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Risk Analysis of Human Resource Competence on Occupational Safety in Rural Construction

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Abstract

Purpose: This study analyzes the influence of human resource competency on occupational safety risks in rural construction projects in Bojonegoro Regency and develops mitigation strategies using the Human Factors Analysis and Classification System (HFACS).

Methodology: A mixed qualitative–quantitative descriptive approach was employed in the Ngasem, Dander, and Gayam Districts. Data were collected through observations, interviews, questionnaires, and documentation involving construction workers, Activity Implementation Teams, and technical assistants. Risk factors were analyzed using the HFACS and evaluated through likelihood and severity assessments.

Results: Seventeen human resource competency-related risk factors were identified, comprising 13 high-risk and four medium-risk factors. The main high-risk factors included low technical competency, insufficient construction training, poor PPE compliance, inadequate safety knowledge, weak supervision, and the absence of standardized OSH systems. HFACS analysis showed that unsafe acts, unsafe conditions, supervision weaknesses, and organizational factors collectively contribute to accident risks in rural construction.

Conclusions: Human resource competency is the primary determinant of occupational safety performance in rural construction projects. Strengthening workforce competency, supervision, and organizational safety systems is essential for reducing workplace accidents in the construction industry.

Limitations: This study was limited to three districts in Bojonegoro Regency and relied on perception-based assessments without statistical hypothesis testing.

Contributions: This study extends the application of the HFACS to rural construction by identifying priority human factor risks and proposing competency-based mitigation strategies for improving occupational safety management in village infrastructure projects.

Keywords: *Construction Occupational Safety and Health, Human Factors Analysis and Classification System, Human Resource Competency, Rural Construction Projects, Work Accident Risks*

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1. Introduction

Rural infrastructure development in Indonesia has experienced rapid growth in line with the Village Fund Policy and equitable regional development. Bojonegoro Regency, one of the regions with a large number of villages in East Java, has also experienced developments in rural construction, such as concrete roads, drainage, embankments, village bridges, irrigation channels, and public-service buildings. This development plays a crucial role in improving village economies, regional connectivity, and community welfare. However, it still faces major challenges in terms of human resource competency and the implementation of Occupational Safety and Health (OSH) (Zhou, Goh, & Li, 2015).

Most rural construction projects in Bojonegoro are self-managed by the Activity Implementation Team with technical assistance from the village facilitators. The workforce is dominated by local workers with varying competencies, many of whom lack formal certifications or training. This situation results in lower technical standards, risk control, and occupational safety systems than those found in professional construction projects (Mohammadi, Tavakolan, & Khosravi, 2018). Human resource issues are a key factor in the success of construction projects. Feryanto, Mulyanti, and Soma (2025) stated that human resource performance is influenced by competence, work experience, discipline, supervision, and human resource management systems (Wijaya, Putera, Adi, Bahri, & Bora, 2026). Weak competence impacts productivity, work quality, project delays, and increases the risk of workplace accidents (Rodhi & Aulady, 2025).

Rodhi (2023) emphasized that human resource risks are directly related to occupational safety, project quality, and construction success (Huang, Hu, Xu, Zhang, & Tao, 2023). The implementation of Occupational Safety and Health (OSH) in rural construction remains a major challenge. Many workers are reluctant to use Personal Protective Equipment (PPE), such as helmets, gloves, safety shoes, and masks, because they are considered uncomfortable and hinder their work. This situation results in the continued occurrence of minor-to-moderate workplace accidents, such as nail punctures, material scratches, slips, and accidents requiring medical attention. Juhari, Rasli, Yusoff, and Khalid (2023) explained that low PPE use is the dominant cause of construction workplace accidents and demonstrated the continued prevalence of unsafe acts.

Fang, Zhao, and Zhang (2016) Previous studies have emphasized that human factors are among the primary causes of workplace accidents, including limited understanding of safe work practices, insufficient training, improper use of Personal Protective Equipment (PPE), and non-compliance with Standard Operating Procedures (SOPs). Data from BPJS Ketenagakerjaan (Indonesian Workers' Social Security Agency) indicate that the construction sector contributed 32% of the 123,041 reported workplace accidents in 2017, highlighting the high-risk nature of this sector. International studies have further demonstrated that occupational safety performance is significantly influenced by worker competence, safety behavior, supervisory practices, and risk control mechanisms. Liang, Fung, Xiong, and Luo (2019) stated that worker competence directly influences safety performance. Gao, Chan, Utama, and Zahoor (2016) emphasized that safety behavior, work culture, communication, and supervision are critical factors in a construction safety system.

Rodhi (2023) found using Fuzzy AHP and Fuzzy TOPSIS, that the dominant factors in workplace accidents were low competency, training, supervision, and non-compliance with procedures. Sidiq and Rohman (2023) added that human error is influenced by experience, fatigue, weak supervision, and poor understanding of risks, making strengthening competency and safety culture a primary strategy for accident prevention (Bourahla, Fernandes, & Ferreira, 2024). The HFACS approach shows that construction accidents are not solely caused by workers, but also by organizational and supervisory systems (Liang et al., 2019). Magda, Yustiarini, and Nurasiyah (2023) found that PPE failure, weak SOPs, and poor supervision were the main factors contributing to workplace accidents. This is relevant to rural construction conditions, which still have limited formal safety systems in place.

