Ramadhan (2019) reported that in a furniture manufacturing setting, 43 risks were identified and categorized using HIRA, with JSA applied to manage them through SOPs, PPE enforcement, and

supervisory oversight. Similarly, Dzaldi and Samanhudi (2021) examined safety risks in a fuel distribution company, revealing 59 accident cases within a one-year period, which prompted the need for enhanced control strategies. Rachmanto and Destara (2021) assessed the implementation of OHSMS in a generator manufacturing company and identified 30 specific risks, concluding that structured risk evaluation is essential to improve system effectiveness and adapt to field-specific hazards.

This research introduces a novel application of the HIRADC method within the context of a dynamic oil refinery construction project. It aims to comprehensively identify potential hazards associated with lifting operations, evaluate risk levels based on severity and occurrence scores, and determine the RPN for each identified activity. The objective is not only to assess the initial risk but also to propose appropriate mitigation measures that are tailored to each risk level. These mitigations reduce the RPN and ultimately lower residual risk, enhancing the overall safety of lifting operations in the project environment. While the HIRADC method has been widely used in more stable industrial settings, its application in the ever-changing conditions of large-scale construction projects, particularly in the oil and gas sector, remains limited, highlighting the novelty and relevance of this study.

## 2. RESEARCH METHOD

### 2.1. Research Design

This study adopts a mixed-methods case study approach to assess risk in lifting operations within an oil and gas refinery construction project. The research combines quantitative analysis, which involves numerical scoring of hazard likelihood and severity using the HIRADC framework, with qualitative insights gathered from field observations and semi-structured interviews with key personnel, including crane operators, riggers, and HSSE supervisors. The qualitative data serve to contextualize the operational environment and validate the scoring process, while the quantitative component enables objective measurement of inherent and residual risks. This integrated approach ensures a comprehensive understanding of safety practices and the effectiveness of risk mitigation in dynamic, high-risk industrial settings.

### 2.2. Location and Time of Research

The research was conducted at the RDMP Project, explicitly focusing on oil and gas refinery construction within the ISBL (Inside Battery Limit) 2 area. Field data collection took place over 10 working days in February 2025, with a focus on lifting activities in Areas 41 and 50, which are categorized as critical lifting zones due to their high load and material sensitivity.

### 2.3. Data Collection Techniques

The research utilized several tools and documents as instruments, including field observation checklist tailored to lifting safety protocols (e.g., barricades, signaling, PPE use), interview guide with structured and open-ended questions, standard HIRADC forms and RAM (Risk Assessment Matrix) tables from PT KPI (2025) as templates for risk scoring. Primary data were obtained through direct observation of lifting and safety procedures as well as mitigation efforts on-site. Semi-structured interviews were conducted with 11 personnel, comprising five certified crane operators (with at least 3 years of experience), four riggers with critical lifting experience, and two HSSE supervisors who oversee lifting permits and job site inspections. To ensure the validity of the qualitative data, triangulation was employed by cross-checking observational data, interview responses, and official documents, including JSA, SILO, SIO, PTW, and incident reports. Secondary data were gathered from internal company documents, including the existing HIRADC records, SOPs related to lifting, HSSE audit logs, and relevant risk matrices issued by PT KPB and PT KPI.

### 2.4. Data Analysis Techniques

The analysis employed the HIRADC method. Each work activity was evaluated based on its Probability Rating (PR) and Severity Rating (SV) (Figure 1). Risk scores were calculated using a multiplication method ( $PR \times$

SV) and categorized according to the RAM. The process included the identification of inherent risks (prior to mitigation), the application of recommended controls, and the evaluation of residual risks (after mitigation). This numerical data was then used to classify risk levels into five categories: low, low-to-moderate, moderate, moderate-to-high, and high. The impact of mitigation measures was assessed by comparing risk scores before and after interventions.

