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UNDERSTANDING THE CORRELATES OF CONSTRUCTION SAFETY OF HIGH-RISE BUILDINGS: A BAYESIAN PERSPECTIVE

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Abstract

Safety in high-rise building construction is a critical concern, particularly in the densely populated urban areas of Vietnam. Understanding the complex interplay of factors influencing safety on construction sites is essential for reducing accidents and enhancing overall project outcomes. This study aims to identify and analyze key factors impacting safety in high-rise construction projects. Utilizing Bayesian Poisson Regression, the research investigates the relationship between various safety-related factors and the occurrence of non-fatal accidents. The study adopts a comprehensive approach, selecting potential safety factors from the existing literature and developing a rating system validated by site safety managers. Data were collected from 48 high-rise building projects in Vietnam, constructed between 2019 and 2022. Bayesian Poisson Regression was employed to analyze the impact of 15 variables on safety outcomes, including management commitment, worker participation, training programs, emergency preparedness, and safety inspections. The findings underscore the multifaceted nature of construction safety and the need for a holistic approach that involves strong safety training, engaged management and workers, protective measures, and proactive safety audits. This research provides actionable insights for practitioners and contributes to the academic discourse on construction safety, emphasizing the utility of Bayesian methods in unraveling complex safety dynamics in high-rise construction.

Keywords: construction safety; safety factors; high-rise buildings; Bayesian Poisson regression; non-fatal accidents.

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1. Introduction

The construction industry, marked by its inherently high-risk environment, continues to record a substantial proportion of occupational accidents. According to the 2022 Report by the Ministry of Labor, War Invalids and Social Affairs [1], the construction sector accounted for 14.73% of all occupational accidents in the economy and a staggering 15.26% of total occupational fatalities. The primary causes of these incidents reveal the perilous nature of construction work. Falls were the most common, constituting 22.4% of total accidents and 22.51% of deaths. Structural collapses were also significant, representing 12.3% of accidents and 13.16% of fatalities. Furthermore, electric shocks accounted for 10.73% of accidents and 10.4% of deaths, while impacts were responsible for 9.25% of accidents and 8.85% of fatalities. These statistics underscore the urgent need for enhanced safety measures and protocols in the construction industry to mitigate these risks effectively. In the bustling urban landscapes of Vietnam, a marked surge in the demand for residential and commercial spaces has propelled the construction of high-rise buildings into a significant development trend. Amidst the complexities of such construction projects, the issue of safety stands paramount. Occupational accidents in these towering structures not only pose dire risks to human life but also lead to substantial setbacks including delays in project timelines, increased financial costs, and potential damage to the

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reputation of owners and contractors. This study delves into the realm of construction safety within the context of high-rise buildings, focusing specifically on understanding the correlates between various potential factors and non-fatal accidents. The study concentrates on non-fatal accidents as they provide a more stable data set for analyzing safety factors over time, without the biases introduced by the drastic changes often following fatal incidents. This approach allows for a consistent examination of safety practices and their effectiveness in the everyday context of high-rise construction projects.

The significance of this research lies in its targeted approach to unravel the intricate dynamics of safety in high-rise construction. While existing studies have addressed construction safety to varying extents, there remains a gap in comprehensively understanding how specific factors interplay to influence safety outcomes, especially in the unique context of high-rise projects. This research aims to bridge this gap by offering a detailed analysis of key safety factors, their impacts, and the complex relationships between different safety measures and accident rates. In doing so, it seeks to provide actionable insights and recommendations that can enhance safety practices, reduce accident rates, and contribute to the overall well-being of construction workers and project efficiency.

The primary objectives of this research are to identify key safety factors through extensive literature review, understand the impact of various safety interventions, and explore the relationship between different safety measures and accident rates. The study aims to answer crucial questions regarding the most influential factors in construction safety and how these can be effectively managed to minimize the risks of accidents in high-rise building projects. The study employs Bayesian Poisson Regression, a methodology chosen for its robustness in handling count data and its ability to provide probabilistic insights. This approach is particularly relevant for analyzing construction safety data as it allows for a nuanced understanding of the complex relationships between various safety-related factors and the likelihood of accidents occurring. As synthesized by [2, 3], Bayesian approaches have been utilized widely in construction engineering and management research. Compared to traditional statistical analyses, the Bayesian framework offers the flexibility to incorporate prior knowledge and update beliefs in light of new data, making it exceptionally suitable for this research. Focusing on large cities in Vietnam, this study analyzes 48 high-rise building projects constructed between 2019 and 2022. The data encompasses 15 independent variables, ranging from management commitment to workers' experience, rated by site safety managers.

The paper is structured into several key sections: an introduction setting the stage for the research, a literature review that provides context and background, a detailed methodology section describing the Bayesian Poisson Regression approach, a data analysis section outlining the Bayesian model construction, followed by a discussion that interprets the findings, and a conclusion that summarizes the study and its implications for construction safety in high-rise buildings.