Magda et al. (2023) explained that unsafe behavior and unsafe conditions are the main causes of reinforced concrete construction accidents, such as falls from heights, being struck by falling

materials, and injuries caused by reinforcement steel. This indicates that occupational safety awareness in the construction sector remains low. Developments in construction safety technology are being used for risk mitigation. Rodhi (2023) developed a fuzzy logic system to predict workplace accidents. Risk models can be built based on accident data with human error as the main factor, while Huang et al. (2023) demonstrated that AI could predict accident severity based on human factors and occupational risks. Recent advances have also shown that artificial intelligence can enhance hazard identification, safety monitoring, and predictive risk assessment in construction projects (Badhan & Samsami, 2025).

Workplace accidents also affect the social sustainability of construction projects. Bourahla et al. (2024) stated that occupational safety is a part of social sustainability. Estudillo, Forteza, and Carretero-Gómez (2025) emphasized that accidents affect project productivity, costs, and quality. Juhari et al. (2023) also highlighted low safety culture, training, supervision, and PPE compliance as key challenges in the construction industry. Rural construction risks are more complex because of limited supervision, resources, and formal systems. Rodhi (2023) stated that rural projects carry high risks because of uncertainty and low human resource capacity. Rodhi and Aulady (2025) emphasized that productivity is influenced by experience and skill. Rodhi (2025b) added that risk mitigation requires strengthening human resources, supervision, and a sustainable risk-management system.

Although previous studies have extensively examined occupational safety in the construction industry, most have focused on large-scale commercial or urban infrastructure projects, emphasizing general safety performance, safety culture, or technological approaches such as BIM, fuzzy methods, and artificial intelligence. Studies applying the Human Factors Analysis and Classification System (HFACS) have primarily investigated accidents in industrial or professional construction settings, where formal organizational structures and occupational safety management systems are well-established. Consequently, limited attention has been paid to rural construction projects implemented through community-based management systems, characterized by informal labor, limited supervision, varying workforce competencies, and inadequate occupational safety infrastructure. This gap limits the understanding of how human factors contribute to occupational safety risks in the development of village infrastructure.

The novelty of this study lies in the application of the HFACS framework to analyze occupational safety risks associated with human resource competency in rural construction projects managed by Village Activity Implementation Teams. Unlike previous studies that mainly identify accident causes or evaluate general safety performance, this study systematically classifies competency-related risks into HFACS levels, identifies priority risk factors through likelihood and severity assessments, and develops competency-based mitigation strategies tailored to the characteristics of rural construction. The findings provide both theoretical contributions by extending the application of HFACS to rural construction contexts and practical recommendations for strengthening occupational safety management and workforce competency in village infrastructure projects. Based on these conditions, this study aims to analyze the risks of human resource competency to occupational safety in rural construction in Bojonegoro to formulate a mitigation strategy based on improving competency, supervision, and the K3L system.

2. Literature Review

2.1 Human Resource Competencies in Construction Projects

Human resources are a key element in the success of construction projects because they are directly related to work quality, productivity, occupational safety, and the achievement of project targets. Workforce competency includes technical skills, work experience, knowledge of work procedures, use of equipment, and understanding of occupational safety and risk control (Fang, Zhao, & Zhang, 2016). Rodhi (2025a) emphasized that construction workforce performance is influenced by technical competency, work experience, discipline, and supervision. Low competency impacts decreased productivity, work delays, and an increased risk of workplace accidents (Feryanto, Mulyanti, & Soma, 2025). Rodhi (2025b) explained that human resource risks are directly related to occupational safety

and the overall success of a construction project, with workers with low competency tending to make more errors.

Similarly, Liang, Fung, Xiong, and Luo (2019) demonstrated that worker competency is directly related to safety performance, particularly in high-risk jobs. Bedi, Rahman, and Din (2021) emphasized that low worker competency is a dominant factor in construction workplace accidents. Sidiq and Rohman (2023) explained that human error is influenced by work experience, fatigue, and risk awareness, whereas Pourmazaherian and Musonda (2022) added that competency and safety culture are the foundation for developing safe work behaviors. Estudillo, Forteza, and Carretero-Gómez (2025); Bedi et al. (2021) also showed that weak competency and lack of training increase the risk of workplace accidents. In rural construction, competency issues are more complex because the workforce generally comes from local communities with self-taught skillsets. Therefore, Rodhi (2025a) emphasized that improving human resource competency is a primary requirement for increasing productivity and workplace safety.

2.2 Occupational Safety and Health (OSH) in Construction Projects

Occupational Safety and Health (OSH) is a risk control system aimed at protecting workers from potential hazards during construction projects. This system includes the use of Personal Protective Equipment (PPE), occupational safety supervision, occupational hazard identification, risk control, safe work procedures, and the development of a safety culture within the project environment (Mohammadi, Tavakolan, & Khosravi, 2018). Juhari, Rasli, Yusoff, and Khalid (2023) explained that poor use of PPE is a major cause of construction workplace accidents, such as nail punctures, slips, and sharp object injuries. Non-compliance with PPE indicates a persistently high level of unsafe behavior in the construction sector.