|                        | LIKELIHOOD        |                            |                                               |                                               |                                |                |
|------------------------|-------------------|----------------------------|-----------------------------------------------|-----------------------------------------------|--------------------------------|----------------|
| HAZARD EFFECT/SEVERITY | LEVEL             | 1                          | 2                                             | 3                                             | 4                              | 5              |
|                        |                   | 0% < X < 20%               | 20% < X < 40%                                 | 40% < X < 60%                                 | 60% < X < 80%                  | 80% < X < 100% |
|                        |                   | <10 <sup>-6</sup> per year | 10 <sup>-6</sup> to 10 <sup>-4</sup> per year | 10 <sup>-4</sup> to 10 <sup>-2</sup> per year | 10 <sup>-2</sup> to 1 per year | >1 per year    |
|                        | 5<br>Catastrophic | 5                          | 10                                            | 15                                            | 20                             | 25             |
|                        | 4<br>Significant  | 4                          | 8                                             | 12                                            | 16                             | 20             |
|                        | 3<br>Moderate     | 3                          | 6                                             | 9                                             | 12                             | 15             |
|                        | 2<br>Minor        | 2                          | 4                                             | 6                                             | 8                              | 10             |
| 1<br>Insignificant     | 1                 | 2                          | 3                                             | 4                                             | 5                              |                |

**Figure 1.** Risk Assessment Matrix for HIRADC

Source: PT KPI (2025)

## 2.5. Identification of Lifting Operation

Lifting operations refer to a series of activities that involve the elevation and relocation of heavy loads using mechanical equipment such as cranes, hoists, or forklifts. These tasks are inherently high-risk due to the potential for load drops, equipment failure, or human error, which can lead to serious injuries or fatalities. As such, lifting operations are recognized as one of the ten critical elements in the Corporate Life Saving Rules (CLSR). The CLSR is a safety framework developed to address the most common causes of fatal incidents in high-risk industries. The CLSR was established based on extensive incident data collected since 2011, particularly within the oil and gas sector, and serves as a proactive guideline to mitigate risks and enforce safe working behaviors.

Within the context of an oil and gas refinery project in Balikpapan, lifting operations are classified into two main categories: regular lifting and critical lifting. Regular lifting refers to routine activities involving the movement of loads typically under five tons. These operations, while considered standard, still require a lifting certificate to ensure they meet safety and regulatory requirements (Alverius et al., 2023). On the other hand, critical lifting encompasses higher-risk scenarios, such as lifting loads exceeding five tons, handling materials of high value or with long lead times, and conducting lifting operations within operational facilities or congested work zones. Due to the complexity and potential hazards involved, critical lifting requires a comprehensive lifting plan, strict supervision, and the involvement of certified personnel to ensure safety and operational integrity (Hu et al., 2021; Hu et al., 2023).

Critical lifting operations require the preparation of a detailed lifting plan that defines step-by-step procedures to minimize potential hazards and ensure the safety of all personnel involved. Insights gathered through interviews and on-site assessments involving riggers, crane operators, supervisors, and HSSE staff revealed several documented lifting activities within ISBL 2, specifically in Area 41 and Area 50. As illustrated in Figure 1, each lifting operation must be accompanied by essential documentation, including a Job Safety Analysis (JSA), a valid Operator License (SIO), an Operational Feasibility Certificate (SILO), a Permit to Work (PTW), and a certified Lifting Certificate. The lifting equipment used in these areas includes a Tadano GR 500 EXL

crane with a capacity of 50 tons. The lifting crew comprises six riggers (two at the base, two at the top, and two signallers), one crane operator, and one HSSE supervisor responsible for securing the operation zone.

Typical lifting operations are carried out through several interrelated stages that must be executed in a structured and coordinated manner. The process begins with the issuance of a Permit to Work (PTW) and, when applicable, a Lifting Certificate to authorize the activity. This is followed by a thorough inspection of tools and equipment to ensure they are in proper working condition. Personnel coordination is crucial at this stage, as clear communication between riggers, operators, and supervisors directly influences the safety and efficiency of the operation. Once coordination is established, the mobilization of materials and the rigging setup on trailers take place. The actual lifting is then performed using cranes or forklifts, depending on the load and conditions. Subsequent steps may include stringing activities, dismantling of lifting gears, and housekeeping measures, particularly during or after night operations, to maintain a safe and organized work environment. In line with OHSAS 18001 (2007), managing risks throughout these stages involves a systematic process comprising three core components: hazard identification, risk assessment, and risk control. Each of these elements plays a crucial role in proactively addressing potential hazards and ensuring that appropriate safety measures are implemented at every stage of the lifting operation.