2. Literature Review for Construction Safety Factors and the Development of Rating Scales

2.1. *Construction safety factors*

In the realm of construction safety, especially within the context of high-rise buildings, a diverse range of factors contribute to the overall safety environment. This understanding is reflected in an array of both international and Vietnamese research studies that have explored various dimensions of construction site safety. The table that follows encapsulates findings from a selection of these studies, highlighting how each research work contributes to our understanding of fifteen key safety factors. The safety factors selected for this study were chosen for their direct relevance to high-rise construction and the unique challenges it poses, such as verticality and logistics. Each factor's inclusion was also based on the ability to reliably measure and analyze it across projects. These factors range from

Work Environment Conditions (F1) to Safety Personnel Presence (F15), encompassing aspects like Management Commitment (F4), Safety Training (F3), and Emergency Preparedness (F12).

The studies, such as those by [4–6], illustrate the multifaceted nature of construction safety, emphasizing the interplay of various elements like worker demographics, safety protocols, and management practices. This comprehensive compilation serves not only as a testament to the complexity of safety management in high-rise construction but also as a foundation for analyzing how these factors interact to influence safety outcomes on construction sites. The diversity of the studies, spanning different geographical contexts and methodological approaches, enriches the analysis, allowing for a more global understanding of construction safety practices and challenges.

Table 1. Construction safety factors by literature

Study Reference	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15
Abas et al. [4]	x	x	x	x	x	x	x	x	x		x	x			x
Alruqi and Hallowell [7]	x	x		x	x	x	x					x	x		
Cheng et al. [8]	x	x	x			x	x						x		
Choudhry et al. [9]	x	x	x	x		x	x								
Han et al. [10]	x			x											
Hinze et al. [5]	x	x	x	x	x	x	x		x	x		x	x		
Khosravi et al. [11]	x							x							
Leung et al. [12]	x		x			x	x								
Liu and Tsai [13]	x						x								
Zaira and Hadikusumo [14]	x	x	x	x	x	x	x								
Mohammadi et al. [15]	x	x	x	x		x			x	x	x				
Sawacha et al. [16]	x	x	x	x	x	x	x				x	x	x		x
Teo et al. [17]	x	x	x						x						
Pham Phu Cuong [6]	x	x		x		x							x		
Nguyen Luong Hai [18]	x		x	x		x		x	x	x	x				
Tran Hoang Tuan [19]	x		x	x	x		x	x		x	x	x	x		x

where F1 is Work Environment Conditions, F2 is Worker Demographics, F3 is Safety Training, F4 is Management Commitment, F5 is Worker Participation, F6 is Accident Reporting, F7 is PPE Usage, F8 is Safety Inspections, F9 is Safety Audits, F10 is Production Pressure, F11 is Compliance & Regulations, F12 is Emergency Preparedness, F13 is Worker Experience Level, F14 is Subcontractor Safety, F15 is Safety Personnel Presence.

The analysis of safety factors in high-rise construction, as reflected in the collected literature, reveals intriguing trends about the most and least emphasized aspects in safety research. Notably, factors like Management Commitment (F4), Safety Training (F3), and Safety Inspections (F8) appear as recurrent themes in numerous studies. This prominence suggests a general consensus in the academic and professional community about their critical role in shaping a safe construction environment. Conversely, factors such as Production Pressure (F10) and Safety Personnel Presence (F15) have received considerably less attention. This disparity in focus is particularly noteworthy, as it may imply that certain aspects of construction safety, potentially crucial within the high-rise context, are not being adequately addressed in existing research.

The limited exploration of certain factors raises questions about their impact on high-rise construction safety. Given the unique challenges of high-rise projects—such as heightened risks due to verticality, complex logistics, and more significant consequences of accidents - it is essential to understand how these less-studied factors play into the overall safety landscape. The underrepresentation of these aspects in current research indicates a gap in our understanding, underscoring the need for this study.

By examining both the frequently cited and the less-explored safety factors in the context of high-rise construction, this study aims to provide a more holistic understanding of safety dynamics. It seeks to elucidate not just the impact of well-recognized factors but also to uncover the potential influences of the less-discussed elements. This approach is crucial for developing comprehensive safety strategies that cater to the unique requirements of high-rise building projects, ensuring that all critical safety aspects are adequately addressed.

2.2. Factors Identification and the Development of Definition and Rating Standards

Each factor in the entire set was then clearly defined to ensure consistency in understanding and assessment. Rating standards were developed for these factors on a scale of 1 to 10, with 1 indicating the poorest condition or lowest level of implementation, and 10 representing the highest or best condition. These standards were designed to capture a quantitative measure of each factor's presence or quality in the construction projects. Table 2 provides a sample of the rating standards for several factors.

Table 2. Samples of rating standards for safety factors

Factor	1-3	4-6	7-9	10
Safety Training	Infrequent and basic training; not all workers are trained.	Regular training that covers essential topics; most workers are trained.	Comprehensive training program with refreshers; nearly all workers are trained.	Continuous and adaptive training program; all workers are trained with records maintained.
Worker Experience Level	Mostly inexperienced workers with little on-site guidance.	Mixed experience levels, with some experienced workers leading.	Experienced workers prevalent, mentoring and leading safety practices.	Highly experienced workforce with ongoing skill development and safety leadership.
Accident Reporting	Inadequate reporting system with underreporting and no follow-up.	Functional reporting system, with some follow-up on incidents.	Robust reporting system, with thorough investigations and learning from incidents	State-of-the-art incident reporting with real-time tracking, full investigations, and shared learning.
Safety Audits	Rare or non-existent safety audits	Periodic audits with some actions taken on recommendations	Regular audits with a systematic approach to addressing findings	Continuous auditing process with immediate action, feedback, and integration into safety programs

3. Methodology

3.1. Collection and Validation of Data

a. Project selection

The selection of projects for this study was strategically based on the reputation and scale of the general contractors involved. Within the prestigious top 500 company list [20], 29 entities were recognized as building contractors, of which 15 had a notable presence in the high-rise building sector.

