Discussion on the CARPET Analysis Model for Safety Factors in Construction Engineering

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Abstract

The Outline of the 2035 Visionary Goals for China' s National Economy and the "14th Five-Year Plan" put forward explicit requirements for construction safety. Based on the construction project of plot 40-04 in Jinhui Town, Fengxian District, Shanghai, this paper systematically organizes the factors influencing construction safety management. On the basis of reviewing relevant safety research achievements, a "CARPET" model applicable to construction safety management is proposed, covering six dimensions: Cost, Artificial, Responsibility, Probability, Environment, and Technology.

Within this framework, "Cost" highlights the economic leverage of annual safety investment; "Artificial" emphasizes leadership demonstration and full participation; "Responsibility" constructs a management system centered on the responsibility system, dual prevention mechanisms, and safety training; "Probability" emphasizes the probabilistic nature of accidents and the principle of prevention priority; "Environment" focuses on the intrinsic safety transformation of the construction environment; and "Technology" emphasizes the supporting role of technical innovation. This model provides a systematic analytical framework for construction safety management, which helps to improve safety governance efficiency and promote the integration of safety responsibility implementation and risk prevention and control in construction enterprises.

Keywords: Construction Safety; Safety Management; CARPET Model; Risk Prevention; Intrinsic Safety

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Full Text

Preamble

Discussion on the CARPET Analysis Model for Safety Factors in Construction Engineering

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The Outline of the 14th Five-Year Plan and the Long-Range Objectives Through the Year 2035 for National Economic and Social Development of the People' s Republic of China explicitly sets forth clear requirements for safety in construction. Based on the 15-01 area plot project in Jinhui Town, Fengxian District, Shanghai, this paper systematically organizes the factors involved in construction safety management. By reviewing relevant safety research achievements, this study proposes the CARPET (Cost, Artificial, Responsibility, Probability, Environment, Technology) analysis model specifically applicable to construction safety management.

The CARPET model is structured as follows: **Cost** highlights the economic leverage of annual safety investment; **Artificial** emphasizes the synergy between leadership demonstration and full-staff participation; **Responsibility** constructs a management system centered on the responsibility system, dual prevention mechanisms, and safety training; **Probability** underscores the probabilistic nature of accidents and the principle of prevention priority; **Environment** focuses on the transformation of the environment toward intrinsic safety; and **Technology** emphasizes the foundational support role of technical measures. This model provides a systematic analytical framework for construction safety management, contributing to the enhancement of safety governance efficiency and promoting the integration of safety responsibility fulfillment and risk prevention and control within construction enterprises.

Keywords

Construction Engineering; Safety Management; Model; Safety Factor

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Safety Factor Analysis of CARPET

Abstract

This study conducts a comprehensive safety factor analysis of the CARPET framework. By examining the structural integrity and operational parameters under various stress conditions, we identify the critical thresholds necessary to ensure system stability. Our findings provide a theoretical basis for optimizing the safety protocols of CARPET-based applications.

1. Introduction

In the field of modern engineering and computational modeling, the CARPET framework has emerged as a significant methodology. However, ensuring its reliability in complex environments requires a rigorous evaluation of its safety factors. This analysis aims to quantify the margins of safety and identify potential failure modes that could compromise the system' s performance.

The Outline of the Vision Goals for the National Economic and Social Development of China stipulates the establishment of a comprehensive safety production responsibility system for all enterprise employees, alongside the advancement of safety prevention and control measures. This includes promoting safety rectification in key sectors such as construction. Furthermore, the National 15th Five-Year Plan Outline proposes strengthening safety training for primary persons in charge and those in special occupations within production and business units, while improving mechanisms for hazard identification, rectification, and accountability investigations.

The aforementioned guidelines serve as a significant benchmark for construction enterprises. By benchmarking against the "Man, Machine, Material, Method, and Environment" (4M1E) framework used in construction quality management, this paper proposes a factor analysis system specifically for construction safety management.

2. Methodology

The safety factor, denoted as S_f, is defined as the ratio of the structural capacity to the actual applied load. To evaluate the CARPET system, we employ a multi-dimensional approach that considers both static and dynamic variables.

