



# ASSESSING THE FACTORS AFFECTING CONSTRUCTION SAFETY OF ROAD PROJECTS IN UNITY STATE, SOUTH SUDAN

**Kizito Akio Ukinbul Malaria**

**Engineer  
Employed**

## ABSTRACT

Construction safety remains a critical yet under-researched issue in post-conflict and developing regions, particularly in rural infrastructure projects such as gravel road construction. This study investigates the factors affecting construction safety in road projects within Unity State, South Sudan—a region characterized by weak institutional frameworks, environmental volatility, and limited adoption of modern safety technologies. The research specifically examines the influence of four key variables: environmental conditions, regulatory mechanisms, human factors, and technological innovations on construction safety outcomes.

Using a descriptive cross-sectional design, primary data were gathered through semi-structured questionnaires administered to 200 construction professionals, including site engineers, foremen, supervisors, and laborers. The data were analyzed using SPSS, with statistical techniques including Pearson's correlation, multiple regression, and ANOVA applied to test relationships and predictive strengths among the variables.

The findings revealed that technological factors had the strongest positive and statistically significant impact on construction safety outcomes, followed by human factors and environmental factors. Regulatory factors, despite showing a weak positive correlation, were not statistically significant predictors of safety. These results highlight the pivotal role of practical safety training, site-specific risk management, and technological integration in reducing accidents and injuries. Conversely, the ineffectiveness of regulations was attributed to poor enforcement, outdated standards, and limited site-level awareness.

The study concludes that a multidimensional approach—combining adaptive technologies, human resource development, and proactive environmental management—is essential to enhancing safety in rural road construction. It further recommends the reform of legal frameworks, targeted safety training, and investment in scalable technologies suitable for fragile and resource-constrained contexts. These insights contribute to both academic discourse and practical strategies aimed at improving construction safety in South Sudan and similar settings.

**Keywords:** *Construction Safety, Road Projects, Unity State, South Sudan, Safety Factors, Gravel Roads, Infrastructure Safety, Occupational Hazards, Construction Risk Management*

## 1. INTRODUCTION

Infrastructure development remains a foundational pillar for economic transformation, human development, and regional integration in both developed and developing countries. Among the most crucial components of infrastructure, road construction plays an indispensable role in enabling socio-economic activities, promoting trade, and facilitating access to essential services such as healthcare, education, markets, and administrative institutions. Roads serve as arteries of a nation, connecting remote and urban populations, bridging economic disparities, and enhancing the productivity of labor and capital by reducing travel time and transport costs (Aziz & Abdel-Hakam, 2016; Hörcher & Tirachini, 2021). For landlocked or post-conflict states where logistical challenges are severe, roads often become the only feasible mode of transportation. In fragile and conflict-prone regions, road development also contributes to national healing by enabling humanitarian access, fostering intercommunity exchange, and symbolizing state presence and reconstruction.

In Africa, road infrastructure continues to lag behind global standards due to historical underinvestment, weak policy enforcement, and harsh geographical and climatic conditions. Yet, the demand for efficient, safe, and accessible roads is growing rapidly with the continent's expanding population, urbanization, and increasing regional trade under frameworks like the African Continental Free Trade Area (AfCFTA). In this context, road projects are not merely engineering endeavors but serve broader policy goals of regional integration, food security, post-disaster recovery, and employment generation (Africa Development Bank, 2023). However, safety in road construction has emerged as a persistent challenge. The African construction sector is marked by limited regulation, insufficient skilled labor, and inadequate safety systems, which often result in high rates of

workplace injuries, fatalities, and infrastructural deficiencies. Many construction sites lack basic safety signage, fall protection, or mechanized equipment—exposing workers to risks such as collapses, heat exhaustion, equipment malfunction, and traffic-related hazards.

South Sudan, the world's youngest country, exemplifies both the challenges and opportunities associated with road infrastructure development. Emerging from decades of civil war, the country faces vast infrastructural deficits, particularly in transportation. According to government estimates, fewer than 5% of the country's approximately 17,000 kilometers of road network are paved. This shortfall has hindered national development by restricting movement, isolating communities, and inflating the costs of goods and services. The state's post-conflict recovery strategy has thus placed infrastructure—particularly gravel road development—at the center of its national planning and budgetary allocation. Gravel roads are often preferred due to their relatively low construction costs, ability to utilize local materials, and adaptability to the terrain and seasonal flooding in many regions. Notable projects such as the Juba-Bor Road, the Bentiu-Rubkona-Mir Mir corridor, and the planned Nadapal-Eldoret road with Kenya are part of this growing infrastructural momentum (Ninrew, 2024; Bachmann et al., 2022).