The author, leveraging established relationships with 12 of these companies, secured permission to access and analyze information from the projects overseen by these distinguished general contractors. This access provided a valuable foundation for the research, enabling a focused examination of safety practices in the high-rise construction domain.

b. Training of site safety managers

The training of site safety managers from 48 high-rise building projects in Vietnam was meticulously organized to ensure a consistent understanding of safety protocols. Prior to the training sessions, comprehensive material covering the study details, definitions, and rating standards were disseminated to the trainees via email. This preparatory step allowed participants to familiarize themselves with the content in advance. Subsequently, three interactive Q&A sessions were conducted online using Zoom, offering the safety managers an opportunity to clarify any uncertainties and engage directly with the trainers. The aim was to guarantee that their evaluations were informed by both a thorough understanding of the study's framework and their own professional judgment and experience.

c. Achieving ratings from site safety managers

Following the training, these managers were tasked with rating the 15 factors for their respective construction projects. They conducted these assessments independently, providing scores based on their direct observation and knowledge of the project's safety conditions and practices.

d. External validation

To ensure the reliability of the data, external validation was conducted. Project managers and other relevant personnel were consulted to validate the ratings given by the site safety managers. This cross-verification helped in enhancing the credibility of the data.

e. Data collection from project reports

In addition to the ratings, data on non-fatal accidents were collected from the project reports. These data provided the dependent variables for the Bayesian analysis, allowing for a correlation assessment between the rated factors and the safety outcomes.

3.2. Bayesian Poisson Regression Analysis

In addressing the complexities of safety in high-rise construction, the application of Bayesian Poisson Regression offers a robust and nuanced analytical approach. This method is particularly suited to the context of this paper as it efficiently handles count data [21], such as the number of accidents. Bayesian methods bring the advantage of incorporating prior knowledge and uncertainty into the model [22], allowing for a more comprehensive understanding of the factors influencing safety outcomes. Unlike traditional regression models, Bayesian Poisson Regression can effectively manage over-dispersion in count data [21], a common issue in accident statistics. Moreover, it provides a probabilistic framework that yields more informative and interpretable results, crucial for making informed decisions in the high-stakes realm of construction safety. By employing this sophisticated modeling technique, the study aims to unravel the intricate web of factors impacting safety in high-rise building projects, paving the way for more targeted and effective safety interventions.

The following offers a detailed walkthrough of the Bayesian Poisson Regression process [23]:

- Step 1. Setting up the Model:

The Poisson regression model is set up to handle count data, Y_i, the number of accidents for each observation i. The Poisson distribution is defined as (Eq. (1)):

$$Y_i \sim Poisson(\lambda_i) \tag{1}$$

where λ_i is the rate of events (non-fatal accidents). The natural logarithm of λ_i is expressed as a linear combination of predictors (Eq. (2)):

$$\log(\lambda_i) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_p X_{pi} \tag{2}$$

here, β_0 is the intercept, $\beta_1, \beta_2, \ldots, \beta_p$ are the coefficients for predictors $X_1, X_2, \ldots, X_p$, and p denotes the number of predictors.

- Step 2. Prior beliefs:

In the Bayesian context, an analyst starts by specifying prior distributions for the intercept (β_0) and coefficients (β). These priors represent his initial beliefs about the parameters, even before observing the data. A common choice for regression coefficients is the Normal distribution (Eq. (3)):

$$\beta_j \sim N\left(\mu_j, \sigma_j^2\right) \tag{3}$$

where μ_j and σ_j^2 are the mean and variance of the prior distribution for the j-th coefficient.

- Step 3. Likelihood function:

The likelihood function links the model to the observed data. For Poisson regression, the likelihood of observing the data given the parameters is (Eq. (4)):

$$L(\beta_0, \beta | Y) = \prod_{i=1}^{n} \frac{e^{-\lambda_i} \lambda_i^{Y_i}}{Y_i!} \tag{4}$$

where n is the number of observations.

- Step 4. Posterior distribution:

Bayesian inference updates the priors to posteriors using Bayes' Theorem. The posterior distribution represents the updated beliefs after considering the observed data. Mathematically, it is given by (Eq. (5)):

$$P(\beta_0, \beta | Y) \propto L(\beta_0, \beta | Y) \times P(\beta_0, \beta) \tag{5}$$

where $P(\beta_0, \beta | Y)$ is the posterior distribution, $L(\beta_0, \beta | Y)$ is the likelihood, and $P(\beta_0, \beta)$ is the joint prior distribution of the parameters.