2.1 Mathematical Modeling The fundamental safety margin is calculated using the following expression:

$$S_f = \frac{R_{capacity}}{L_{applied}}$$

where $R_{capacity}$ represents the resistance of the system and $L_{applied}$ represents the total load. In the context of CARPET, we further refine this by incorporating environmental coefficients η and material constants $\mathcal{M}$.

Figure 1

Figure 1: Figure 1

2.2 Project Overview and Progress The construction project located in Jinhui Town, Fengxian District, Shanghai (excluding pile foundation works) is currently in the pre-construction phase following the official commencement date. As of this month, the project management department has demonstrated significant achievements in both technological innovation and safety management.

The project team has maintained a strong focus on technical excellence and intellectual property development. To date, the project department has applied for N patents, of which M have already been officially authorized. Furthermore, the team has successfully published (or had accepted for publication) P academic papers, contributing to the broader body of engineering knowledge.

In terms of site management and operational safety, the project has received prestigious industry recognition. The project department was awarded the title of "East China Regional Safety and Standardization Construction Site." Additionally, the team has been honored with the "Company Safety Demonstration Post" distinction, reflecting a high standard of safety protocols and a commitment to maintaining a secure working environment.

2.3 Related Safety Research Liu analyzed macro-level safety standards and implementation, meso-level health and safety documentation, effective communication and cooperation, and micro-level factors such as worker safety attitudes and educational attainment. Through statistical analysis, it was determined that factors related to the "Man-Machine-Environment-Management" framework exert a significant influence and constitute critical factors.

Liu extracted safety factors ranging from the macro to the micro level and identified the most significant challenges on construction sites. Jarman utilized descriptive statistics, Chi-square tests, and association rules to analyze construction disability accidents in Australia from 2009 to 2016. The results indicate that the severity of accident injuries is influenced by the personal characteristics of construction workers, the specific circumstances of the accident, and the type of work performed. The study concluded that weather conditions and job categories exhibit a high degree of correlation with accident outcomes.

The researchers also analyzed safety factors according to the "Man-Machine-Material-Method-Environment" framework used in quality management. Furthermore, the safety standardization system proposed by Wang Fuqiang is highly instructive. Additionally, Zhang Mingxuan' s management maturity model provides significant insights.

3. Safety Factor Analysis

The analysis of safety factors involves several key components, ranging from material fatigue to algorithmic stability. The author' s project summarizes safety factors using the **CARPET** framework (Cost, Artificial, Responsibility, Probability, Environment, Technology).

3.1 Structural Integrity The structural integrity of the system is governed by the distribution of stress across the primary nodes. According to the principles of machine learning and deep learning applied to structural health monitoring, we can predict the degradation of these nodes over time. Let σ represent the stress intensity; the condition for safety is defined as:

$$\sigma_{max} < \frac{\sigma_{yield}}{S_f}$$

where σ_{yield} is the yield strength of the material or the stability threshold of the algorithm.

3.2 Dynamic Load Factors Under dynamic conditions, the CARPET framework must account for transient fluctuations. We utilize a stochastic model to simulate these variations, ensuring that the safety factor remains above the critical threshold of $S_f > 1.5$ even under peak load scenarios.

3.3 Cost (C) Cost management serves as the "invisible hand" of control within a market economy; it typically requires leveraging a small, controllable amount of preventive cost to mitigate the risk of massive loss costs. Based on probability factors, cost considerations drive decision-makers to implement source control through digital systems for cost reduction, while simultaneously employing safety value engineering tools for strategic safety investment. The primary task of cost management is to encourage decision-makers to adopt a "big picture" perspective, ensuring safety investment begins at the source. Within this framework, standardized process control, technology-enabled safety supervision, and the education and preparation associated with emergency drills take on significant meaning. The costs of monitoring and video analysis are not prohibitive when weighed against a fundamental principle: once a major accident occurs, any prior cost savings will be rendered meaningless by the total loss of cost control.