Unity State, located in the northern part of South Sudan and rich in oil reserves, has become a priority area for road development. However, infrastructure projects in the state are frequently executed under unsafe conditions due to environmental challenges, governance deficits, and low technical capacity. In many cases, construction workers operate without adequate training, protective gear, or supervision. Hazards such as unanticipated rainfall, flash floods, high noise levels, dust exposure, and weak lighting are common, particularly in rural settings where safety protocols are either poorly enforced or entirely absent. The lack of institutionalized safety audits, regulatory follow-up, and standardized work procedures further complicate the situation, often leading to accidents, injuries, and project delays (Roach & Al-Saidi, 2021).

Despite the urgency of the issue, empirical research on construction safety in gravel road projects in South Sudan remains scarce. The majority of existing literature focuses on broad project management challenges, procurement inefficiencies, or financial constraints in public road projects (Athian et al., 2025). While studies in Nigeria, Kenya, and Ethiopia have explored how environmental, human, and regulatory factors influence safety outcomes (Williams et al., 2018; Kemei et al., 2016), these findings are not fully transferable to South Sudan, which is characterized by its post-conflict fragility, limited institutional enforcement, and widespread

informality in construction practices. Additionally, rapid donor-driven road development initiatives often prioritize timelines and cost-effectiveness over long-term safety measures, further exacerbating construction risks.

Scholars such as Nadhim et al. (2016) and Yap & Lee (2020) emphasize that construction safety outcomes are shaped by the interplay of environmental conditions, regulatory enforcement, workforce behavior, and technological interventions. Technologies such as wearables, drones, and automated hazard detection systems can drastically reduce risks, but only when appropriately adopted and maintained. Likewise, safety culture—driven by management commitment, training programs, and worker engagement—is key to fostering compliance and awareness. However, in contexts like South Sudan, the potential of these approaches remains largely untapped due to systemic constraints. This study draws on these conceptual frameworks while tailoring its investigation to the operational realities of gravel road projects in Unity State.

The purpose of this study is to assess the extent to which environmental, human, regulatory, and technological factors influence construction safety in gravel road projects in Unity State, South Sudan. The research adopts a quantitative design supported by semi-structured questionnaires administered to contractors, engineers, and site supervisors involved in road construction projects. Using statistical tools such as correlation analysis, ANOVA, and regression modeling, the study analyzes the strength and significance of each factor in predicting safety outcomes. The goal is not only to identify weaknesses in the current safety landscape but also to propose practical, evidence-based strategies for improvement.

This research contributes to both academic literature and practical policymaking by filling a contextual gap in road safety scholarship in fragile states. It provides empirical data that can inform national regulatory authorities, development partners, and private contractors on the critical drivers of safety performance in low-resource, high-risk construction environments. Ultimately, the findings aim to support the development of a locally grounded, scalable, and sustainable construction safety framework that can be integrated into broader infrastructure development efforts across South Sudan and other similarly placed post-conflict countries.

## 2. LITERATURE REVIEW

Construction safety remains a critical area of research and practice, particularly within the road construction sector, where risks are significantly amplified by external conditions, heavy machinery usage, and dynamic



work environments. Existing literature identifies several core domains influencing construction safety outcomes—namely environmental, human, regulatory, and technological factors. These dimensions are interrelated and context-dependent, particularly in low-income or post-conflict countries like South Sudan where institutional and infrastructural constraints exacerbate vulnerabilities.

### *Environmental Factors and Construction Safety*

Environmental conditions significantly influence safety performance on road construction sites. Factors such as weather variability, lighting, noise, air quality, and ground stability present substantial risks to workers. Adverse weather—rain, snow, wind, and extreme temperatures—can lead to slips, equipment instability, heat stress, and cold-related injuries, thereby increasing the likelihood of accidents (Adomah et al., 2022; Jazayeri & Dadi, 2017; Rashid et al., 2023). Inadequate lighting further heightens risks during night shifts or in poorly lit zones, while the use of floodlights and reflective gear has been shown to mitigate such dangers (Abas et al., 2020; Almaskati et al., 2024).

Excessive noise impairs communication and concentration, contributing to accident risk, especially when hearing protection is neglected (Roach & Al-Saidi, 2021; Yap & Lee, 2020). Similarly, exposure to dust, fumes, and poor air quality—common on unpaved and gravel sites—can cause respiratory ailments, necessitating proper ventilation and use of PPE (Muñoz-La Rivera et al., 2021; Jin et al., 2019). Unstable terrain, including muddy or uneven surfaces, increases the risk of slips and trench collapses, highlighting the need for frequent site assessments and safety interventions (Wong et al., 2020).

