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A Qualitative Study Understanding Unsafe Behaviors of Workers in Construction Sites

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Abstract : Construction accidents result from a combination of factors, including both the actions of workers and the safety conditions on site. Despite advancements in enhancing construction site safety, there remains a gap in comprehending the cognitive processes underlying workers' unsafe behavior. This paper investigates and validates a qualitative model that delves into the potential causes of workers' unsafe actions by examining their cognitive processes, employing a system dynamics approach. By analyzing the interplay of various loops within this model, it offers both short- and long-term safety strategies for managers intent on minimizing unsafe behavior among workers. Specifically, safety managers should prioritize increasing workers' awareness of hazards through education and fostering a positive safety mindset. Moreover, they should task front-line supervisors with directly addressing and rectifying instances of unsafe behavior by workers. Lastly, construction safety managers ought to formulate safety strategies that take into account the cognitive states of workers to mitigate any adverse consequences of biased safety management. The outcomes of this research contribute to our comprehension of methods to enhance hazard perception among workers, curtail unsafe actions, and ultimately reduce construction accidents from a cognitive standpoint.

Keywords : Construction Management; Construction Safety; Cognitive Process; System Dynamics

1. Introduction

In recent decades, construction sites have consistently ranked among the most hazardous workplaces in numerous countries (Mearns & Flin, 1995). Despite ongoing efforts to reduce these incidents, the safety of construction workers continues to be at risk (Park et al., 2013; Salinas et al., 2022; Tixier et al., 2014).

Previous research has consistently highlighted that the primary underlying causes of construction accidents are workers' unsafe behaviors and unsafe working conditions (Heinrich, 1941; Shin et al., 2014; Svenson, 2001; Zhu et al., 2022). Unsafe conditions refer to hazardous physical situations or scenarios that directly increase the likelihood of accidents. For instance, not suggesting adequate safety manager or protective equipment to workers, or supplying them with defective tools, can create unsafe conditions on construction sites. Unsafe acts refer to behaviors that are inappropriate in situations that have the potential to be dangerous, such as ignoring safety procedures or failing to use personal protective equipment (Mitropoulos et al., 2005).

Dangerous conditions are usually recognizable by construction managers and workers, enabling them to take immediate action to mitigate hazards at construction sites. However, the origins of unsafe acts among workers in construction sites retain unclear, as these behaviors are often transient and linked to individual cognitive processes (Donald & Young, 1996). Understanding the motivations behind engaging in unsafe behaviors is of paramount importance, as these behaviors serve as precursors to accidents.

Unsafe behaviors among construction workers can be classified based on their awareness of potential hazards that could lead to accidents. Construction sites are inherently complex and rife with potential dangers, and workers may not always be fully aware of all these risks

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(Tixier et al., 2014). While previous papers have primarily examined intentional behaviors of construction workers related to hazard perception, this may not capture the complete spectrum of unsafe acts, as incidents can result safety contravention as well as a lack of hazard awareness (Namian et al., 2016). Hence, this study specifically explores workers' unintentional unsafe actions stemming from their failure to perceive hazards.

The cognitive processes of workers involve various feedback loops (Shin et al., 2014). For instance, incidents and accidents frequently occur due to unsafe acts, and there accidents' outcomes can affect subsequent behaviors through cognitive processes. Moreover, implementing management approaches to positively alter mental processes of people may have unintended consequences, as workers might develop biased attitudes in situations where accidents do not occur. However, comprehending these time-dependent cognitive processes and feedback loops for each step is challenging when proposing management policies and decision-making at higher levels. Consequently, qualitative modeling using system dynamics serves as an suitable method for elucidating these feedback effects.

In this context, this research has investigated and validated a qualitative model of the mental processes of workers. From this model, it derives effective management strategies aimed at reducing workers' unsafe behaviors. The models that used in this paper is based on Kim et al. (2017). The author modified the models, and verification part is newly added in this paper. The study places particular emphasis on workers' knowledge and attitudes, as these factors constitute the primary sources of hazard perception and decision-making in matters of safety.

2. Preliminary Study

2.1 Cognitive Process in Construction

Cognitive processes encompass mental activities like interpreting and perceiving one's surroundings. In the context of workers' safety at construction sites, hazard cognitive processes involve the interpretation of potential risks present. The cognitive process related to the safety of workers can be broken down into three parts. Workers initially collect data about the site through their sensory perception, subsequently recognize potential hazards, make decisions guided by these identified risks, and ultimately take actions aligned with their decisions (Kim et al., 2017).