Computing the posterior distribution often involves complex integrals, especially with large datasets or numerous predictors. Markov Chain Monte Carlo (MCMC) methods [24] such as the No-U-Turn Sampler (NUTS) [25] are frequently used. These techniques generate samples from the posterior distribution, which are then used to estimate the posterior characteristics (mean, variance, credible intervals).

The final step is to interpret the posterior distributions of the parameters. This interpretation provides insights into the relationship between predictors and the count outcome (e.g., accident rates), accounting for the uncertainty inherent in the data and the model.

4. Bayesian Model Construction and Discussions

4.1. Data descriptive

The study encompasses a comprehensive dataset from 48 high-rise building projects (15-30 floors) situated in the bustling urban landscapes of Vietnam, constructed over a span from 2019 to 2022. In assessing the safety conditions of these projects, 15 input variables were meticulously rated on a scale from 1 to 10—where 1 represents the lowest adherence to safety standards and 10 signifies the highest. These ratings were provided by the site safety managers of the respective projects under conditions guaranteeing confidentiality, ensuring unbiased and truthful evaluations.

The data on non-fatal accidents were rigorously gathered from official site reports and the recollections of these site safety managers. To enhance the data's reliability, this information was further cross-verified with project managers representing the owners. This triangulation method not only reinforces the accuracy of the reported figures but also encapsulates a realistic portrayal of the safety landscape in these high-rise construction endeavors. The heatmap in Fig. 1 depicts correlations between each pair of variables, independent and dependent wise.

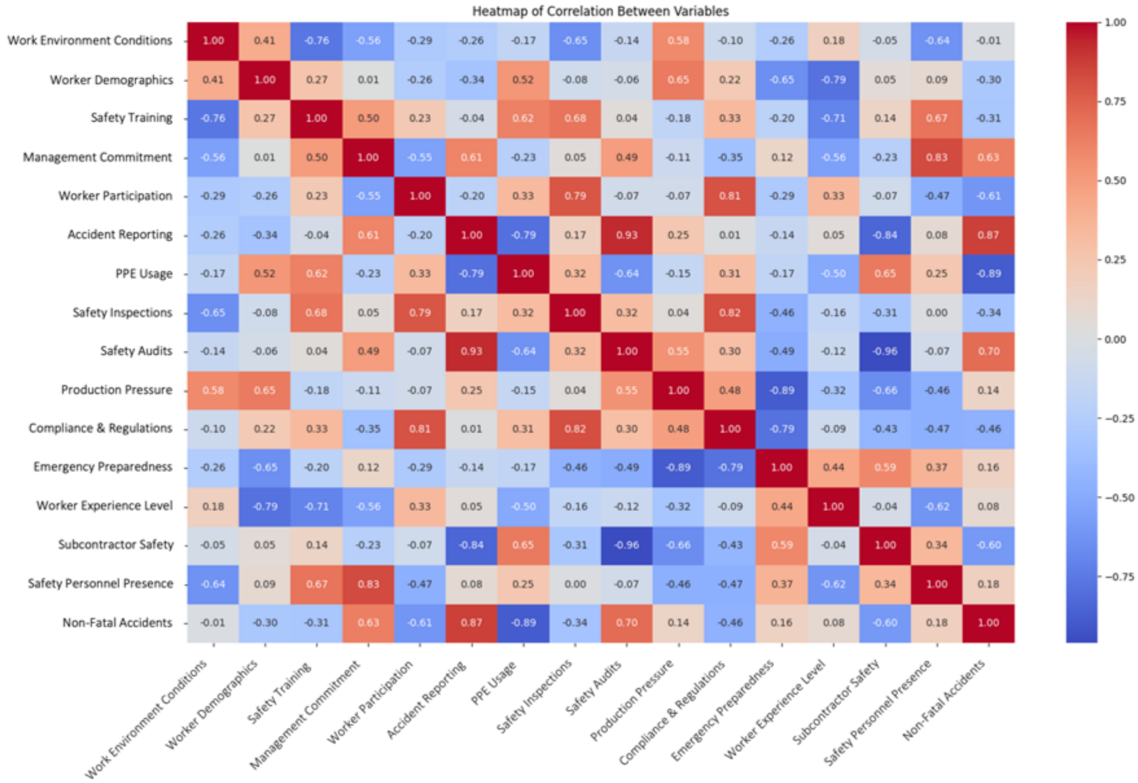

Figure 1. Correlations between pairs of variables

The analysis indicated that challenging work environments correlate with an increase in near-miss incidents, potentially due to heightened vigilance in such settings. Safety training showed a beneficial effect, with a strong inverse relationship to non-fatal accidents, suggesting its effectiveness in mitigating risks. Management commitment and worker participation both have crucial roles in safety, as evidenced by their strong negative correlations with non-fatal accidents, emphasizing the importance of leadership and worker engagement in promoting safe practices. Safety inspections and audits are proven to be key in preventing accidents, while production pressure has the opposite effect, potentially compromising safety and increasing near-miss incidents. Emergency preparedness aligns with overall safety measures, reducing accidents. Experienced workers and subcontractors with strong safety records are associated with fewer non-fatal accidents, highlighting the value of experience and reliable safety practices in ensuring construction site safety.