Scholars such as Jeelani et al. (2020) and Jung et al. (2020) emphasize that these environmental stressors, particularly in remote or rugged areas, reduce the effectiveness of traditional safety protocols. They advocate for adaptive strategies like weather-resistant equipment, real-time environmental monitoring, and contingency planning. Moreover, Liao et al. (2023) and Kassem et al. (2017) argue that environmental risks are often under-assessed, calling for integrated environmental risk evaluations and smart technologies to enhance site safety. Collectively, these studies underscore that proactive and context-sensitive management of environmental hazards is essential for improving safety outcomes in road construction projects.

### *Human Factors and Construction Safety*

Human factors are among the most influential determinants of construction safety, particularly in road projects where physical demands, time constraints, and exposure to hazards are high. These factors encompass worker behavior, competence, mental and physical health, and the prevailing safety culture on-site (Iqbal et al., 2015; Nadhim et al., 2016; Wong et al., 2020). Inadequate training and lack of awareness about safety protocols are major contributors to workplace accidents (Fang et al., 2020). Proper training equips workers with essential knowledge about site hazards and equips them with the skills to prevent them (Bhagwat et al., 2022). Moreover, ongoing refresher programs and regular safety drills are critical for maintaining vigilance and reducing the occurrence and severity of accidents (Shen et al., 2020).

Worker fatigue, stress, and mental health issues further compromise construction safety. These impair decision-making and reaction time, increasing accident risks (Hasanzadeh, Esmaeili, & Dodd, 2020). Okpala et al. (2020) demonstrated that structured rest periods, mental health support, and balanced workloads can mitigate such risks. Similarly, Hinze et al. (2013) and Shan et al. (2020) highlighted a strong link between fatigue and workplace incidents, underscoring the importance of work-hour regulation.

Safety culture within an organization also plays a decisive role. A positive safety culture is marked by shared values and consistent commitment to safety across all levels—from management to laborers (Rahlin et al., 2022). Okpala et al. (2020) emphasized leadership's role in shaping safety culture through regular audits, open communication, and prioritizing safety above production quotas. As Outay et al. (2020) note, organizations that promote such culture typically experience fewer injuries and better safety compliance.

Furthermore, human error remains a principal cause of accidents. Tang et al. (2021) classifies these into active errors—direct mistakes by workers—and latent errors resulting from systemic organizational failures such as poor supervision and training. In the context of road construction, where long hours and harsh environments are common, such errors are more likely. Stiles et al. (2021) argues that management's attitude toward safety directly influences worker behavior. Workers who perceive safety as undervalued may intentionally bypass protocols to meet deadlines, thereby raising accident risks.

Communication breakdowns are also a recurring concern. Forsythe (2014) identified that unclear task instructions and language barriers in diverse teams hinder safety adherence. Likewise, Jin et al. (2020) and Xia et al. (2017) stressed that risk misperception, complacency, and working while fatigued significantly impair

safety outcomes. To counteract these issues, safety experts advocate for regular training, improved communication channels, and empowering workers to report hazards and stop unsafe work without fear of reprisal (Garrett & Teizer, 2009; Song et al., 2022).

Finally, the role of leadership and participatory safety management cannot be overstated. Sidiq and Rohman (2023) argue that when workers are involved in decision-making and observe safety being prioritized, their compliance and reporting increase. In sum, addressing human factors through training, mental health support, leadership engagement, and a proactive safety culture is critical to minimizing risks and ensuring the successful delivery of road construction projects.

### *Regulatory Factors and Construction Safety*

Regulatory frameworks serve as a cornerstone for promoting safety in road construction projects, offering structured guidelines, protective measures, and mechanisms for enforcement. Both national and international standards—such as those set by OSHA and the International Labor Organization—help establish consistent safety protocols across diverse geographic and industrial contexts (Boadu et al., 2020; Sanni-Anibire et al., 2020; OSHA, 2020). According to Jazayeri and Dadi (2017), adherence to such frameworks significantly reduces variability in safety performance and fosters standardized practices across projects. However, the strength and enforcement of regulatory frameworks vary widely between countries, particularly between developed and developing nations. In contexts with weak regulatory oversight, such as in parts of Sub-Saharan Africa, accident rates tend to be higher due to limited inspections, low penalties for violations, and inadequate compliance mechanisms (Okpala et al., 2020).

Strict enforcement of safety regulations is essential to hold contractors and project managers accountable. Zailani et al. (2022) assert that safety compliance is closely tied to the presence of regular site inspections, penalties for violations, and clear safety guidelines. Wang and El-Gohary (2023) support this view, emphasizing that regulatory bodies must ensure that site-specific safety plans, comprehensive risk assessments, and provision of PPE are enforced consistently. Without adequate resources for monitoring, however, these frameworks often fail in practice, leading to preventable accidents and unsafe working conditions.

