A Cognitive Model of Construction Workers’ Unsafe Behaviors
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Abstract: This paper focuses on construction workers’ unsafe behaviors and develops a cognitive model of construction workers’ unsafe behaviors (CM-CWUB). In the construction industry, many accident investigations reveal that workers’ unsafe behaviors are the most frequent and direct causes of on-site accidents, and thus need to be addressed urgently. Based on cognitive and social psychology theories and existing accident causation models, this paper develops a CM-CWUB by adopting a five-stage form, specifically representing the construction workers’ cognitive processes when confronted with potential hazards on construction sites. Using a cognitive perspective can reveal the mechanism of human error and thus can elucidate how unsafe behaviors are produced. The five stages include obtaining information, understanding information, perceiving responses, selecting response, and taking action, with obtaining information and selecting response as the two key stages. Obtaining information elaborates construction workers’ observations and processing of hazard information on sites by themselves, and selecting response adopts the theory of planned behavior to reflect various factors of influence when workers select unsafe behavior. Based on the developed model, cognitive failures that would lead to construction workers’ unsafe behaviors at different cognitive stages are then systematically analyzed. DOI: 10.1061/(ASCE)CO.1943-7862.0001118. © 2016 American Society of Civil Engineers.

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Introduction
Construction work, with its inherently dangerous characteristics such as working in awkward positions and on nonrepetitive tasks (Jeong 1998), is one of the most injury-prone industries worldwide (Kines et al. 2010). In the United States, there were 806 fatal work injuries in the construction industry in 2012, accounting for the highest number (17.41%) of fatal injuries in all sectors, according to news released by the U.S. Bureau of Labor Statistics (2013a). However, construction work employment accounted for only 4% of all employees on nonfarm payrolls at the end of 2012 in the United States (U.S. Bureau of Labor Statistics 2013b). Similar challenges exist in China and other countries in the world. Accident investigations revealed that workers’ unsafe behaviors are the most frequent and direct causes of on-site accidents (Bohm and Harris 2010; Haslam et al. 2005). This study attempts to develop a cognitive model of construction workers’ unsafe behaviors in order to represent and study their cognitive process when confronted with potential hazards. This model can help reveal the mechanism of human error and thus can elucidate how unsafe behaviors are produced.

Unsafe Behaviors: Most Frequent and Direct Causes of On-Site Accidents
In order to reveal causes of on-site accidents, many accident investigations have been conducted since the 1960s. Haslam et al. (2005) examined 100 accidents, 70% of which originated from worker and work team factors and 49% from workers’ unsafe behaviors. Suraji et al. (2001) studied approximately 500 accident reports and found 29.9% were caused by inappropriate operative actions and 88.0% were caused by inappropriate construction operation, both of which includes workers’ unsafe behaviors. Bohm and Harris (2010) analyzed on-site dumper drivers’ accidents in the United Kingdom, and found that most of the accidents were consequences of dumper drivers’ unsafe actions. These investigations clearly indicate that unsafe behavior accounts for the majority of on-site accidents, and should more emphasis should be placed on construction safety management. In addition to these, there are also many accident causation models theoretically highlighting the importance of unsafe behaviors, even though they adopted different perspectives. Heinrich’s famous domino theory proposed that the two most direct causes of accidents are unsafe human behavior and unsafe object condition (Heinrich et al. 1950). This causation chain is also supported by other research (Chua and Goh 2004). Abdelhamid and Everett (2000), from the perspective of workers’ risk perception, pointed out three root causes, namely unsafe conditions, worker response to unsafe conditions, and worker unsafe acts. A model proposed by Suraji et al. (2001) described constraints and responses experienced by all the parties in a construction project. Based on this model, different parties’ inappropriate responses to constraints will increase the risk of accident, and operatives’ factor is the most direct factor in the causation chain. Specifically, unsafe behavior is a key factor in on-site accidents (Hinze 1997; Mitropoulos et al. 2009). If the mechanisms of how unsafe behaviors happen can be understood, then based on this understanding, workers and managers can thus be equipped with specific preparations that will significantly control unsafe behaviors and reduce on-site accidents.
Cognitive Models for Human Error

The human factors analysis and classification system (HFACS), based on the Swiss Cheese human error model, identifies and describes four levels of human causes of an accident (Shappel and Wiegmann 2000). In this framework, unsafe behaviors (i.e., unsafe acts) are classified as the first level of human error. Human error refers to the misjudgment or inappropriate decision in the cognitive process (Chi et al. 2012; Hinze et al. 2005). Systematic studies of human error and its related cognitive reliability began in the 1960s. Reason (1990) suggested that although many different classifications of human error exist, there are three levels at which all classifications are attempted by posing what, where, and why questions about human errors. How questions (also called the conceptual level) explore the mechanism of human error production, and therefore are the deepest level and can reflect the essence and real causes of human error. This cognitive perspective, based on cognitive theories of such as human memory (e.g., Ashcraft 1989), attention (e.g., Barnes et al. 2002), and calling conditions (e.g., Reason 1990), has drawn the attention of researchers in the construction industry. In fact, in psychology, one traditional and effective way of studying a dynamic thinking process is to build a model to describe the parts and how they work together (Flower and Hayes 1981). Examples can be seen in the cognitive models for writing (Flower and Hayes 1981), document classification (Farrows 1991), and second-language reading (Koda 1988).