a) Lifting Certificate



b) Certificate of Crane Operator dan Rigger



c) Lifting Activities by Crane Operator

**Figure 2.** Lifting Operations in Oil and Gas Project Construction

Source: PT KPB (2024)

## 2.6 HIRADC Process

Primary data were obtained through direct field observations and semi-structured interviews with crane operators, riggers, and HSSE supervisors. Each stage of the lifting operation was carefully analyzed to identify physical, mechanical, ergonomic, and procedural hazards. This comprehensive hazard identification process ensured that both visible and latent risks were systematically documented as input for the Hazard Identification, Risk Assessment, and Control (HIRADC) model. Subsequently, inherent risk assessment was conducted to evaluate the initial level of risk before any controls were applied. Each identified hazard was assigned a severity and likelihood score, determined using historical incident data, expert judgment, and real-time field conditions. These scores were plotted on the RAM to determine the priority level of each risk.

Once the inherent risks were established, mitigation strategies were formulated based on the hierarchy of controls, starting with elimination and substitution and then progressing to engineering and administrative measures, and finally the use of appropriate PPE. After implementing the proposed controls, residual risks were reassessed to evaluate the effectiveness of these interventions in lowering risks to acceptable levels. If certain risks remained elevated, further action was recommended. The final stage involved a comprehensive evaluation of the HIRADC process itself, including the identification of any operational gaps and the necessary improvements to align the model with field realities. This ensured that the framework remains responsive, adaptable, and suitable for ongoing application in high-risk construction environments such as oil and gas refinery projects.

### 3. RESULTS AND DISCUSSIONS

This section presents the findings from data analysis and field observations. It aims to explain the lifting operation practices within an oil and gas refinery construction site, highlight the potential hazards involved, evaluate the associated risks, and propose appropriate control measures to ensure compliance with occupational health and safety standards.

#### 3.1. Hazard Identification.

Hazard identification aims to provide comprehensive and detailed information on risks ranging from minor to severe consequences (ILO, 2001). This process must anticipate all foreseeable hazards associated with lifting operations that may endanger workers, visitors, or surrounding communities. In line with the Ministry of Manpower of the RI (2018), hazards in a work environment can be grouped into five categories (Table 1).

#### 3.2. Risk Assessment.

Risk assessment is the process of evaluating potential hazards by quantifying the level of risk based on two key parameters: the severity of the consequences and the likelihood of their occurrence, as outlined in Tables 2 and 3, respectively. This scoring approach enables organizations to prioritize risk mitigation strategies more effectively, often by integrating the results into a JSA framework. After assigning numerical values to both severity and likelihood, the two scores are multiplied to produce a composite risk score. This final value is then plotted on a Risk Assessment Matrix (RAM), as illustrated in Figure 1, to determine the overall risk level and guide the appropriate control measures (PT KPI, 2025). Through this methodical approach, decision-makers can ensure that risks are managed systematically and proportionally to their potential impact on personnel and operations.

**Table 1.** Hazard Identification in Oil and Gas Refinery Construction in Lifting Operations

| No. | Type of Hazard | Source of Hazard                                                                      |
|-----|----------------|---------------------------------------------------------------------------------------|
| 1   | Ergonomic      | Improper lifting posture, repetitive motions, and overexertion during manual handling |
| 2   | Mechanical     | Crane malfunction, dropped loads, gear failure                                        |
| 3   | Physical       | Noise, vibration, extreme temperatures, and poor lighting during night work           |
| 4   | Chemical       | Exposure to oils, grease, or fuel during equipment maintenance                        |
| 5   | Electrical     | Crane contact with overhead power lines, faulty grounding                             |