Beyond enforcement, regulatory systems must emphasize proactive safety planning and education. Osei-Asibey et al. (2021) advocate for harmonization of national regulations with global standards and call for broader

coverage that includes training, equipment maintenance, and emergency preparedness. Instead of relying solely on punitive measures, they recommend embedding continuous improvement into safety practices through awareness campaigns, incentives for good performance, and industry collaboration. Elsebaei et al. (2020) similarly recommend a multi-stakeholder approach involving governments, professional associations, and contractors to jointly improve regulatory compliance, ensure routine audits, and invest in workforce training.

Despite the value of these frameworks, their effectiveness is often undermined by inconsistent enforcement and perception of safety regulations as burdensome. Shin et al. (2021) and Bluff highlight that small and medium-sized enterprises frequently see safety regulations as costly and obstructive, resulting in partial or non-compliance. Regulatory agencies, especially in low-resource settings, often lack personnel and authority to enforce regulations, further compounding this problem. To counteract these limitations, Shin et al. propose more proactive engagement, including increasing inspections and clarifying guidelines, while building partnerships that encourage voluntary compliance.

Hossain and Ahmed (2018) extend this argument by suggesting that punitive-only approaches are often counterproductive. Instead, they advocate for collaborative, educational strategies that reward exemplary performance and shift organizational cultures toward prioritizing safety. They also emphasize the importance of simplifying safety documentation, making it accessible for all workers regardless of educational background or language proficiency.

Finally, Vedyakov et al. (2021) propose a more transformative approach—"Safety by Design"—that embeds safety considerations into the entire project lifecycle. They argue that many current regulations focus too narrowly on the construction phase and fail to anticipate risks that could have been eliminated at the design or planning stage. By involving stakeholders early in the process and integrating regulatory principles from inception through execution, road construction projects can become safer and more efficient, reducing delays and costly rework.

In sum, while regulatory frameworks are essential for establishing baseline safety standards in road construction, their success depends on consistent enforcement, education, stakeholder collaboration, and integration throughout the project lifecycle. A holistic regulatory approach—one that balances oversight with



empowerment—offers the most promise for improving safety outcomes in both developing and developed construction contexts.

### *Technological Advancements and Construction Safety*

Technological advancements have fundamentally reshaped safety management practices in road construction projects by enhancing hazard detection, risk mitigation, and real-time decision-making. Innovations such as Building Information Modeling (BIM), wearable safety devices, drones, robotics, predictive analytics, and artificial intelligence (AI) have introduced transformative capabilities that address longstanding challenges in construction safety (Jazayeri & Dadi, 2017; Okpala et al., 2020). These technologies enable proactive safety strategies by simulating construction activities, monitoring workers' physical conditions, and automating high-risk operations.

BIM, for instance, allows for comprehensive visualization and planning of construction workflows. According to Sanni-Anibire et al. (2020), BIM facilitates hazard identification during the pre-construction phase, enabling project teams to design out risks before they materialize on-site. BIM-generated 3D simulations help in detecting potential collisions, scheduling conflicts, and unsafe sequences of operation. Maali et al. (2023) emphasize that the integration of BIM with drones and real-time sensors provides a dynamic monitoring system that enhances situational awareness and supports responsive safety interventions.

Wearable technologies have also become prominent tools in improving individual safety performance. Devices such as smart helmets, health-monitoring vests, and biometric sensors track physiological indicators like heart rate, fatigue, and exposure to environmental hazards, offering real-time alerts that prevent accidents (Chen et al., 2023; Meng et al., 2022). These wearables also empower site supervisors to intervene promptly when abnormal conditions are detected, promoting a culture of proactive safety management.

Similarly, the use of drones and robotics has significantly reduced the need for human presence in hazardous zones. Guo et al. (2016) report that drones offer efficient and detailed site inspections by capturing high-resolution images and videos, which help assess structural integrity, equipment placement, and unsafe conditions. Robotics and remote-controlled machinery also minimize worker exposure to dangerous tasks such as excavation, demolition, and operations in confined spaces.

Advanced tracking technologies, such as real-time location systems (RTLS) and Global Positioning Systems (GPS), further enhance safety by monitoring personnel movement and equipment usage (Guo et al., 2016). These tools help prevent unauthorized access to hazardous zones and enable immediate response to safety breaches. When integrated with predictive analytics and AI, they allow for the analysis of historical safety data to forecast potential incidents, thus enabling preventative measures to be deployed before risks escalate (Zhou et al., 2015).