The generic error modeling system (GEMS) proposed by Reason (1990) is a general cognitive framework to examine human error. It distinguishes three different types of human error: skill-based, rule-based, and knowledge-based errors. To further explain how such errors were originally produced, Rasmussen (1987) developed a stepladder model (SLM), identifying eight general stages in the decision-making process: activation, observation, identification, interpretation, evaluation, goal selection, procedure selection, and activation. In contrast to other cognitive models with paralleling stages, SLM is in the shape of stairs, intuitively illustrating different levels in the cognitive process and possible shortcuts that people tend to take (Reason 1990). Hollands and Wickens (1999) proposed a human general information-processing model to describe the cognitive processes when interacting with the outside environment. This model includes four cognitive stages, namely sensory processing, perception, response selection, and response execution, and three functional modules, namely attention resources, working memory, and long-term memory. It focuses on information processing and elaborates the roles of long-term memory, working memory, and attention resources. In addition to these general cognitive models, there is also research focusing on specific high-risk industries and proposing specific cognitive models to study human reliability. The model of information, decision, and action in crew context (IDAC) is a newly proposed cognitive model to study operation behavior in nuclear plants (Chang and Mosleh 2007a). There are three main blocks in IDAC: information preprocessing (I), diagnosis and decision making activities (D), and action execution processes (A), with I, D, and A representing the cognitive process influenced by factors such as human memory mechanism, external/internal filters, and problem/goal decomposition. Nakayasw et al. (2010) proposed a simple human cognitive reliability model, consisting of perception, cognition, and action processes, to study human errors in driving by using response time to evaluate the performance. Mohan and Duarte (2006) found that the majority of mining accidents in India are due to human error, so they established a cognitive model to better understand workers during mining work. This cognitive model consists of five main stages, namely sense transducer, integration, decision-making, response selection, and response execution, and also considers personal/internal and external influence factors.

All of these mentioned cognitive models contributed a great deal to exploring the root causes or mechanisms of human error production and facilitating targeted management tools from a cognitive perspective. These models mainly focused on errors in high-risk industries such as nuclear plants and aviation. Studies related to these industries have developed into the stage of cognitive science theories (i.e., cognitive systems engineering perspective) according to the paradigms of safety research identified by Rasmussen (1997). Different from these industries, the construction industry, despite its record of a considerable number of accidents, still insists on safety practices on the basis of normative and prescriptive theories, which puts emphasis on the design of safety regulations, incentives, and punishment, and elimination of error-prone individuals but overlooks cognitive factors (Mitropoulos et al. 2009). This condition in safety management research partly lies in the fact that the characteristics of the construction industry are very different from the aviation or nuclear industry. High-risk industries contain relatively well-defined work procedures (Mitropoulos et al. 2009). However, because of highly varied and loosely defined work processes, construction workers to a large extent do not have to follow strict operation instructions, so they have the freedom to organize their work and deal with problems. Hence, in order to improve safety management in the construction industry, it is necessary to consider construction work’s characteristics and make adaptations to these working conditions when introducing cognitive science theories into this industry.

Current Studies of Construction Workers’ Unsafe Behaviors

Based on large literature review of current studies on construction workers’ unsafe behaviors, three major research directions in this field can be distinguished: safety climate/culture research, behavior-based safety research, and cognition-related safety research. The former two account for a large portion of current construction safety related research, and contribute a great deal to this field. However, their disadvantages have been argued by different scholars (Choudhry et al. 2009; Cooper et al. 1994; Edelson et al. 2009; Lingard and Rowlinson 1998). For safety climate/culture research, one problem is the controversial terms of safety climate and safety culture. Because of this, different scholars developed different questionnaires to measure safety climate/culture using different sets of factors, and found different reasons for unsafe behaviors, which cannot be generalized to all contexts. Another problem lies in that safety climate/culture only focuses on the organization level but ignores the individual level. On the other hand, behavior-based safety research focuses on the individual level and attempts to improve workers’ behavior by designed goals and feedback (Austin et al. 1996; Laitinen and Ruohomäki 1996). However, after behavior interventions, safety performance dropped to normal levels (DeJoy 2005). Behavior-based safety research does not explain why interventions are effective or not effective, and also does not clarify why workers behave unsafely.