As an illustration, Shin et al. (2014) introduced a model that encompassed elements of hazard perception and attitudes, integrating feedback loops associated with worker habituation and the incidence of accidents. However, this model does not comprehensively account for the influence of safety management on individual perceptions and falls short in addressing failures in hazard perception. Fang et al. (2016) explained the decision-making process behind unsafe behavior from a cognitive standpoint and detailed the kinds of cognitive errors workers may make by integrating various social science theories. Previous cognitive studies on unsafe behaviors have often overlooked the concept of workers failing to perceive hazards in dangerous scenarios. Workers can sometimes misinterpret or overlook hazards, with studies demonstrating misunderstandings of construction site dangers and concurrent cognitive overload due to the complex construction environment. This study delves into workers' cognitive processes, including the failure of hazard perception, in greater depth compared to previous research, aiming for a more rigorous investigation of these cognitive processes.

2.2 Hazard Identification

Construction sites are highly dynamic work environments where workers face daily tasks in ever-changing conditions. Moreover, each construction project carries its own unique characteristics, resulting in the emergence of new and unexpected situations on a daily basis (Lee et al., 2012). Therefore, the accurate recognition of hazards is a fundamental requirement to prevent accidents and unsafe behaviors among workers (Carter & Smith, 2006).

When construction workers encounter hazardous situations (as illustrated in Fig. 1), there are two potential responses: successful hazard perception and a failure in hazard perception. When construction workers correctly identify a hazard, their ability to protect themselves against risks depends on their intentions during their