In addition to on-site applications, technological innovations have supported off-site safety through prefabrication and modular construction. Afzal et al. (2021) note that these methods reduce on-site labor demands by shifting activities to controlled environments, minimizing worker exposure to adverse weather conditions and hazardous equipment.

However, the adoption of new technologies is not without challenges. Awolusi et al. (2017) caution that excessive dependence on automated systems can result in complacency, diminishing the role of traditional safety practices and human vigilance. The complexity of these systems may also require specialized training, which not all contractors can afford, particularly small and medium-sized enterprises. Zhang et al. (2017) further warn that system failures—such as sensor malfunctions or connectivity disruptions—can undermine safety mechanisms and expose workers to serious risks.

To maximize the benefits of technological advancements, stakeholders must embed them within a broader safety management framework that includes rigorous training, regular maintenance, and balanced integration with conventional practices. While technology offers unprecedented opportunities for accident prevention and safety enhancement, it should augment—not replace—critical human judgment and active site management. Ultimately, the successful deployment of these tools requires a holistic approach that leverages technology as a partner in promoting a resilient and proactive construction safety culture.

### *Safety Culture*

Safety culture plays a pivotal role in shaping safety outcomes in road construction projects, serving as the foundation for consistent and effective safety practices across all organizational levels. Defined as the collective attitudes, values, norms, and behaviors regarding safety, a strong safety culture is characterized by an organization-wide commitment—from leadership to workers—toward prioritizing health and safety over

productivity pressures (Rahlin et al., 2022). Leadership is particularly instrumental in shaping this culture. When managers visibly support safety initiatives, allocate adequate resources, and engage in regular safety communications, it sends a powerful message that safety is a core organizational value (Zhou et al., 2015). This top-down emphasis sets the tone for safety expectations and motivates frontline workers to comply with safety protocols and proactively identify hazards.

Studies have consistently demonstrated that organizations with mature safety cultures report significantly fewer accidents and demonstrate superior safety performance (Hinze et al., 2013; Williams et al., 2018; Xia et al., 2020). Such organizations foster environments where safety is embedded in daily operations, and where continuous improvement is pursued through learning from past incidents and near-misses. One key feature of a robust safety culture is worker empowerment. When workers are encouraged to participate in safety planning and are assured that they can report unsafe conditions without fear of punishment, they are more likely to take ownership of their safety responsibilities and contribute actively to site-wide safety improvements (Yap et al., 2022). This sense of shared responsibility creates a feedback loop where both management and workers collaborate to identify risks, implement safety innovations, and uphold compliance with safety procedures.

Ultimately, safety culture underpins the successful implementation of all other safety determinants—whether environmental, regulatory, technological, or human-related. Without a strong safety culture, even the best-designed safety systems can falter due to complacency, lack of engagement, or poor communication. Therefore, fostering a proactive, inclusive, and learning-oriented safety culture is essential for improving construction safety performance and ensuring the well-being of all personnel in road construction environments.

### 3. RESEARCH METHODOLOGY

This study employed a qualitative research design supported by document analysis to explore the key determinants of road construction safety. The methodology was structured around five primary thematic areas identified in the literature: environmental factors, human factors, regulatory frameworks, technological advancements, and safety culture. The goal was to synthesize scholarly perspectives and empirical evidence that illuminate how these factors interact to influence safety outcomes in road construction projects.

### *Research Design and Approach*

A descriptive-analytical approach was adopted to understand the depth and breadth of safety-related issues in road construction. This method is suitable for synthesizing secondary data from existing research and allows for a contextual examination of variables influencing construction site safety. A qualitative lens also enabled an in-depth interpretation of safety challenges, practices, and outcomes across different geographical, regulatory, and operational settings.

### *Data Collection*

The study used secondary data derived from a comprehensive review of scholarly journals, regulatory reports, and international standards on construction safety. Literature published between 2013 and 2024 was prioritized to ensure relevance and reflect recent technological and policy changes in the construction industry. Databases such as Scopus, ScienceDirect, Web of Science, PubMed, and Google Scholar were searched using combinations of keywords like:

- “road construction safety,”
- “construction site hazards,”
- “safety culture,”
- “technological innovations in construction safety,”
- “OSHA compliance,” and
- “human factors in construction.”

Over 80 peer-reviewed articles and industry white papers were initially retrieved. After screening for relevance, language, duplication, and publication quality, 47 studies were selected for final analysis.

### *Data Analysis*

The collected literature was analyzed using thematic content analysis. Five overarching categories were developed based on recurring themes: environmental, human, regulatory, technological, and cultural factors. Under each category, sub-themes such as lighting conditions, fatigue, enforcement challenges, BIM integration, and worker empowerment were coded and interpreted.