This finding is supported by Magda, Yustiarini, and Nurasiyah (2023), who stated that failure to use PPE and weak safe work procedures are the dominant factors contributing to construction workplace accidents. Gao, Chan, Utama, and Zahoor (2016) emphasized that workers' safety behavior is influenced by occupational safety culture, safety communication, training, and field supervision. Larasandi and Satrya (2025) demonstrated that a psychosocial safety climate established through effective human resource systems strengthens employee engagement and supports safer organizational behavior. Estudillo, Forteza, and Carretero-Gómez (2025) also indicated that a lack of training and weak safety supervision are dominant factors contributing to high levels of workplace accidents.

Similarly, Liang, Fung, Xiong, and Luo (2019) used the HFACS approach and stated that workplace accidents are not only caused by worker factors but also by weak organizational oversight and occupational safety culture. This condition is relevant to rural construction projects with limited oversight systems. Bourahla, Fernandes, and Ferreira (2024); Juhari et al. (2023) added that a low safety culture, weak oversight, and high workplace accident rates affect the productivity, costs, and sustainability of construction projects. Sadeghi, Cheung, Yunusa-Kaltungo, and Manu (2025) emphasized that effective occupational safety management requires systematic hazard identification, administrative controls, and continuous supervision during construction activities.

2.3 Risk of Human Error in Construction

Human error is a human error that causes failure in the execution of work and increases the potential for workplace accidents. In the construction sector, this condition is generally triggered by low worker competence, fatigue, lack of experience, weak supervision, and poor understanding of work safety procedures. Therefore, the human factor is a crucial component in the formation of occupational safety risks in construction projects (Fang, Zhao, & Zhang, 2016). Sidiq and Rohman (2023) explained that human error is directly related to an increased risk of construction work accidents, with work experience, work pressure, and fatigue being the main causes of work procedure errors.

This aligns with Rodhi (2025b), who asserted that human error is a key variable in the formation of construction project safety risks. Furthermore, Xia, Griffin, Ye, and Yuan (2020) stated that human factors contribute to a large proportion of workplace accidents owing to poor safety understanding and

non-compliance with SOPs. Bedi, Rahman, and Din (2021) showed that low technical competence increases the risk of unsafe acts. Pourmazaherian and Musonda (2022) added that fatigue and project environmental stress are significantly related to the potential for workplace accidents, reinforcing the importance of human factor control in construction safety management.

2.4 Occupational Safety Risk Analysis in Construction

Occupational safety risk analysis is an approach to identifying, assessing, and controlling potential hazards that can cause workplace accidents in construction projects (Zhou, Goh, & Li, 2015). Occupational safety risks are influenced by various factors, such as people, the work environment, implementation methods, equipment, and monitoring systems. The construction sector has a high level of risk owing to the dynamic nature of work, use of heavy equipment, physical activity in the field, and direct interaction with hazardous conditions. Huang, Hu, Xu, Zhang, and Tao (2023) explained that construction safety risk analysis has evolved from a conventional approach to a data-driven approach and human factor analysis, where the human factor is a key component of risk. Human error, unsafe work behaviors, and weak field controls have been shown to directly contribute to an increase in construction workplace accidents.

The risk analysis approach is also strengthened through classification methods such as the Human Factors Analysis and Classification System (HFACS). Liang, Fung, Xiong, and Luo (2019) explain that HFACS groups the causes of workplace accidents into unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences, thus demonstrating that workplace accidents are not solely caused by workers but also by supervisory and organizational systems. Rodhi (2023) added that the dominant factors in workplace accidents include low workforce competency, lack of safety training, weak supervision, and non-compliance with PPE use, confirming the significant contribution of human factors to construction risks. Effective safety leadership and supervisory commitment significantly improve workers' safety compliance and reduce unsafe behaviors (Wu, Wang, Zou, & Fang, 2022).

Research developments have also demonstrated the use of technological approaches in risk management (Abbasinia & Mohammadfam, 2022). Huang et al. (2023) stated that Artificial Intelligence (AI) can be used to predict the severity of workplace accidents, while Gao, Chan, Utama, and Zahoor (2016) explained that Extended Reality (XR) can improve hazard identification and worker safety awareness. However, the application of these systems in rural construction remains limited because of low workforce competency, minimal training, and weak supervision and safety systems (Sihombing, Simarmata, Banjarnahor, Farisyi, & Suvittawat, 2025). Rodhi (2023); Rodhi (2025b) emphasize that rural projects carry a high level of risk, necessitating the strengthening of human resource competencies, safety oversight, and a sustainable risk mitigation system. Recent systematic evidence indicates that AI-based systems improve hazard detection, safety monitoring, and predictive decision-making in construction safety management (Badhan & Samsami, 2025).