4.2. Bayesian Model Construction

The data analysis and modeling in this study were conducted using Python (version 3.9.6) on the Ventura (13.0.1) macOS operating system. Fig. 2 shows a sample of trace plots for the coefficients.

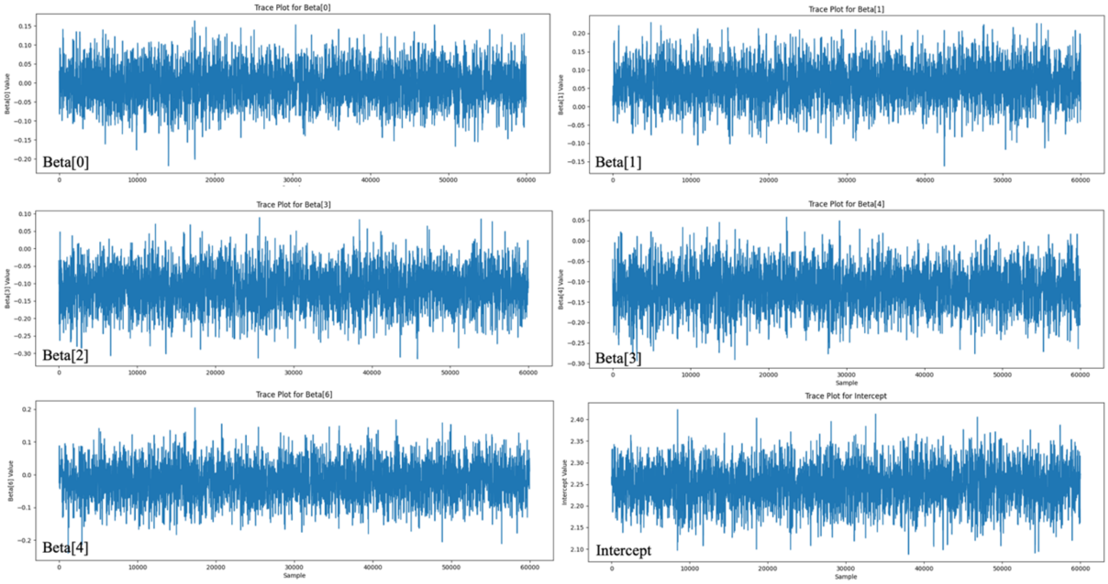

Figure 2. A sample of coefficient trace plots

Convergence, mixing, and *stationary* can be evaluated from the trace plot of each coefficient. Convergence refers to the point where the chains start to sample from the true posterior distribution. If the chains have not converged, some trends or drifts are visable instead of a stable fluctuation. Good mixing is indicated by the chains moving back and forth across the posterior distribution without getting stuck for long periods. The chains should ideally display stationarity, where there are no trends over time in the trace plots. A stationary chain implies that the distribution of the chain is stable, which is a key assumption for valid MCMC sampling.

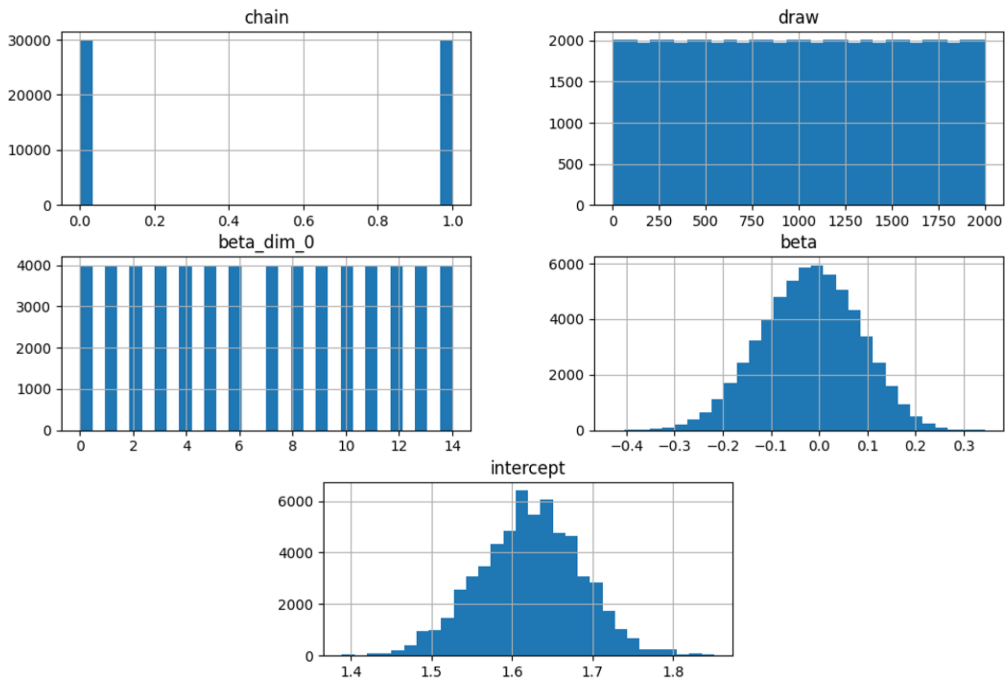

Figure 3. Trace analysis of the Bayesian model construction

Furthermore, graphs in Fig. 3 add more insights about how the Bayesian model was constructed and validated. The presence of two chains is indicative of a standard practice in Bayesian modeling to assess convergence. The uniform distribution of draws – shown by a flat shape – confirms that the sampling process was stable and covered the entire range of iterations evenly. The beta and intercept distributions are symmetric imply a balanced model, reflecting no apparent skewness in the factor weights and a non-biased model framework. Their bell curves confirm that the model has successfully captured the central tendency and variability in the data, which are essential for making probabilistic statements about the impact of each factor on construction site safety.