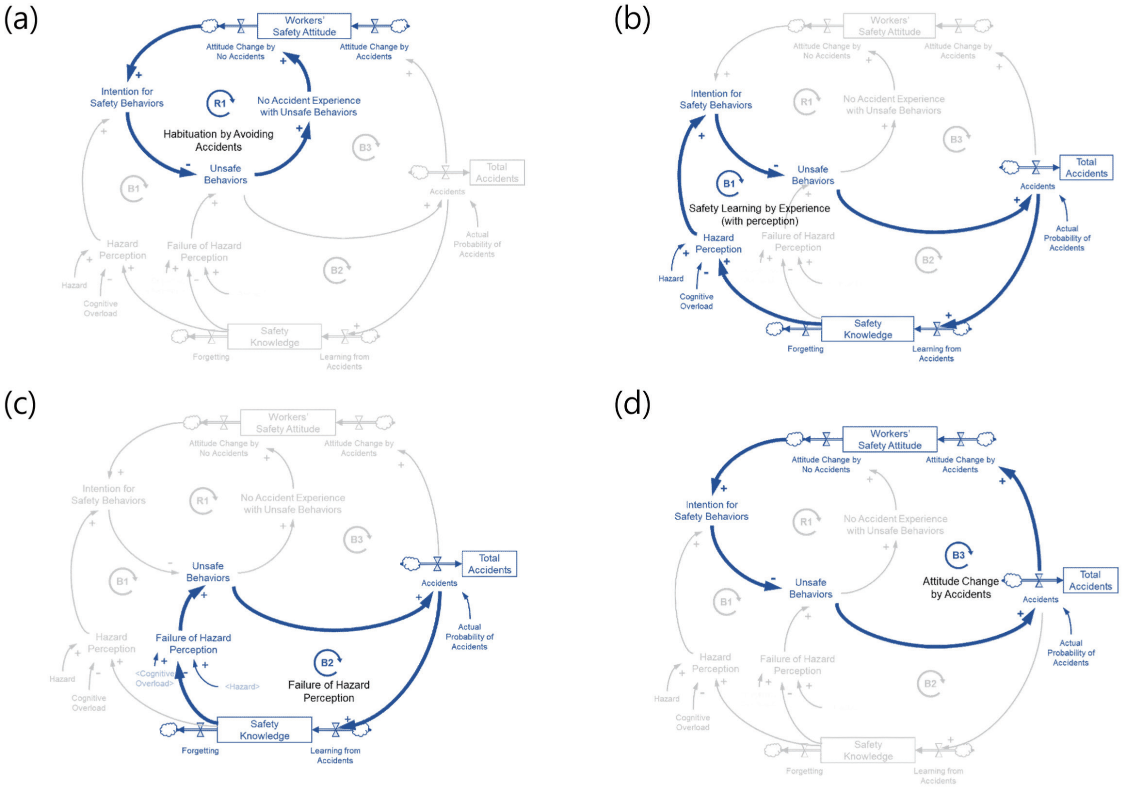

Fig. 1. Workers' hazard perception and response feedback process

mental processes. On the contrary, even if proper controls or management measures are in place, incidents or accidents may still occur, as accidents often result from a combination of multiple errors or oversights (Carter & Smith, 2006). Given that workers typically operate within teams, accidents can happen when other team members fail to effectively manage dangerous situations. Similarly, in instances where construction workers do not recognize a hazard, they may not have sufficient time to prepare for the associated risks, potentially leading to accidents (Carter & Smith, 2006). Therefore, it is imperative for construction workers to enhance their proficiency in recognizing hazards effectively.

Construction workers generally rely on their expertise and prior experiences to identify potential hazards, with accurate information contributing to correct hazard assessments. Knowledge can be categorized into two main types: tacit and explicit knowledge (Hallowell, 2012). Explicit knowledge encompasses formal information that can be easily imparted to workers through safety management training and educational programs (Sherehiy & Karwowski, 2006). In contrast, tacit knowledge is often acquired through a construction worker's personal experiences and interactions with fellow team members (Sherehiy & Karwowski, 2006). Both forms of knowledge are vital for understanding hazards, but tacit knowledge, stemming from practical experience, requires careful validation. For instance, knowledge gained through discussions with colleagues may not always be applicable in specific situations, given that worksite conditions are continually evolving. Additionally, workers may occasionally share incorrect information, leading to inaccurate hazard perceptions or failures in hazard perception. As a result, this study places particular emphasis on construction workers' safety knowledge obtained through experiential learning and safety education.

2.3 System Dynamics

System dynamics (SD) is an approach designed to comprehend the behavior of intricate systems over time. It was originally developed in 1961 by Jay W. Forrester at the Massachusetts Institute of Technology (Forrester, 1997) and has since found widespread applications in analyzing diverse systems, including those in industry, economics, society, and the environment. SD delves into the internal feedback loops and time delays that influence an entire system. It incorporates both negative (balancing) loops, which promote stable system operation, and positive (reinforcing) loops, which perpetuate the system's dynamics (Forrester, 1997).

Given that workers' behaviors are shaped by the complex environment of construction sites and their psychological states, research efforts have been made to represent their comprehension of safety using SD (Cooke, 2003; Jiang et al., 2015; Shin et al., 2014). These studies have primarily concentrated on understanding the cognitive processes underlying workers' unsafe behaviors in hazardous construction settings. By examining workers' cognitive processes through the lens of SD, a deeper understanding of various feedback loop relationships can be gained.

3. Model Development

3.1 Qualitative Mental Process Model

The model aims to comprehend the intricate interactions within the mental processes of workers. In this model, workers use their knowledge of safety to identify hazards, and their perception of risk shapes their intentions, which then influence their actions in a cascading manner. These actions can result in favorable outcomes. Conversely, when workers fail to perceive a hazard, the likelihood of engaging in unsafe behavior increases. The sequences within the critical balancing and reinforcing loops can be summarized as follows.

Unsafe behaviors by workers elevate the risk of accidents or near misses compared to safe behaviors. However, it's important to note that not all instances of unsafe behavior directly lead to accidents. Accidents do not solely originate from unsafe behaviors but often result from a combination of overlapping errors and environmental circumstances.

〈Fig. 1〉 illustrates the concept of habituation in accident avoidance. When a worker engages in unsafe behavior without experiencing an accident as a consequence, their perception of the “Absence of Accidents Resulting from Unsafe Actions” factor increases. This can lead to a negative attitude towards safety. If this pattern continues, workers may learn from their experiences that engaging in unsafe behaviors doesn't necessarily lead to accidents. Consequently, they may develop a negative safety attitude over time (Choudhry & Fang, 2008; Geller, 2016). In such cases, even though workers may still recognize hazards, they may not be motivated to act safely due to their past experiences. This behavior can persist over time through the reinforcing loop R1 and ultimately contribute to construction accidents by causing a shift in workers' safety attitudes from positive to negative.

As workers accumulate safety knowledge from past accidents, the “Likelihood of Recognizing Hazards” factor also increases (Loop B1). This heightened awareness enables workers to recognize hazards, form intentions for safe actions, and translate those intentions into safe behaviors, ultimately reducing the likelihood of accidents.

