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Analysis and Risk Mitigation Strategies for Occupational Accidents in Construction Activities at PT PP Site Development, Nickel Mining Area of PT X Using the HIRADC–Fuzzy TOPSIS Method

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***Abstract*— This study aims to identify potential hazards and establish priority risk control strategies in nickel mining operations using the Hazard Identification, Risk Assessment, and Determining Control (HIRADC) method combined with the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) approach. The HIRADC analysis revealed several activities with high risk levels, including girder lifting, material/piping unloading, maintenance lifting, stone crushing, civil works, cathodic installation, and material loading/unloading operations. The most significant hazards identified were falling or being struck by objects, falls from heights, electrical shock, collisions with heavy equipment, and entrapment by materials. Five hazards were classified as very high risk, including falling objects (score 25), while falls from heights, electrical shock, collisions, and entrapment each scored 20. To determine mitigation priorities, the Fuzzy TOPSIS method was applied, resulting in recommended risk control strategies. The top-ranked strategies include ensuring areas are clear of falling objects and verifying lifting equipment capacity (C1), providing lifelines and full-body harnesses (C2), installing standard-compliant electrical panels with grounding (C3), segregating pedestrian pathways from heavy equipment routes (C4), and installing emergency stops and machine guards (C5). The findings demonstrate that integrating HIRADC with Fuzzy TOPSIS offers a systematic approach for effective risk management in nickel mining operations.**

Keywords— HIRADC, Fuzzy TOPSIS, Hazard Identification, Risk Mitigation Startegy

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I. INTRODUCTION

The mining sector in Indonesia plays a pivotal role in driving national economic growth, with nickel mining emerging as one of the most strategic commodities due to its essential role in battery production, stainless steel, and clean energy transitions. The government's initiative to downstream the mining industry has led to increased investments in the construction of mining facilities and infrastructure, particularly in regions like Morowali, Sulawesi. This region has become a hub for nickel-based industrial activities, demanding rapid development of supporting infrastructure.

In response to these developments, PT X Indonesia Tbk has initiated the expansion of its mining area by appointing PT PP (Persero) Tbk to undertake construction activities for site development. While this initiative aligns with national development goals, it also introduces significant occupational safety challenges. Construction work in mining environments is inherently high-risk due to factors such as unstable terrain, the use of heavy equipment, electrical installations, and dynamic work environments that frequently change as projects progress.

Statistical data from BPJS Ketenagakerjaan reveals a consistent increase in workplace accidents in the construction sector, with over 200,000 cases reported annually in recent years. This alarming trend highlights the critical need for proactive risk assessment and mitigation strategies. Given the dynamic and hazardous nature of mining construction, traditional safety approaches are often insufficient to identify and control complex risks effectively.

To address these concerns, this study integrates the Hazard Identification, Risk Assessment, and Determining Control (HIRADC) method with Fuzzy Technique for Order Preference by Similarity to Ideal Solution (Fuzzy TOPSIS). HIRADC provides a structured framework for identifying potential hazards, evaluating their severity and likelihood, and recommending appropriate control measures. However, prioritizing these controls objectively requires a decision-making tool capable of handling uncertainty and subjective judgments—hence the use of Fuzzy TOPSIS.

This research aims to identify high-risk construction activities in the PT X mining site, determine their risk levels through HIRADC analysis, and propose prioritized mitigation strategies using Fuzzy TOPSIS. The ultimate goal is to support safety

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practitioners in making data-driven decisions that enhance workplace safety, minimize the likelihood of accidents, and ensure the well-being of workers in high-risk environments.

II. METHOD

This study adopts a mixed-method approach combining qualitative and quantitative techniques to analyze occupational risks and determine effective mitigation strategies in the construction activities of the PT X nickel mining project. The methodological framework is structured into three primary stages: hazard identification, risk assessment, and strategy prioritization.

Data were collected through field observations, structured interviews, and expert judgment via questionnaires. Primary data included qualitative assessments of work activities and quantitative risk evaluations using the HIRADC method. The likelihood and severity of identified hazards were measured using predefined scales, producing risk scores for each activity. High-risk activities such as girder lifting, unloading, and heavy equipment operation were prioritized.

To address the uncertainty in subjective expert judgments, Fuzzy TOPSIS was used to evaluate and rank potential mitigation strategies. Respondents assessed five proposed strategies for each critical risk factor using linguistic variables (e.g., 'important', 'very important'), which were then converted into fuzzy numbers. The steps followed include: (1) construction of the decision matrix, (2) normalization of fuzzy values, (3) application of weightings, (4) calculation of distances from ideal and anti-ideal solutions, and (5) computation of a closeness coefficient for final ranking.

III. RESULTS AND DISCUSSION

The HIRADC analysis revealed that among the various construction tasks, five were identified as having the highest risk ratings: falling objects (risk score 25), falls from height (20), electrical shock (20), collisions with heavy equipment (20), and entrapment (20). These activities occur in critical areas such as mine infrastructure installation, port operations, and quarry development. Based on these findings, mitigation strategies were developed and evaluated using Fuzzy TOPSIS. The following five strategies were proposed:

a. C1 : Regular inspection and clearance of overhead zones, along with load testing of lifting equipment.
b. C2 : Implementation of lifeline systems and mandatory use of full-body harnesses.
c. C3: Installation of grounded and certified electrical panels.
d. C4: Design of separate pathways for pedestrians and heavy equipment.
e. C5: Emergency stop systems and protective machine guards on all equipment. Through the Fuzzy TOPSIS analysis, strategy C1 emerged as the highest priority, followed by C2, C3, C4, and C5. The closeness coefficients indicated that overhead safety and lifting equipment controls are the most critical interventions, considering the frequency and severity of related incidents. These results highlight the importance of technical controls and procedural compliance in minimizing high-risk exposures.

IV. CONCLUSION

This study successfully demonstrates the integration of HIRADC and Fuzzy TOPSIS as an effective method for analyzing and mitigating occupational risks in construction activities within nickel mining operations. By systematically identifying high-risk activities and objectively prioritizing mitigation strategies, this approach enhances the effectiveness of safety interventions.The findings suggest that technical improvements—such as improved lifting protocols, fall prevention systems, and safer electrical installations—should be prioritized to prevent severe workplace incidents. In addition, the Fuzzy TOPSIS method offers flexibility in incorporating expert judgment, making it a practical tool for dynamic and high-risk environments. Future research may explore its application across other mining sectors or integrate real-time data monitoring systems to further improve occupational safety outcomes.

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