**Table 2.** Severity Levels

| No. | Severity      | Rating | Description                                                                               |
|-----|---------------|--------|-------------------------------------------------------------------------------------------|
| 1   | Catastrophic  | 5      | Disaster – Results in more than one permanent disability or fatality                      |
| 2   | Significant   | 4      | Fatal incident – Involves more than one serious injury or, permanent disability, or death |
| 3   | Moderate      | 3      | Major injury – One injury requiring medical treatment resulting in work loss > 24 hours   |
| 4   | Minor         | 2      | Moderate injury – Requires medical treatment or work loss ≤ 24 hours                      |
| 5   | Insignificant | 1      | Minor injury – Includes first aid cases or medical treatment with no work restriction.    |

Source: PT KPI (2025)

**Table 3. Likelihood Levels**

| No. | Probability / Likelihood | Rating | Description                                                              |
|-----|--------------------------|--------|--------------------------------------------------------------------------|
| 1   | Almost Certain           | 5      | Has occurred more than once a year within the local Refinery Unit (RU)   |
| 2   | Likely                   | 4      | Has occurred within the local RU or more than once a year in another RU  |
| 3   | Possible                 | 3      | Has occurred in a Refinery Unit or more than once a year in the industry |
| 4   | Unlikely                 | 2      | This has been reported to occur within the industry                      |
| 5   | Rare                     | 1      | This has never occurred in the industry.                                 |

Source: PT KPI (2025)

### 3.3. Risk Categories and Acceptance Criteria.

Following the risk scoring process, each risk is categorized according to its level of severity and likelihood, and then mapped against standardized Risk Acceptance Criteria, as detailed in Table 4 (PT KPI, 2025). These categories are essential for determining the urgency and type of action required under the ALARP (As Low as Reasonably Practicable) principle. Risks falling within the "High" category, with scores between 15 and 25, are deemed unacceptable and demand immediate corrective measures within three months. Scores ranging from 10 to 12 are considered "Moderate to High" and are not tolerable without further controls being implemented within six months. Risks with moderate scores between 5 and 9 may be tolerable if further risk reduction is impractical or cost-prohibitive; however, additional controls or close monitoring are still recommended. Lower risks, with scores of 4 or below, are generally considered tolerable or acceptable, and may not require further intervention unless desired for precautionary reasons. This structured categorization ensures that organizations respond proportionally to varying degrees of risk, optimizing both safety and resource allocation.

**Table 4. Risk Categories, Acceptance Criteria, and Required Actions**

| Risk Category           | Acceptance Criteria (ALARP)                              | Score   | Required Action                                      |
|-------------------------|----------------------------------------------------------|---------|------------------------------------------------------|
| <b>High</b>             | Unacceptable                                             | 15 - 25 | Immediate additional control within 3 months         |
| <b>Moderate to High</b> | Not Tolerable                                            | 10 - 12 | Additional control is needed within 6 months         |
| <b>Moderate</b>         | Tolerable only if the reduction is impractical or costly | 5 - 9   | Additional control recommended or ongoing monitoring |
| <b>Low to Moderate</b>  | Tolerable                                                | 4       | Acceptable, additional controls may be considered    |
| <b>Low</b>              | Acceptable                                               | 1 - 3   | No additional controls required                      |

Source: PT KPI (2025)

### 3.4. Risk Control

Risk control represents the most critical and actionable phase in the overall risk management process. Unlike the preceding stages that focus on identification and assessment, this phase emphasizes the implementation of practical and effective measures to reduce or eliminate identified risks. According to OHSAS 18001 (2007), managing HSSE risks should be guided by a structured Hierarchy of Controls, which is illustrated in Figure 3 (PT KPI, 2025). This hierarchy prioritizes control methods from the most effective—such as eliminating the hazard—to the least effective, including the use of personal protective equipment (PPE). By adhering to this tiered approach, organizations can ensure that risk reduction efforts are both systematic and aligned with best practices in occupational safety and health.

### 3.5. Application of Risk Control in Lifting Operations

In a practical field case, the use of elimination and substitution as primary risk control methods is highly preferred due to their effectiveness in removing hazards at the source. However, these options are not always feasible in oil and gas refinery construction projects, particularly during lifting operations, as they may conflict with operational limitations or budgetary constraints. As a result, organizations frequently rely on a combination of engineering and administrative controls, supplemented by personal protective equipment (PPE), to reduce risk exposure to an acceptable level.