2.5 Conceptual Framework

Human resource competency, occupational safety, and human factors are interrelated components that determine safety performance in construction projects. Human resource competency, including technical knowledge, work experience, safety awareness, and compliance with standard operating procedures, influences workers' ability to recognize hazards, make safe decisions, and perform construction activities correctly. Workers with inadequate competency are more likely to commit unsafe acts, experience difficulty identifying hazards, and fail to comply with occupational safety requirements, thereby increasing the probability of workplace accidents.

The Human Factors Analysis and Classification System (HFACS) provides a systematic framework for explaining how deficiencies in human resource competency contribute to the causation of accidents. HFACS classifies accident factors into four hierarchical dimensions: unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences (Liang et al., 2019). Within this framework, inadequate competency and limited training constitute preconditions for

unsafe acts, whereas insufficient supervision and the absence of occupational safety management systems represent organizational deficiencies that indirectly increase accident risk. Therefore, workplace accidents should not be interpreted solely as individual worker failures but as the outcome of interactions among human, supervisory, and organizational factors.

From this perspective, occupational safety risk formation in rural construction is conceptualized as a multidimensional process in which human resource competency serves as the primary antecedent affecting worker behavior, safety compliance, and organizational safety performance. Limited technical competency, inadequate occupational safety training, weak supervision, and insufficient organizational support collectively increase the likelihood of unsafe practices and workplace accidents. Accordingly, this study adopts the HFACS as the analytical framework to identify competency-related risk factors, classify their causal mechanisms, and develop appropriate mitigation strategies for improving occupational safety in rural construction projects. The conceptual framework of this study is presented in Figure 1.

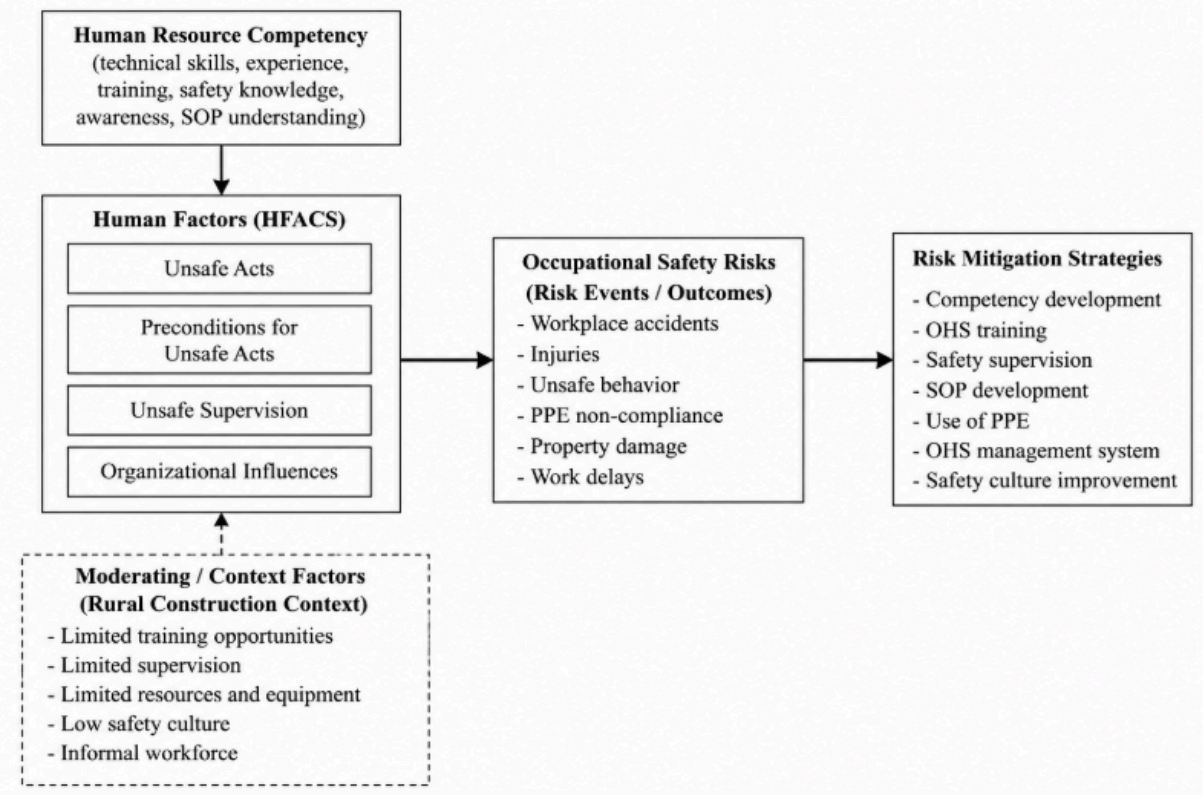

Figure 1. Conceptual framework of human resource competency and occupational safety risk formation

3. Research Methodology

This study employed a descriptive mixed-methods approach, combining qualitative and quantitative techniques, to analyze the influence of human resource competency on occupational safety risks in rural construction projects in Bojonegoro Regency. The Human Factors Analysis and Classification System (HFACS) was adopted as the analytical framework because it systematically classifies accident causation into four dimensions: unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influence. The study was conducted in Ngasem, Dander, and Gayam Districts, Bojonegoro Regency, covering village infrastructure projects such as concrete roads, drainage systems, embankments, irrigation channels, and public facilities managed by the Village Activity Implementation Team (TPK).