Table 1. Structure verification tests for the proposed model

Test	Methods	Model Structures
Structure verification	Comparing the structure of the model with the actual system or generalized knowledge in the literature (Senge & Forrester, 1980)	• The cognitive processes of workers leading to unsafe behavior are well-established and supported by numerous research findings. (Eagly & Chaiken, 1993; Fang et al., 2016; Jiang et al., 2015; Mearns & Flin, 1995; Shin et al., 2014). • Established theories such as Ajzen's theory of planned behavior serve as the foundational concepts underpinning the causal loops in the model. • Construction accident scenarios are aligned with the cognitive processes modeled in the study.
Direct extreme condition	Evaluating the validity of model equations under extreme conditions (Senge & Forrester, 1980)	• In the absence of hazard perception, workers would not form intentions for safety behaviors, resulting in a heightened occurrence of unsafe behaviors. This, in turn, increases the risk of construction accidents, considering their safety knowledge. • In the absence of a failure in hazard perception, workers' attitudes toward safety have a direct influence on unsafe behaviors.

Nevertheless, if accidents do not occur, workers' working memory fades over time following a forgetting curve. Consequently, this loop acts as a stabilizing mechanism.

Within the “Lack of Hazard Recognition” loop (B2), when workers begin their tasks without recognizing potential hazards, it leads to a lack of hazard perception. This failure to identify hazards is typically associated with subsequent unsafe behaviors. It's worth noting that this issue is not limited to new workers; even experienced workers may fail to perceive hazards, especially when they are under cognitive strain, such as stress, limitations, excessive workload, or adverse weather conditions. Additionally, construction sites are dynamic environments, and engaging in work without hazard detection can result in unsafe behavior, posing risks even when workers are following their usual routines. Hence, in this study, the model emphasizes that the failure of hazard perception increases the likelihood of unsafe behavior among workers.

Loop B3 explains the changes in workers' attitudes following accidents. When accidents occur, workers naturally desire safety and become more cautious to protect themselves (Shin et al., 2014). This heightened sense of caution fosters a positive attitude towards safety among workers. Furthermore, accidents serve as valuable sources of safety-related information for workers, whether they have experienced the accidents personally or learned from the experiences of their colleagues. This exposure to accident-related information increases the probability that hazards will be recognized.

3.2. Model Verification

This study aimed to comprehend the cognitive processes associated with unsafe behaviors through the utilization of a System Dynamics (SD) model. However, because the proposed SD model represents an individual's cognitive processes, it presents challenges in terms of verification through experimental observations and statistical analysis. In future research, the plan involves the collection of actual accident records and the use of computational tools like Vensim software, which could provide a more comprehensive understanding of workers' cognitive processes in hazardous situations. The study employed structural verification tests based on the framework proposed by Forrester and Senge (1980) for qualitative analysis. As outlined in Table 1, structural verification and direct extreme condition tests were conducted on the model structures (Choi et al., 2017; Senge & Forrester, 1980; Sterman, 2002).

Furthermore, a scenario-based verification method, as suggested by Park et al. (2009), was employed to ensure that the model aligns with the study's objectives. This method involved a qualitative examination of whether actual cases corresponded to the SD model. To carry out this validation, thirty summaries of fatality and catastrophe investigations from the Occupational Safety and Health Agency were utilized (Goetsch, 2017; Korea Ministry of Employment and Labor, 2022). These cases were categorized into types such as falls, electrocutions, collisions, and cutting incidents. After summarizing the accident processes in each case, they were applied to the model, and their compatibility with the modeled workers' cognitive processes was confirmed.

4. Model Discussion and Managerial Implications

4.1. Discussion of the worker cognitive process model

The model's behavior in relation to workers' cognitive processes demonstrates that when factors contributing to unsafe behaviors are minimized, there is a reduction in the short-term rate of construction accidents. This aligns with previous research highlighting the crucial role of construction supervisors and managers in mitigating unsafe behaviors and emphasizes the intervention effect of these supervisors and managers. However, in the long term, if supervisors solely focus on preventing workers' unsafe behaviors, this intervention effect may unintentionally lead to a decline in safety knowledge and attitudes, potentially resulting in the resurgence of unsafe behaviors. In essence, while short-term intervention is critical, it may, over time, contribute to unsafe worker behavior in the long run.