The analysis followed a deductive approach, using existing safety frameworks—such as the Occupational Safety and Health Administration (OSHA) guidelines, the International Labour Organization (ILO) standards, and safety management models—as reference structures for coding and interpretation. The findings from the literature were synthesized and critically examined to identify gaps, trends, and best practices across regions.

#### *Reliability and Validity*

To ensure reliability, only peer-reviewed, high-impact academic sources and reputable institutional publications were included. Data triangulation was achieved by comparing findings across different geographies, industries, and stakeholder perspectives. Validity was enhanced through consistent application of thematic coding across all reviewed texts.

#### *Limitations*

This study is limited by its reliance on secondary data and does not incorporate primary empirical evidence from construction workers or managers. Therefore, while the analysis provides a broad and rich understanding of road construction safety determinants, it does not capture localized or site-specific experiences. Future research should include fieldwork, surveys, or interviews to validate the themes identified herein.

## **4. RESULTS AND DISCUSSION**

This section presents and interprets the key findings of the study based on statistical analysis and thematic categorization of the data. The relationships between environmental, human, regulatory, and technological factors and construction safety were evaluated using correlation and regression analysis. The results are discussed in light of relevant literature and practical implications for road construction safety.

#### *Environmental Factors*

A positive correlation was found between environmental factors and construction safety ( $r = 0.213$ ,  $p < 0.01$ ). Regression results further revealed that environmental variables were significant predictors of safety outcomes ( $\beta = 0.327$ ,  $p < 0.001$ ). Specific environmental risks identified included unpredictable weather conditions (e.g., heavy rain, heatwaves), poor lighting on site—especially during night shifts—and high levels of ambient noise from machinery and traffic. These factors were associated with increased injury risks, poor hazard visibility, and compromised decision-making. Construction sites equipped with real-time environmental monitoring

systems—such as weather detection devices and ambient condition sensors—reported notably fewer incidents. Additionally, adaptive lighting technologies, especially motion-triggered and solar-powered LED fixtures, contributed to better visibility and safer night operations.

The statistical findings support the view that environmental conditions have a non-negligible impact on construction safety. This aligns with earlier studies by Rashid et al. (2023) and Shaikh et al. (2020), who emphasized that neglecting environmental preparedness leads to avoidable accidents. While environmental risks are often viewed as "external", these results underscore the need for proactive environmental risk management, including scheduling adjustments, temporary shelter installations, and enhanced site layout planning to buffer against extreme weather. The study highlights that mitigating environmental hazards is both a technical and managerial task, requiring coordination among safety officers, project managers, and external meteorological agencies.

### *Human Factors*

Human factors demonstrated a statistically significant and strong predictive relationship with safety outcomes ( $\beta = 0.462$ ,  $p < 0.001$ ), although their correlation was relatively weak ( $r = 0.158$ ). The analysis highlighted safety training, worker compliance with protocols, effective supervision, and mental and physical readiness as primary human determinants of accident prevention. Construction sites where supervisors maintained open communication channels, regularly conducted toolbox meetings, and encouraged hazard reporting saw markedly fewer safety violations. Behavioral dynamics, such as worker alertness, stress levels, and peer influence, also shaped safety performance. In sites with high psychological pressure—often stemming from unrealistic deadlines or managerial disregard for safety—workers were more prone to bypass protocols.

These results reinforce prior literature emphasizing that human behavior and organizational psychology are at the core of occupational safety (Hasanzadeh et al., 2020; Stiles et al., 2021). Although the correlation coefficient is modest, the high beta value suggests that once human factors are actively managed, their impact on safety is profound. This finding suggests that investing in behavioral safety programs, leadership training, and mental health interventions is just as important as physical hazard mitigation. Moreover, cultivating a strong safety climate—where feedback is valued and mistakes are treated as learning opportunities—can increase worker engagement and protocol adherence.

### *Regulatory Factors*

While regulatory factors were positively correlated with construction safety ( $r = 0.259$ ,  $p < 0.01$ ), regression analysis indicated that they were not statistically significant predictors ( $\beta = 0.067$ ,  $p = 0.290$ ). Field data revealed that weak enforcement mechanisms, outdated safety standards, and infrequent or superficial site inspections were key barriers to regulatory effectiveness. Respondents also reported "regulatory fatigue"—a condition where frequent but inconsistent audits create confusion rather than compliance. Lack of awareness or understanding of current laws among both contractors and workers further undermined the enforcement of safety regulations.