Respondents were selected using purposive sampling based on their direct involvement in rural construction projects and their familiarity with occupational safety practices. A total of 30 respondents

participated in this study, consisting of 20 construction workers, five members of the Village Activity Implementation Team, and five technical assistants involved in village infrastructure projects. The inclusion criteria required respondents to have direct experience in project implementation and knowledge of occupational safety. Primary data were collected through field observations, semi-structured interviews, questionnaires and project documentation. The questionnaire was developed based on previous studies on construction safety, human resource competency and the HFACS framework. The research variables included worker competency, work experience, Personal Protective Equipment (PPE) use, unsafe work behavior, unsafe working conditions, safety supervision, organizational safety practices, and human error. Data credibility was ensured through source and method triangulation by comparing the results of the observations, interviews, questionnaires, and documentation.

Risk analysis was conducted by classifying the identified risk factors according to the four dimensions of the HFACS. Each risk factor was evaluated using two assessment criteria: likelihood (L) and severity (S), measured on a five-point scale ranging from 1 (very low) to 5 (very high). The risk level was calculated using the equation $R = L \times S$, where R represents the risk value, L the likelihood of occurrence, and S the severity of the potential impact. The resulting scores were classified into low, medium, and high-risk categories to identify priority risks requiring mitigation. High-risk factors were subsequently used as the basis for developing mitigation strategies focusing on workforce competency improvement, occupational safety training, supervision enhancement, development of Standard Operating Procedures (SOPs), and strengthening occupational safety management systems in rural construction projects.

4. Results and Discussions

4.1 Identification of Human Resource Competency Risks to Occupational Safety

The results of field observations, interviews, and questionnaires indicate that occupational safety risks in rural construction projects in Bojonegoro Regency are significantly influenced by the competence of human resources involved in construction work. Most workers still have limited technical skills, minimal formal work experience, and a poor understanding of Occupational Health and Safety (OHS) procedures, thus increasing the potential for human error and unsafe acts during fieldwork. Furthermore, dominant risks also stem from a poor understanding of the use of Personal Protective Equipment (PPE), an inability to read simple work drawings, a weak understanding of safe work procedures, and limited ability to identify work hazards. This condition is exacerbated by work habits based on experience without formal training and adequate safety briefings, which ultimately increases the risk of accidents, such as nail punctures, slips, incorrect use of tools, and injuries due to non-compliance with work procedures and safety standards. The identified risks were then categorized using the Human Factors Analysis and Classification System (HFACS) approach, as presented in Table 1.

Table 1. Identification of human resource competency risks to occupational safety

No	Risk HR Competence	HFACS Classification	Occupational Safety Impact
1	Poor understanding of PPE use	Unsafe Acts	Head, hand, and foot injuries
2	Non-compliance with PPE use	Unsafe Acts	Increased risk of workplace accidents
3	Misuse of work tools	Unsafe Acts	Injuries caused by work tools
4	Inability to understand safe work procedures	Unsafe Acts	Errors in the execution of work
5	Poor ability to identify work hazards	Unsafe Acts	Risk of field accidents
6	Low technical competence of workers	Preconditions for Unsafe Acts	Human error in construction work
7	Lack of construction work experience	Preconditions for Unsafe Acts	Technical errors in work

No	Risk HR Competence	HFACS Classification	Occupational Safety Impact
8	Never attended construction training	Preconditions for Unsafe Acts	Low understanding of work safety
9	Poor understanding of OHS	Preconditions for Unsafe Acts	Unsafe worker behavior
10	Fatigue in field workers	Preconditions for Unsafe Acts	Decreased work concentration
11	Weak work safety supervision	Unsafe Supervision	Violations of safety procedures
12	Absence of work safety briefings	Unsafe Supervision	Low safety awareness
13	Lack of technical direction for work	Unsafe Supervision	Errors in work execution
14	Lack of occupational safety training:	Organizational Influences	Low worker competency
15	Lack of a project occupational safety system	Organizational Influences	There is a high risk of workplace accidents
16	Lack of project occupational safety SOPs	Organizational Influences	Irregular work procedures
17	Limited occupational safety facilities	Organizational Influences	Increased potential for occupational hazards

Table 1 shows the results of identifying human resource competency risks to occupational safety in rural construction projects in Bojonegoro Regency using the Human Factors Analysis and Classification System (HFACS). The identification results indicate that the dominant risks stem from low workforce competency, non-compliance with Personal Protective Equipment (PPE) use, incorrect use of work tools, and a weak understanding of safe work procedures. These conditions increase the potential for human error, unsafe acts, and the risk of workplace accidents during village construction projects. The classification results also indicate that occupational safety risk factors are influenced not only by field workers but also by weak occupational safety supervision and a minimal organizational system for village projects. Low construction training, the absence of occupational safety briefings, limited Standard Operating Procedures (SOPs), and a lack of occupational safety facilities contribute to suboptimal construction risk control. These findings indicate that improving occupational safety in rural construction requires strengthening workforce competency, field supervision, and the overall occupational safety system for village projects.