Table 5 outlines the specific control strategies commonly applied during lifting activities in refinery construction. Engineering controls may involve physical modifications to equipment or the installation of protective covers, while administrative measures include equipment inspections, rigging training, SOPs, work rotation schedules,

and the placement of HSSE signage. PPE, such as safety helmets, gloves, and reflective vests, serves as the last line of defense to protect workers if other controls are insufficient. This multi-tiered approach ensures that lifting operations are conducted with a balanced emphasis on hazard reduction, regulatory compliance, and worker safety.

**Table 5.** Risk Control in Oil and Gas Refinery Construction in Lifting Operations

| No. | Type of Risk Control                | Risk Control                                                                                                                                                                                                      |
|-----|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Engineering Controls                | Physical modifications to equipment or processes, and exhaust cover installation                                                                                                                                  |
| 2   | Administrative Controls             | <ul style="list-style-type: none"> <li>Tools and equipment inspection (lifting gears, etc.)</li> <li>Training rigging</li> <li>Procedures (SOP)</li> <li>Scheduling or rotations</li> <li>HSSE signage</li> </ul> |
| 3   | Personal Protective Equipment (PPE) | Safety helmets, gloves, vests, etc                                                                                                                                                                                |

Source: PT KPB (2024)

The HIRADC-based analysis identified nine critical work activities in lifting operations, five of which were initially classified as high-risk. These included crane-based material lifting, nighttime lifting operations, and rigging setup. The inherent risk scores, which ranged from 12 to 15, reflected a high potential for serious incidents due to factors such as equipment failure, inadequate communication, and limited barricading in congested areas.

**Table 6.** Example of HIRADC Application for Lifting Operation Activities

| No | Work Sequence                   | Hazard                                                                                                                                                | Risk Description                                                                | Potential Impact                                                                                    | Inherent Risk |    |    | Mitigation                                                                                                                                                       | Residual Risk |    |   |
|----|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|---------------|----|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----|---|
|    |                                 |                                                                                                                                                       |                                                                                 |                                                                                                     | PR            | SV | R  |                                                                                                                                                                  | PR            | SV | R |
| 1  | Lifting materials using a crane | Movement of heavy equipment, falling materials, overloading, miscommunication, absence of barricades, and lack of safety measures in the lifting area | Workers hit or stumble over materials; workers walking through the lifting zone | Dropped load due to broken sling; injury due to lack of barricade or communication; material damage | 3             | 5  | 15 | Install hard barricades to restrict unauthorized access; inspect and ensure lifting equipment is in safe condition; use proper signals during lifting operations | 2             | 3  | 6 |

Source: PT KPB (2024)

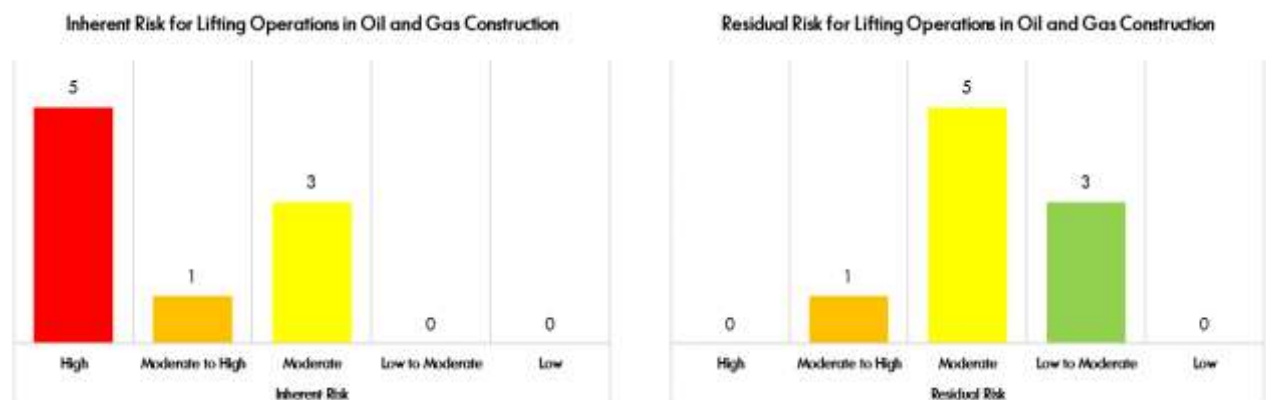
Note:

PR: Probability Rating

SV: Severity Rating

Inherent Risk (Before Mitigation)

Residual Risk (After Mitigation)



**Figure 4.** Risk Assessment Analysis with HIRADC Method

Source: Data processing results

After implementing additional mitigation strategies, including the installation of hard barricades, reinforcement of signaling procedures, and routine pre-lift inspections, the residual risk scores showed a measurable decline. Specifically, risks were reduced to a range of 6 to 9, falling under moderate-to-high categories. While this reduction indicates that the interventions were partially effective, it also reveals that some risks remain significantly elevated. This persistence is primarily attributed to limitations in real-time control, variability in worker compliance, and environmental unpredictability during construction phases.

One key finding is that mitigation strategies, although technically sound, often encounter implementation barriers in the field. Interviews with HSSE officers and riggers revealed several challenges: limited availability of certified personnel, inconsistent adherence to PPE protocols, and a work culture that sometimes prioritizes task completion over procedural compliance. Additionally, the high turnover rate among subcontractor workers leads to frequent retraining needs and knowledge gaps that diminish the continuity of safety practices.

Identifying work activities is a crucial foundation for implementing control measures to mitigate the risk of accidents and potential hazards in oil and gas refinery construction (PT KPB, 2024). The process begins by classifying risks based on the likelihood of occurrence from rare to most probable events. Each work activity is then assessed for its severity level, after which appropriate mitigation strategies are developed and implemented. Table 6 provides an example of hazard identification and risk control using the HIRADC method specifically for lifting operations. Using the HIRADC method, risk assessment in refinery construction is categorized into Inherent Risk and Residual Risk, covering a total of nine key work activities: (1) work permit issuance, (2) equipment preparation and inspection, (3) mobilization check including equipment units and materials, (4) job preparation and work method validation, (5) stringing process, (6) material lifting using cranes, (7) material release and lifting gear removal, (8) night-time work activities, and (9) worksite cleaning activities. As shown in Fig. 4, the HIRADC-based risk assessment reveals that the Inherent Risk includes High Risk (55.5 percent), Moderate to High Risk (11.1 percent), and Moderate Risk (33.3 percent). After implementing mitigation measures, the Residual Risk assessment shows improvement, with risks reduced to Moderate to High (11.1 percent), Moderate (55.5 percent), and Low to Moderate (33.3 percent).

### 3.6. Discussion

In the lifting operation process, heavy equipment is indispensable to ensure the successful execution of tasks. However, these tools carry inherent hazards during operation and job stages. Therefore, the initial step involves observing ongoing activities in the work area to identify potential hazards, followed by conducting a risk assessment based on the identified hazards and associated risks. Lifting operations are particularly prone to risks, including hand injuries, falling materials, and unforeseen incidents during the lifting process. These hazards can be mitigated through various strategies: Workers should be mindful of hand placement, avoid high-risk zones during lifts, and use hard barricades to restrict access to lifting areas. Pre-job TBMs and thorough equipment checks are also vital to ensuring a safe working environment, particularly before lifting.

Daily inspection and preparation of lifting equipment are crucial due to the routine nature of lifting tasks. Any malfunction in lifting units, such as cranes or forklifts, may lead to material damage during lifting, posing threats to worker safety through risks like falling loads. Such incidents can also result in financial losses and delays in project timelines. In response, proper job preparation and the formulation of safe work methods are essential. Conducting Toolbox Meetings (TBM) before commencing work and ensuring that all workers are briefed on the contents of the JSA can greatly minimize such hazards.