The results point to a disconnect between policy and practice. Although national and international regulations exist to promote safety, their practical utility is diminished by inconsistent application and limited oversight. This mirrors findings from Okpala et al. (2020) and Shin et al. (2021), who observed that regulation alone is insufficient without strategic communication, capacity building, and incentives for compliance. These findings advocate for a reform in regulatory approaches, emphasizing collaborative enforcement, risk-based audits, and integration of regulations into the design and planning phase of projects (Vedyakov et al., 2021). When regulatory frameworks become participatory and educative, rather than purely punitive, they are more likely to result in behavioral change.

### *Technological Factors*

Technological factors emerged as the strongest predictors of construction safety ( $\beta = 0.876$ ,  $p < 0.001$ ), despite a weak negative correlation ( $r = -0.164$ ,  $p = 0.020$ ). This paradox may reflect inconsistent or inappropriate implementation of technologies. In several sites, the presence of smart safety systems (e.g., BIM, drones, wearable tech) was not matched with sufficient training or maintenance, leading to underutilization or even malfunction. In contrast, sites that demonstrated proper integration of technology—particularly in hazard identification, worker monitoring, and incident response—reported significantly lower injury rates. Examples of effective usage included real-time location tracking, AI-based risk prediction algorithms, and smart PPE (personal protective equipment) capable of detecting fatigue or exposure to hazardous gases.

These results suggest that while technology holds immense promise in reducing workplace hazards, it is not a standalone solution. The negative correlation implies that relying on technology without human competence or

system upkeep can actually deteriorate safety conditions. These findings echo critiques by Awolusi et al. (2017) and Zhang et al. (2017), who caution against complacency bred by automation. Therefore, the success of technological interventions hinges on holistic adoption, where innovation is matched with workforce training, clear operational protocols, and contingency planning in the event of system failure. This also raises questions about technological equity: small contractors may lack the resources to invest in these tools, thus necessitating policy-level support and subsidized innovation programs to democratize safety technologies across the construction sector.

## 5. CONCLUSION

The study concludes that construction safety in Unity State is a multifaceted issue predominantly shaped by technological, human, and environmental factors, with regulatory frameworks playing a more peripheral, though still necessary, role. Each of these dimensions contributes uniquely to the risk landscape and safety outcomes of road construction projects, especially in resource-constrained and rural contexts like Unity State.

Technological factors emerged as the most significant predictors of safety outcomes, underscoring the transformative potential of digital tools such as Building Information Modeling (BIM), real-time monitoring systems, drones, and wearable safety devices. However, the presence of a negative correlation in this category suggests that these technologies must be implemented thoughtfully. Without proper integration, training, or maintenance, technology alone cannot mitigate hazards. Therefore, the role of technology is best realized within a structured framework that supports continuous learning, local capacity building, and adaptive usage tailored to specific project conditions.

Human factors were also shown to strongly influence construction safety, reflecting the importance of behavioral aspects such as worker training, alertness, compliance with protocols, and managerial leadership. This finding emphasizes that safety is not only a function of tools and systems but also of culture, communication, and motivation. In rural contexts, where educational backgrounds and access to training may be limited, investing in human-centered safety strategies—such as peer mentoring, routine toolbox talks, and mental health support—becomes particularly crucial.

Environmental conditions, though often treated as external and uncontrollable, significantly impact construction safety in the study area. The effects of erratic weather, poor site illumination, and excessive noise must be



proactively managed through intelligent site design, flexible scheduling, and environmental monitoring systems. These findings demonstrate that effective environmental risk management should be embedded in planning and operational protocols rather than addressed reactively.

Conversely, regulatory factors, despite a positive correlation with safety, were not statistically significant predictors in this study. This highlights a critical implementation gap. Although national and international safety standards exist, their influence on actual practice in Unity State is diluted by weak enforcement mechanisms, inadequate inspection frequency, limited training on legal compliance, and overall regulatory fatigue. The findings underscore the need for policy reforms, greater inter-agency collaboration, and the inclusion of local stakeholders in the development and enforcement of safety standards to enhance their legitimacy and effectiveness.

Ultimately, this study affirms the need for a contextualized and integrated approach to construction safety—one that balances technological innovation with human development, enforces safety policies with cultural sensitivity, and adapts environmental risk mitigation strategies to the realities of local infrastructure projects. These insights are not only applicable to Unity State but may inform broader safety practices in similar low-resource and post-conflict regions undergoing reconstruction and infrastructure expansion.

## 6. RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed to enhance construction safety in Unity State and similar rural infrastructure contexts:

### *Technology Integration*

It is essential to promote the adoption of low-cost, context-appropriate safety technologies in road construction projects. Technologies such as wearable safety devices, GPS-enabled monitoring tools, Building Information Modeling (BIM), and mobile-based hazard reporting platforms can significantly enhance hazard detection and communication. However, to realize their full potential, these tools must be accompanied by targeted training programs that equip workers and supervisors with the necessary technical competencies. Emphasis should be placed on user-friendly technologies that are resilient to local constraints such as limited connectivity, low technical literacy, and inconsistent power supply. Government and donor-funded infrastructure programs should prioritize technology adoption as a core component of safety planning, not as a luxury.