4.2 HR Competency Risk Classification Based on HFACS

The risk classification stage was carried out after identifying the risks of human resource competency towards occupational safety in rural construction projects in Bojonegoro Regency using the Human Factors Analysis and Classification System (HFACS) approach to group risk factors based on the causes of work accidents, which include worker behavior, working conditions, supervision, and organizational systems. The classification process was carried out using four levels of HFACS, such as unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences. Each factor was analyzed based on the level of possibility (likelihood) and impact (severity). The risk assessment uses a scale of 1–5 for likelihood and severity, with the risk level value obtained by multiplying the two using the following Formula 1:

$$R = L \times S \tag{1}$$

Description:
R = Risk level
L = Likelihood (likelihood of the risk occurring)
S = Severity (risk impact level)

The calculation results were then classified into low-, medium-, and high-risk categories. Risks with a high probability and significant impact are categorized as high risk because they have a significant potential to cause workplace accidents and disrupt safety in village construction projects. The results of the human resource competency risk classification for occupational safety based on the HFACS approach are shown in Table 2.

Table 2. Classification of human resource competency risks for occupational safety

No	HFACS Classification	Dominant Risk	Risk Level
1	Unsafe Acts	Poor understanding of PPE use	High
2	Unsafe Acts	Non-compliance with PPE use	High
3	Unsafe Acts	Misuse of work tools	Medium
4	Unsafe Acts	Inability to understand safe work procedures	High
5	Unsafe Acts	Poor ability to identify work hazards	High
6	Preconditions for Unsafe Acts	Low technical competence of workers	High
7	Preconditions for Unsafe Acts	Lack of construction work experience	High
8	Preconditions for Unsafe Acts	Never attended construction training	High
9	Preconditions for Unsafe Acts	Poor understanding of OHS	High
10	Preconditions for Unsafe Acts	Fatigue in field workers	Medium
11	Unsafe Supervision	Weak work safety supervision	High
12	Unsafe Supervision	Absence of work safety briefings	High
13	Unsafe Supervision	Lack of technical direction for work	Medium
14	Organizational Influences	Lack of occupational safety training	High
15	Organizational Influences	Lack of a project occupational safety system	High
16	Organizational Influences	Lack of project occupational safety SOPs	High
17	Organizational Influences	Limited occupational safety facilities	Medium

Table 2 shows that the results of the classification of human resource competency risks to occupational safety in rural construction projects using the HFACS approach are dominated by high-risk categories in the aspects of unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences, particularly related to low understanding and compliance with the use of PPE, low technical competence, lack of construction experience and training, and weak supervision and occupational safety systems in rural projects. In addition, there are moderate risk factors such as incorrect use of work tools, worker fatigue, lack of technical direction, and limited occupational safety facilities that still have the potential to cause accidents if not properly managed. Overall, these results confirm that occupational safety risks in rural construction are influenced by worker behavior and the quality of human resource competence, supervision, and suboptimal occupational safety organizational systems.

4.3 Human Resources Competency Risk Mitigation Strategy for Occupational Safety

The next stage after risk identification, classification, and analysis is the development of a risk mitigation strategy for human resource competency related to occupational safety in rural construction. This mitigation strategy is implemented to reduce the potential for workplace accidents by controlling identified risk factors based on the Human Factors Analysis and Classification System (HFACS) approach, with a focus on improving workforce competency, strengthening occupational safety supervision, increasing compliance with the use of Personal Protective Equipment (PPE), and strengthening the occupational safety system for village projects. The mitigation strategy is based on the risk level of each factor, with the high-risk category being the top priority owing to its higher probability of occurrence and impact compared to the medium category. Therefore, it aims to reduce the potential for human error, increase occupational safety awareness, and strengthen the risk control system on an ongoing basis, as presented in Table 3.

Table 3. Risk mitigation strategy of human resources competence towards occupational safety

No	Kategori HFACS	Dominant Risk	Risk Level	Mitigation Strategies
1	Unsafe Acts	Poor understanding of PPE use	High	Dissemination and training on the use of PPE
2	Unsafe Acts	Non-compliance with PPE use	High	Regular supervision of PPE use
3	Unsafe Acts	Misuse of work tools	Medium	Training on the use of construction tools
4	Unsafe Acts	Inability to understand safe work procedures	High	Development of simple work procedures and field briefings
5	Unsafe Acts	Poor ability to identify work hazards	High	Work hazard identification training
6	Preconditions for Unsafe Acts	Low technical competence of workers	High	Basic construction skills training
7	Preconditions for Unsafe Acts	Lack of construction work experience	High	Technical assistance for field work
8	Preconditions for Unsafe Acts	Never attended construction training	High	Village construction training program
9	Preconditions for Unsafe Acts	Poor understanding of OHS	High	Occupational safety and health socialization
10	Preconditions for Unsafe Acts	Fatigue in field workers	Medium	Setting work hours and rest periods
11	Unsafe Supervision	Weak work safety supervision	High	Strengthening occupational safety supervision
12	Unsafe Supervision	Absence of work safety briefings	High	Pre-work safety briefings
13	Unsafe Supervision	Lack of technical direction for work	Medium	Technical assistance for construction work
14	Organizational Influences	Lack of occupational safety training	High	Village occupational safety training program
15	Organizational Influences	Lack of a project occupational safety system:	High	Development of a project occupational safety system
16	Organizational Influences	Lack of project occupational safety SOPs	High	Development of occupational safety SOPs
17	Organizational Influences	Limited occupational safety facilities	Medium	Provision of PPE and occupational safety facilities