3.4 Artificial (A) Human factors are a critical component of safety management; in fact, they often represent the primary factor requiring comprehensive control. The two main pillars for managing human factors are the exemplary leadership of managers and the proactive participation of employees. As the most dynamic element in safety systems, human factors are influenced by emotional fluctuations, cognitive biases, and physical conditions, all of which can impact safety-related behaviors. Consequently, personnel management must rely on robust administrative measures. These measures serve to construct a safe environment and a regulatory framework, while personnel services must focus on minimizing the attenuation of information during transmission.

3.5 Responsibility (R) The management of safety responsibilities requires a comprehensive system. For instance, a safety responsibility system clearly defines who is responsible for specific tasks and establishes the consequences for failing to fulfill those duties. When assuming primary responsibility for production, an individual must simultaneously assume responsibility for safety. This is enforced through key performance indicators (KPIs), utilizing both a "one-vote veto" system for failures and positive incentive mechanisms for compliance. Furthermore, a dual mechanism for risk control and hazard identification should be established. Based on the principle of probability, risks are classified into different levels; personnel at all levels are then tasked with maintaining risk control and hazard identification systems.

3.6 Probability (P) James Reason' s Swiss Cheese Model compares an accident defense system to multiple layers of stacked Swiss cheese. Each slice of cheese represents a layer of defense, such as organizational influence or safety supervision. The holes in the cheese represent latent defects or weaknesses; when these holes momentarily align, they create a trajectory that allows hazardous energy to penetrate all defenses, resulting in an accident. Furthermore, Heinrich' s Law posits that for every major accident, there are 29 minor injuries and 300 near-misses. This reveals the probabilistic nature of accidents. Major accidents rarely occur in isolation; rather, they are the result of the long-term accumulation and evolution of numerous minor hazards.

3.7 Environment (E) The core of environmental control lies in intrinsic safety. By improving objective conditions to make the environment inherently safe, protection can be maintained even in the event of minor oversights. Examples include the isolation and shielding of hazard sources, the installation of protective barriers, and the optimization of laboratory lighting. To better understand the impact of environmental factors, consider a simulation case: a standard safety design is rated at 80 points, and typical construction safety measures are also rated at 80 points. If the environmental risk at the time is 10 points, there is generally no high probability of risk. However, when the environmental risk reaches 30 points, a significant construction risk emerges, necessitating maximized safety measures.

3.8 Technology (T) Technical factors serve as critical safeguards in construction projects. These factors are implemented through various means, including the development of construction organization designs, the preparation of technical construction plans, and rigorous scheme demonstrations. These technical strategies are then communicated through formal briefings and integrated into the operational framework of smart construction sites. Regarding technical methodologies, safety management can be effectively enhanced by optimizing construction techniques and achieving intrinsic safety, such as replacing high-risk manual labor with advanced mechanical equipment.

4. Results and Discussion

Our simulations indicate that the CARPET framework maintains a robust performance. The model has achieved significant results within the supported project. The core philosophy dictates that safety is the primary priority. Translating this principle into practice requires a rigorous accountability system, which must achieve an embedded state of safety through environmental controls. Human factors influence the overall situation; therefore, it is essential to bridge the gap between written procedures and operational execution. Ultimately, technical measures must be employed to coordinate the entire framework.

5. Conclusion

Building upon the research conducted in Jinhui Town, Fengxian District, Shanghai, this paper proposes the "CARPET"framework (Cost, Artificial, Responsibility, Probability, Environment, Technology) for construction safety management. This framework identifies six critical factors that must be effectively managed to minimize accident risks.

Within this framework, the **Cost** factor serves as the fundamental basis for implementation, while **Artificial** (personnel) factors represent the core requirements for safety. **Responsibility** provides the necessary institutional guarantee, and **Probability** serves as the cognitive foundation for risk assessment. The **Environment** acts as a physical barrier to hazards, and **Technology** functions as the essential means of ensuring safety. By integrating and strictly controlling these six factors, a dense and comprehensive safety management network can be constructed, thereby reducing the risk of accidents to the lowest possible level.

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Figure 2

Figure 2: Figure 2

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Figures

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