The results of the model construction are presented in Table 3 and Fig. 4.

Table 3. Bayesian regression parameter results

	mean	sd	hdi_3%	hdi_97%	ess_bulk	ess_tail	r_hat
beta[0]	0.01	0.07	−0.13	0.14	3767.60	2869.77	1.0
beta[1]	−0.02	0.07	−0.17	0.10	3826.40	3097.77	1.0
beta[2]	0.10	0.07	−0.04	0.22	3827.24	3056.27	1.0
beta[3]	−0.04	0.08	−0.18	0.11	3593.83	3177.95	1.0
beta[4]	−0.04	0.07	−0.17	0.10	4237.19	3315.69	1.0
beta[5]	−0.05	0.07	−0.18	0.08	4107.81	3068.86	1.0
beta[6]	−0.13	0.08	−0.28	0.01	3475.83	3004.23	1.0
beta[7]	−0.12	0.07	−0.26	0.01	3802.66	3269.73	1.0
beta[8]	0.06	0.08	−0.09	0.19	3684.59	2802.91	1.0
beta[9]	−0.01	0.07	−0.15	0.12	3820.37	3111.94	1.0
beta[10]	0.05	0.07	−0.08	0.19	3562.40	3204.40	1.0
beta[11]	−0.14	0.07	−0.27	0.00	4379.07	3216.04	1.0
beta[12]	−0.05	0.08	−0.19	0.09	3431.07	3147.55	1.0
beta[13]	0.05	0.07	−0.08	0.19	3710.85	3188.16	1.0
beta[14]	0.04	0.07	−0.10	0.18	3904.64	3296.34	1.0
intercept	1.62	0.06	1.49	1.73	3570.90	3085.54	1.0

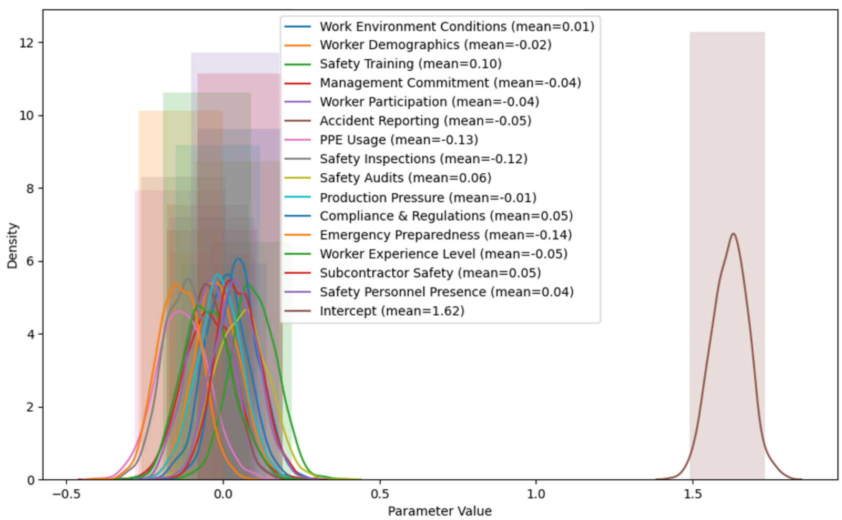

Figure 4. Posterior distribution of the Bayesian model

In exploring the safety dynamics of high-rise building construction through Bayesian Poisson Regression, the model yields nuanced insights into various safety factors:

Work Environment Conditions (beta[0]) and Worker Demographics (beta[1]) have means around zero, indicating uncertain impacts on accidents. Safety Training (beta[2]) shows a positive influence, suggesting more training could lead to increased reporting of incidents. Management Commitment (beta[3]) and Worker Participation (beta[4]) have negative means, implying they might help reduce accidents, though their effects are not definitive. Personal Protective Equipment (PPE) Usage (beta[6]) and Safety Inspections (beta[7]) are likely to decrease accident rates, as indicated by their negative means. Conversely, Safety Audits (beta[8]) are associated with an increased number of reported incidents, possibly due to better detection. Emergency Preparedness (beta[11]) strongly correlates with fewer accidents, while factors like Production Pressure (beta[9]) and Compliance & Regulations (beta[10]) show ambiguous effects. Subcontractor Safety (beta[13]) and Safety Personnel Presence (beta[14]) exhibit small positive means, hinting at beneficial impacts. The intercept suggests a baseline accident rate when other factors are averaged out. In this case, the intercept value of 1.62 is considerably high, suggesting the presence of hidden factors potentially influencing the outcomes. This analysis points to a multifaceted safety landscape, with certain factors like training, management commitment, and emergency preparedness playing critical roles in reducing non-fatal accidents on high-rise construction sites.