Table 3 shows that occupational safety risk mitigation strategies in rural construction focus on strengthening workforce competencies and safety control systems for village projects. High-risk workers require priority control through basic construction training, occupational safety training, PPE use supervision, occupational safety briefings, and the development of occupational safety Standard Operating Procedures (SOPs) for village projects. Moderate-risk risks are managed through technical assistance, regulated working hours, and the provision of adequate safety facilities. The mitigation results indicate that reducing occupational safety risks in rural construction cannot be achieved solely by controlling field worker behavior; it also requires strengthening the village project organizational system and continuously increasing human resource capacity. This approach is expected to improve the occupational safety culture and reduce the potential for workplace accidents in rural construction projects in the Bojonegoro Regency.

4.4 Discussion

The results of this study indicate that human resource competency significantly impacts occupational safety in rural construction projects in the Bojonegoro Regency. Low technical competency among

workers, lack of construction work experience, and minimal occupational safety training increase the potential for human error and unsafe acts during rural construction projects. This indicates that the human factor is a key component in shaping occupational safety risks in rural construction. This finding is consistent with Li, Chan, and Skitmore (2021), who concluded that regular safety training substantially improves hazard recognition and workers' safety behavior.

The dominance of competency-related risk factors can be explained by the characteristics of rural construction projects, which are generally implemented through community-based management systems and rely heavily on local labor. Unlike professional construction projects, rural projects often involve workers with limited formal construction training, inadequate knowledge of occupational safety procedures, and minimal experience in applying standardized construction practices. Consequently, workers are more likely to perform unsafe acts, misuse work equipment, neglect Personal Protective Equipment (PPE), and fail to identify workplace hazards. These conditions explain why competency-related factors consistently emerged as high-risk categories in this study (Bedi, Rahman, & Din, 2021).

The HFACS classification results indicate that most competency-related risks are concentrated in the unsafe acts and preconditions for unsafe acts dimensions. This finding suggests that occupational safety risks in rural construction are primarily associated with workers' competencies, including their understanding of safe work procedures, compliance with Personal Protective Equipment (PPE), and ability to recognize workplace hazards (Fang, Zhao, & Zhang, 2016). These findings are consistent with those of Liang, Fung, Xiong, and Luo (2019),(Pourmazaherian & Musonda, 2022) who reported that worker competency significantly influences construction safety performance through its relationship with unsafe acts and safety behavior. Competency-based safety management has also been shown to improve construction safety performance by strengthening technical capabilities and safety awareness (Pourmazaherian & Musonda, 2022).

The present findings are consistent with those of previous empirical studies. Bedi et al. (2021) identified inadequate technical competency and insufficient safety training as major contributors to construction accidents, whereas Rodhi (2023) reported that low workforce competency, weak supervision, and poor compliance with PPE were dominant factors affecting construction safety performance. However, unlike previous studies that mainly focused on large-scale or commercial construction projects, this study demonstrates that competency-related risks become more critical in rural construction due to limited organizational structures, restricted occupational safety resources, and community-based project implementations. This finding extends the application of the HFACS framework to rural construction sites.

This study also indicates that weak occupational safety supervision and a minimal safety organizational system for village projects are factors that increase occupational safety risks in rural construction. The absence of occupational safety briefings, weak supervision of PPE use, and the absence of occupational safety Standard Operating Procedures (SOPs) have resulted in suboptimal construction risk control. These findings support the research by Sari, Zaman, Waluyo, and Nurfajriah (2020), who explained that construction work accidents are not solely influenced by field worker actions but also by supervisory factors and the occupational safety organizational system. This finding is consistent with Fahrizal, Budiono, Khalid, and Santoso (2025), who reported that psychological safety created through inclusive leadership and supportive organizational practices encourages employee engagement and strengthens positive workplace behavior, including compliance with organizational procedures. Occupational safety risks in rural construction are also influenced by the low occupational safety culture of the field workers. Some workers still perceive the use of PPE as reducing work comfort and slowing down construction work productivity. This situation contributes to frequent noncompliance with PPE use in rural construction projects. These findings are consistent with those of Juhari, Rasli, Yusoff, and Khalid (2023); Magda, Yustiarini, and Nurasiyah (2023), who reported that inadequate PPE use, unsafe work behavior, and weak implementation of occupational safety procedures are among the primary causes of construction workplace accidents.

The mitigation strategies developed in this study demonstrate that improving occupational safety in rural construction requires an integrated approach that combines workforce competency development with strengthened occupational safety management systems. Basic construction training, occupational safety training, continuous supervision of PPE use, development of occupational safety Standard Operating Procedures (SOPs), and provision of adequate safety facilities are essential for reducing workplace accidents. These findings support Abbasinia and Mohammadfam (2022), who emphasized that effective construction safety management requires continuous competency development and strengthened supervision. Therefore, improving human resource competency and safety culture should be strategic priorities for achieving safe, productive, and sustainable rural infrastructure development.