Compared to previous studies, this research builds on established frameworks but advances the methodology by offering a more refined and data-driven approach. Efendi et al. (2018) utilized the HIRA method to assess risk levels in an LPG cylinder repair company. Their study categorized activities broadly as low, moderate, or high risk, identifying 67 percent of tasks as low-risk and 22 percent as high-risk, mainly those involving mechanical processes such as welding and painting. In contrast, Ramadhan (2019) carried out a more comprehensive assessment in a furniture manufacturing company, identifying 43 different types of risks across various departments, including those related to work methods, materials, financial processes, and human factors. Using the HIRA method, the risks were categorized into four levels: Extreme (6 risks), High (21 risks),

Moderate (10 risks), and Low (6 risks). The study went further by applying JSA as a control mechanism, supported by policies, training, SOP enforcement, and supervisory oversight.

By contrast, the current study adopts an HIRADC-based approach tailored explicitly to lifting operations in oil and gas construction. The assessment covered nine key work activities ranging from permit issuance and rigging setup to night work and housekeeping. Risks were analyzed using a numerical Probability Rating (PR) and Severity Rating (SV), which allowed for the calculation of Inherent and Residual Risk scores. The results showed that high-risk activities accounted for 55.5 percent before mitigation but were eliminated after implementing specific controls, leaving only moderate and low-to-moderate risks. This use of quantitative data and post-control comparison highlights the added value of a feedback-integrated HIRADC system in managing high-risk industrial tasks.

The findings align with those of Hu et al. (2023), who emphasized that visualizing crane operation hazards spatially enables stakeholders to comprehend exposure zones better and proactively reduce risks. However, unlike their approach, which leverages digital modeling, this study highlights field-oriented risk reduction practices, suggesting that both digital and procedural controls may be complementary. Furthermore, the current study's inclusion of real-time interviews and residual risk analysis offers a practical framework that is responsive to field dynamics. Hu et al. (2021) acknowledged a gap in automation-led lift planning, where optimization often lacks adaptation to onsite complexities.

Additionally, this research resonates with the study by Alverius et al. (2023), who applied HIRARC to lifting operations in high-rise condominium projects in Sabah, Malaysia. They identified similar hazards, such as falling objects, equipment malfunction, and inadequate supervision, but emphasized the role of training and routine checks in reducing risks. In comparison, the current study strengthens this position by quantifying residual risks post-mitigation and revealing operational constraints that hinder full compliance, including limited certified manpower and frequent subcontractor turnover.

Despite the structured mitigation plan, interviews with HSSE officers, riggers, and crane operators revealed challenges with its implementation. These included a shortage of trained personnel, inconsistent use of personal protective equipment (PPE), and a prevailing culture that prioritizes speed over safety. Moreover, frequent rotation among subcontractor crews often disrupts knowledge transfer and diminishes consistency in safety adherence issues, also highlighted by Hu et al. (2021) in their critique of current crane lift planning practices. The study also uncovered a critical gap during initial HIRADC development, including job preparation and work method validation, which had not been included as a standalone risk activity. Field observations confirmed its relevance, and the updated HIRADC now includes it, reaffirming the importance of iterative review in dynamic environments.

#### 4. CONCLUSION

This study concludes that lifting operations within oil and gas refinery construction projects present significant safety risks, particularly in crane operations, night lifting, and rigging setups. Through the systematic application of the HIRADC method, five high-risk activities were successfully reduced to moderate-to-high residual risks after implementing targeted mitigation measures, including the installation of hard barricades, enhanced signaling, and routine equipment inspections. A critical finding is the identification of job preparation and work method validation as essential activities previously overlooked in conventional HIRADC applications. This adjustment enhances the method's responsiveness to dynamic project conditions, contributing to a more adaptive and effective risk management framework. The study emphasizes the importance of continuously updating risk assessments, integrating real-time field observations, and enforcing periodic training to maintain safety standards in high-risk environments. However, the research acknowledges certain limitations, such as the limited number of informants and the constraints posed by fluctuating subcontractor teams, which may impact the sustainability of safety improvements. Future research should consider integrating digital modeling and simulation to enhance hazard prediction in congested worksites further and conduct longitudinal studies to evaluate the long-term effectiveness of the updated HIRADC framework. By adopting structured, iterative,

and field-adaptive risk assessments, lifting operations can achieve significant improvements in safety, operational efficiency, and workforce engagement.

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