The scatter plot analysis (Fig. 5) presents a compelling visualization of the predicted versus actual non-fatal accidents in high-rise construction projects. Notably, as the number of incidents increases, the predictions tend to align more closely with the actual occurrences. This correlation suggests that the model is particularly effective at reflecting the underlying safety conditions in scenarios with a higher frequency of accidents.

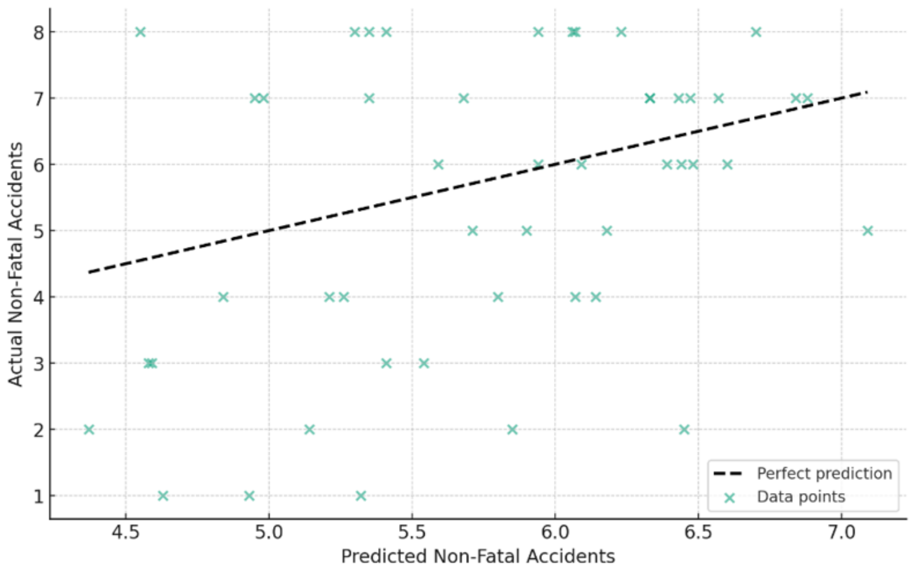

Figure 5. Scatter plot of non-fatal accidents and predicted

The proximity of predictions to actual values in higher incident ranges is significant, indicating the model's robustness in more complex and hazardous environments. Given that the range of non-fatal accidents extends from 1 to 8, the model demonstrates its potential as a reliable tool for safety assessment in construction projects.

The residual plot (Fig. 6) further reinforces the model's performance, revealing a pattern where residuals diminish as the number of incidents escalates. This trend implies that the model's predictions are more precise when the accident count is higher, which could be instrumental for safety management in larger-scale projects or those with a greater number of recorded incidents.

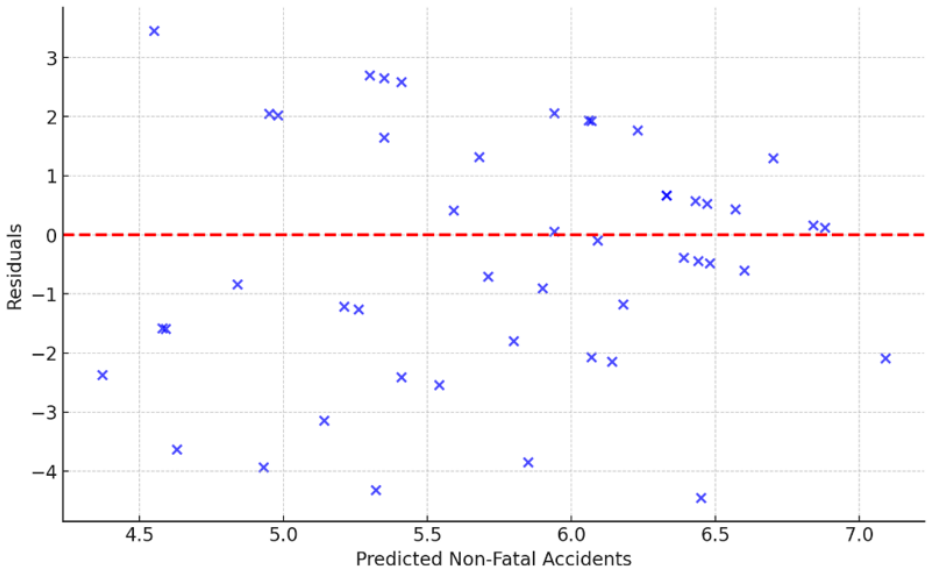

Figure 6. Residual plot for non-fatal accidents prediction

Results can be translated into the management context as follow:

Safety Training: The analysis points to a correlation between intensified safety training and an increased frequency of accident reports. This trend suggests that such training is elevating awareness of safety issues rather than causing an actual increase in hazardous incidents. It's imperative for organizations to not only conduct thorough safety training but also to ensure that this training is effectively reducing actual risks in the workplace, beyond just leading to heightened reporting.

Management and Worker Engagement: The critical importance of both management's dedication and workers' involvement in diminishing accident rates stands out. Companies should develop strategies that enhance the presence of management in safety initiatives and motivate workers to engage with safety practices. This investment aims to cultivate a culture where safety is a shared value among all members of the organization.