The findings indicate that improving worker competency should be supported by a comprehensive occupational safety management system through continuous training, regular supervision, strict enforcement of standard operating procedures, and the consistent use of personal protective equipment. Strengthening these aspects is essential because competency alone is insufficient to reduce workplace accidents without effective organizational support and safety-management practices. Although this study primarily emphasizes competency-based mitigation strategies, future rural construction projects should incorporate digital technologies to enhance occupational safety management. This recommendation is supported by Badhan and Samsami (2025), who concluded that Artificial Intelligence (AI)-based technologies can improve hazard recognition and facilitate proactive occupational safety management in construction projects. Similarly, Daniel, Oshodi, Nwankwo, Emuze, and Chinyio (2025) highlighted that the integration of digital safety technologies, including Artificial Intelligence (AI), Building Information Modeling (BIM), Virtual Reality (VR), and real-time monitoring systems, can significantly enhance hazard identification, risk assessment, and accident prevention. These findings are consistent with Alruqi, Hallowell, and Techera (2018), who identified worker competency, safety culture, organizational commitment, and effective supervision as the dominant determinants of occupational safety performance in construction projects. Therefore, integrating competency development with organizational safety culture, effective supervision, and digital safety technologies is expected to strengthen occupational safety management and substantially reduce workplace accidents in rural construction projects.

4.5 Practical Implications

The findings have practical implications for several stakeholders involved in rural construction projects. Village governments should integrate occupational safety requirements into village infrastructure planning by allocating sufficient resources for occupational safety training, Personal Protective Equipment (PPE), and safety supervision. The Village Activity Implementation Team should establish Standard Operating Procedures (SOPs), conduct routine safety briefings, and ensure compliance with occupational safety regulations throughout project implementation. Technical assistants are expected to strengthen field supervision by providing continuous technical guidance, monitoring workers' safety practices, and assisting in hazard identification and risk control. Implementing these measures will improve occupational safety performance, reduce workplace accidents, and support the sustainable development of village infrastructure projects.

5. Conclusions

5.1 Conclusion

This study demonstrates that human resource competency is a fundamental determinant of occupational safety performance in rural construction projects in the Bojonegoro Regency. By applying the Human Factors Analysis and Classification System (HFACS), this study identified that the most critical occupational safety risks are associated with unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences. The dominant risk factors include low technical competency, inadequate occupational safety training, limited work experience, poor compliance with Personal Protective Equipment (PPE), weak safety supervision, and the absence of standardized occupational safety systems.

The study contributes to the literature by extending the application of the HFACS framework to rural construction projects, a context that has received limited attention in previous occupational safety

research. The findings demonstrate that occupational safety risks in village infrastructure projects are not solely caused by individual worker behavior but are also influenced by supervisory practices and organizational Safety Management Systems (SMSs). This broader perspective provides a comprehensive understanding of accident causation in community-based construction projects. From a practical perspective, this study proposes competency-based risk mitigation strategies that emphasize workforce training, strengthening occupational safety supervision, improving compliance with PPE, developing Standard Operating Procedures (SOPs), and enhancing occupational safety management systems. These strategies are expected to reduce workplace accidents and support safer, more productive, and sustainable rural infrastructure development in the future.

5.2 Research Limitations

This study is limited to rural construction projects in three districts of Bojonegoro Regency and relies on perception-based risk assessments using the HFACS. Future studies should involve larger samples from different regions and incorporate quantitative statistical techniques or predictive models to validate the relationships among human resource competency, occupational safety performance, and accident occurrence. Comparative studies of rural and urban construction projects may provide broader insights into occupational safety management practices.

5.3 Suggestions and Directions for Future Research

Based on the research results, it is necessary to improve the competence of human resources in rural construction through basic construction training, occupational safety training, and increased understanding of the use of PPE, as well as strengthening supervision, preparing occupational safety SOPs, and providing occupational safety facilities by village governments and technical assistants to reduce the risk of work-related accidents. Further research is recommended to expand the study area and number of projects to be more representative, and use a quantitative approach or other methods such as fuzzy risk analysis, BIM, and Artificial Intelligence to improve the accuracy of risk analysis, including developing studies on occupational safety culture, training effectiveness, and occupational safety organizational systems in rural construction.

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Author Contributions

NNR, as the first and corresponding author, was responsible for the development of the research concept, research design, field data collection, HFACS-based risk analysis, interpretation of the findings, development of occupational safety risk mitigation strategies for rural construction projects, as well as drafting, revising, and finalizing the manuscript. BWA contributed to the data validation process, reviewed the analysis results, refined the manuscript's scientific content, and provided academic input throughout the research process until the final approval of the manuscript. BH contributed to the literature review, assisted in data interpretation, reviewed the methods and results sections, critically revised the manuscript for intellectual content, and participated in the final review and approval of the manuscript. All authors have read and approved the final version of the manuscript and agree to be held accountable for all aspects of the work.

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