Furthermore, even if workers maintain a positive safety attitude, the absence of safety knowledge can lead to short-term unsafe behaviors. Nonetheless, the acquisition of both tacit and explicit safety knowledge through a series of construction accidents, including near-misses, can strengthen workers' hazard perceptions. This explains why novice workers, despite harboring positive safety attitudes, still experience construction accidents, including near-misses.

As novice workers accumulate experience and acquire safety knowledge, they become more skilled at identifying hazards, thereby reducing the likelihood of accidents. However, the absence of accident experiences over time can impact their intentions regarding safety behaviors, ultimately contributing to negative safety attitudes. These negative attitudes can result in unsafe behaviors directly associated with accidents and create an environment characterized by poor team safety on construction sites.

Additionally, the SD model illustrates that the failure of hazard perception can directly lead to unsafe behavior. Through scenario-based verification, it was confirmed that workers occasionally experience accidents or near-misses without recognizing the hazards present, partly due to the challenging working conditions on construction sites, such as heat, noise, and darkness. Construction work also varies from day to day, and new workers are often assigned diverse responsibilities, leading to cognitive overload. While previous studies have explored cognitive processes based on the theory of planned behavior, there is limited consensus on unplanned behavior in situations where workers fail to perceive hazards. Therefore, further research focusing on unplanned behaviors related to the failure of hazard perception is warranted.

4.2. Unintended Consequences of Safety Management

While the SD model employs four strategies to address workers' unsafe behaviors, it's crucial to consider potential side effects. Focusing solely on environment-based safety management can initially reduce the likelihood of accidents. However, in the long term, this approach may lead to adverse consequences, such as a rapid decline in workers' safety attitudes. Additionally, due to a lack of safety knowledge, workers may struggle to identify unsafe situations, as depicted in the model. Moreover, safety knowledge may experience temporary declines, as illustrated by the concept of a forgetting curve. Environment-based safety management undeniably plays a pivotal role in accident prevention. Nonetheless, some construction site managers might overly rely on these strategies to mitigate unsafe conditions. It's imperative to recognize that an excessive dependence on biased safety management approaches can potentially result in severe accidents. Therefore, safety managers should exercise discretion and implement managerial strategies judiciously and in a balanced manner.

4.3. Limitations

The model investigated in this study comes with certain limitations. One notable restriction is its incapacity to comprehensively address specific management methods or delve into various cognitive aspects of workers, including cognitive load, subjective norms, and habituation. Furthermore, the model overlooks individual variations, failing to consider that hazard perception is influenced by an array of factors, encompassing individual differences, situational context, and organizational factors. These factors can interact in intricate ways, contributing to scenarios where workers fall short in accurately perceiving hazards. Therefore, it is crucial to encompass a broader spectrum of influences on hazard perception to construct a more holistic understanding of this phenomenon. Future research endeavors could explore additional factors contributing to the failure of hazard perception, such as stress, distractions, organizational culture, and task demands. By incorporating these elements, a more nuanced and comprehensive model can be formulated to better elucidate the underlying causes of hazard perception failures in real-world contexts.

On a positive note, this study effectively developed and validated a qualitative System Dynamics model through an extensive literature review and real-world construction accident scenarios provided by the Occupational Safety and Health Agency. The use of qualitative simulation, as demonstrated in this research, facilitates the analysis of system behavior without being reliant on precise numerical values. It can furnish valuable insights even in situations where data is limited or uncertain, thereby aiding decision-makers in comprehending the qualitative outcomes of diverse scenarios. Consequently, this study has proffered management strategies within the framework of the workers' cognitive process model. Nevertheless, it is pertinent to acknowledge that quantitative simulation can furnish a more profound understanding of system behavior and substantiate evidence-based decision-making. Both qualitative and quantitative approaches can be mutually reinforcing and employed in tandem to achieve a comprehensive grasp of complex systems. While the collection of data concerning the cognitive processes of each construction worker presents undeniable challenges, future research endeavors should strive to simulate the model using at least some numerical data, such as accident counts and instances of unsafe behaviors, to augment its robustness and applicability.

5. Conclusion

This study investigates and validates qualitative model to gain insights into the cognitive processes underlying construction workers' unsafe behaviors. This model has provided a comprehensive understanding of the intricate relationships and influences between various factors, including hazard perception, the execution of unsafe behaviors, and managerial implications. This research significantly contributes to the field of cognitive process modeling by specifically considering the failure of hazard perception by workers.

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