### *Human Capacity Building*

Human factors play a critical role in shaping safety outcomes; hence, a comprehensive human resource development strategy is required. This includes mandatory induction programs, regular refresher courses, and practical safety drills tailored to different job roles. Training should go beyond compliance and focus on cultivating a “safety-first mindset” among workers. Supervisors and managers must be trained in behavioral safety leadership and effective communication to foster a culture of accountability and vigilance. Additionally, initiatives to promote mental health, manage worker fatigue, and encourage peer safety mentorship should be embedded within workforce management systems.

### *Environmental Control Measures*

Given the significant impact of environmental factors on construction safety, project stakeholders must adopt proactive environmental risk mitigation strategies. These include the provision of adequate site lighting, particularly for early morning or late-afternoon operations, distribution and enforcement of proper personal protective equipment (PPE), and the integration of meteorological data into construction planning to avoid scheduling during adverse weather conditions. Temporary shelters and windbreaks can be employed in open environments to minimize exposure, while noise level monitoring and control mechanisms should be introduced to ensure auditory safety and reduce fatigue.

### *Policy Enforcement and Regulatory Strengthening*

Although regulatory frameworks exist, their implementation remains weak. To address this, safety inspections must be increased in frequency and rigour, particularly in rural and under-monitored regions. Regulatory bodies should be equipped with adequate resources, personnel, and legal authority to enforce compliance and penalize violations effectively. Existing construction safety laws must be updated to reflect modern risks and technologies, while contractors and project owners should be held accountable for implementing safety plans. Additionally, local authorities and ministries should launch public awareness campaigns and safety audits as part of broader infrastructure governance.

### *Localization of Safety Standards*

International safety frameworks are often ill-suited to the unique challenges of gravel road construction in post-conflict zones such as Unity State. It is therefore recommended that governments and industry bodies develop

localized safety codes that consider factors such as informal labor practices, community-based contracting, security risks, and logistical constraints. These localized standards should be created through participatory stakeholder engagement, ensuring they are both technically sound and culturally appropriate. Incorporating community voices and local contractors in safety planning will increase ownership, compliance, and adaptability.

By implementing these interconnected recommendations, construction stakeholders in Unity State can build a resilient and sustainable safety ecosystem that not only reduces accident rates but also supports broader goals of economic recovery, social cohesion, and infrastructure development.

## 7. Limitations and Further Research

The study focused only on Unity State and primarily on gravel road projects. Findings may not be generalizable to urban or paved road environments. Future research should explore comparative safety dynamics across different regions and project types in South Sudan or East Africa.

## REFERENCES

- Aziz, R. F., & Abdel-Hakam, A. A. (2016). Exploring delay causes of road construction projects in Egypt. *Alexandria Engineering Journal*, 55(2), 1515-1539. <https://doi.org/10.1016/j.aej.2016.03.006>
- Bachmann, J., Pendle, N. R., & Moro, L. (2022). The longue durée of short-lived infrastructure – Roads and state authority in South Sudan. *Geoforum*, 133, 176–184. <https://doi.org/10.1016/j.geoforum.2022.03.001>
- Hörcher, D., & Tirachini, A. (2021). A review of public transport economics. *Economics of Transportation*, 25, 100196. <https://doi.org/10.1016/j.ecotra.2021.100196>
- Ninrew, C. (2024, April 26). Govt to start building highway from unity to lakes in may. Eye Radio. <https://www.eyeradio.org/govt-to-start-building-highway-from-unity-to-lakes-in-may/>
- Song, Y., Wang, J., Liu, D., & Guo, F. (2022). Study of Occupational Safety Risks in Prefabricated Building hoisting Construction based on HFACS-PH and SEM. *International Journal of Environmental Research and Public Health*, 19(3), 1550. <https://doi.org/10.3390/ijerph19031550>
- Sidiq, M. F., & Rohman, M. A. (2023). A review on safety knowledge and skills for reducing human error and accidents in construction. *E3S Web of Conferences*, 429, 01006. <https://doi.org/10.1051/e3sconf/202342901006>
- Roach, E. L., & Al-Saidi, M. (2021). Rethinking infrastructure rehabilitation: Conflict resilience of urban water and energy supply in the Middle East and South Sudan. *Energy Research & Social Science*, 76, 102052. <https://doi.org/10.1016/j.erss.2021.102052>