Protective Measures: The use of appropriate personal protective equipment (PPE) and the implementation of comprehensive safety inspections are indispensable in preventing accidents. Their predictive effectiveness in safeguarding against accidents underlines that these practices should be mandatory and integral parts of every safety protocol.

Emergency Readiness: The significant impact of emergency preparedness in reducing the number of accidents underscores the necessity for solid emergency procedures. Regular emergency drills and the clear articulation of emergency processes are crucial for ensuring that responses to incidents are both rapid and efficient.

Safety Audits: A small but notable positive correlation between the frequency of safety audits and the reporting of incidents may indicate a proactive stance towards identifying and addressing safety issues. The goal of safety audits should be to prompt significant improvements in safety, leading to tangible enhancements in the workplace.

Subcontractor and Safety Personnel: While the input from both subcontractor safety measures and safety personnel has been acknowledged as valuable, there appears to be potential for further development. It is recommended that current practices be examined to guarantee that subcontractors adhere to safety standards and that safety personnel are fully integrated into the daily workflow to maximize their impact on site safety.

4.3. Discussions

Previous studies (e.g., [6, 7, 11, 15]) have often alluded to the significance of management roles and safety measures in a more conceptual framework. This study extends that understanding by offering a data-driven perspective, which underscores the necessity of a tangible and consistent application of safety protocols. Notably, the link between enhanced safety training and an increase in reported incidents has been contentious in the literature. This study clarifies that the phenomenon likely represents an increase in safety vigilance rather than a spike in hazard occurrences, a nuance that has not been thoroughly explored until now.

The findings of this study are instrumental in shaping a data-backed safety enhancement strategy for high-rise construction projects. By demonstrating the positive impacts of proactive safety measures and management's participatory approach, this research provides a solid foundation for policy recommendations and safety program improvements within the industry.

While the study provides new insights, its scope is limited to high-rise construction projects, which may not encapsulate the safety dynamics of other construction environments. Future research could explore the applicability of these findings across various construction settings, including low-rise and infrastructure projects. Additionally, the inclusion of near-miss accidents, which are prevalent yet underreported in the construction industry, could substantially refine the model's predictive power. Recognizing near-misses as critical precursors to severe incidents allows for a broader understanding of safety factors and offers a more proactive stance in hazard prevention.

However, the challenge remains in the accurate and consistent collection of data on these near-misses. These incidents often go unreported or are intentionally concealed due to cultural and systemic barriers within the industry. Addressing these barriers requires a cultural shift towards open reporting and the implementation of stringent documentation practices. Such improvements in data collection would enable a predictive and preventative approach to construction safety that could reduce both near-misses and actual accidents.

The study's reliance on reported accident rates also opens discussions on potential reporting biases. To counteract this, future inquiries could include direct observation and the use of alternative data sources to triangulate findings and reduce the influence of reporting practices.

As technology continues to advance, the role of technological interventions in enhancing construction safety becomes increasingly pertinent. Subsequent investigations should consider the impact of innovative technologies such as wearable safety devices, drones for site inspections, and artificial intelligence in hazard identification and risk management.

By acknowledging these limitations and incorporating these recommendations for further research, the construction industry can expand its understanding of safety dynamics. This progression is pivotal for the development of effective safety strategies and contributes to a significant reduction in on-site accidents.

5. Conclusions

This investigation into the safety of high-rise building construction in Vietnam has been a meticulous application of Bayesian Poisson Regression to analyze a spectrum of safety factors. The findings offer a granular view of their impact on non-fatal accidents.

Crucially, this research has illuminated the roles of management commitment, worker participation, and safety training. These elements are central to a culture that prioritizes safety and are instrumental in reducing workplace accidents. The analysis revealed that enhanced safety training is associated with an increase in accident reporting, reflecting greater safety awareness rather than a rise in incidents. This indicates a need for training programs that not only promote reporting but also tangibly decrease hazards. Management's visibility and worker engagement in safety processes are identified as significant in mitigating accidents. Firms are encouraged to develop strategies that increase management's role in safety initiatives and support worker involvement to build a collective culture of safety awareness.

The study has further highlighted the preventive value of proper PPE usage, safety inspections, and emergency preparedness. These practices are critical for accident prevention and must be non-negotiable in any safety program. Safety audits also show a positive correlation with incident reports, suggesting a proactive identification and management of safety concerns. Subcontractor safety and the role of safety personnel, while noted as positive, indicate potential areas for improvement to ensure compliance and effective daily safety operations.

The conclusion underscores the necessity of a multifaceted, proactive approach to safety. A strategy that encompasses practical training, leadership by example, active worker participation, rigorous enforcement of protective measures, prioritized emergency readiness, and thorough safety audits is paramount. Additionally, reassessing the roles of subcontractors and safety personnel is crucial for an effective safety infrastructure. By integrating these insights and recommendations, construction firms can aim for a notable and lasting reduction in workplace accidents. The overarching goal of this study goes beyond academic contributions; it aspires to foster a safer, more resilient construction industry where safety is paramount, the wellbeing of every worker is preserved, and high-rise projects are successfully completed with the highest safety standards.

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