The importance of applying cognitive theories to current safety research has drawn the attention of researchers in the construction industry. Some studies have attempted to introduce cognitive theories into studying construction safety, and identified some cognition-related causes of on-site unsafe behaviors. Cognition-related
safety research can to some extent overcome the problems of safety climate/culture and behavior-based safety research because cognitive theories can explain not only individual’s behaviors but also their impact factors from the outside environment. Kines (2003) conducted semistructured interviews with construction workers injured due to falls from heights. His study aimed at understanding the relationship between workers’ cognition and behavior. Organization of the interviews was based on an accident causation model proposed by Surry (1969) to address how construction workers process information, make decisions, and carry out actions. However, this study failed to further explore workers’ cognition and understand why the accidents happened. Hinze (1997) focused on explaining why workers fail to notice on-site hazards, and proposed the theory of distraction. He argued that workers’ attention is limited; if they endure high production pressure, most of their attention will be focused on how to finish tasks instead of guaranteeing personal safety. Lombardi et al. (2009) and Edelson et al. (2009) studied why workers choose unsafe behaviors when they already knew the hazards. They believed worker individuals’ risk assessment, contextual factors, and social factors will influence their decision making. Bohm and Harris (2010) argued that risk assessment (a key stage in workers’ decision-making process) could be recognized as a part of the cognitive process, and they investigated dumper drivers’ objective perception of some unsafe behaviors. At a higher level, some studies pointed out the vital importance of leaders’ daily verbal safety communication with workers (Kines et al. 2010), and the company’s effective safety performance incentives (Hinze 2002). Construction workers often feel cared about when managers are committed to these factors, which, from a cognitive perspective, promotes workers’ safety awareness to a large extent. The influence of teamwork on individual worker’s safety awareness is also explained using cognitive theory (Mitropoulos and Memarian 2012). Though all the reviewed studies prove the feasibility of applying cognitive theories when studying safety issues in the construction industry, for example, considering workers’ cognitive process and teamwork process, the methodology of these studies is still not systematic and they only adopt some points of cognitive theories. These studies thus cannot systematically explain what factors lead to unsafe behaviors, and thus fail to systematically propose what measures can control unsafe behaviors.

Additionally, many other studies, which did not adopt the view of cognition, focused on exploring causes that lead to specific on-site accidents, such as Chi et al. (2009), who analyzed 255 electrical fatalities and found that most fatalities can be attributed to three unsafe behaviors; Lipscomb et al. (2008) analyzed falls from height and found apprentice carpenters commonly do not use fall-protection facilities; Lombardi et al. (2009) examined eye trauma on construction sites and found three factors determine whether or not workers wear safety goggles; Arboleda and Abraham (2004) focused on accidents in trenching operations and discussed unsafe behaviors that would lead to accidents. After qualitative and quantitative analysis, the results of these studies provided many causes of unsafe behaviors. Though they successfully explored causes that lead to specific accidents, these studies did not uncover the root cognitive causes of unsafe behaviors, thus leading to difficulty in understanding how these unsafe behaviors happened and how to effectively control the causes.

**Research Aims**

The models in the literature review provide a good foundation for building a worker-centric cognitive model. However, as neither of them focuses on construction workers they are not adequate to reflect construction workers’ cognitive processes. Considering the limitations of the previous studies, this study attempts to establish a systematic explanation of the mechanism of on-site unsafe behaviors by developing a cognitive model of construction workers’ unsafe behaviors (CM-CWUB). This CM-CWUB will be based on these reviewed models, which can guarantee rationality in theory; moreover, it will largely reflect the characteristics of construction work, which can make the model rational in practice. Based on CM-CWUB, the causes of cognitive failures that lead to unsafe behaviors will be further analyzed.

**CM-CWUB Development**

This section focuses on the theoretical development of CM-CWUB. The aim of this model is to represent construction workers’ cognitive process when confronted with potential hazards. Workers are at the front line and engaged in basic production work on construction sites. As Anderson (2010) pointed out from personal experience in the construction industry, there is little possibility that safety-related regulations and instructions can cover all the procedures in which workers are involved. Workers have to deal with many potential hazards (in these situations, they have no time to think a response over carefully or consult coworkers or forepersons) all by themselves, without the aid of appropriate regulations and instructions.

In the reviewed models (Table 1), there are some common stages, such as obtaining information (both from external environment and from memory), understanding and processing information, selecting which response should be carried out, and taking action. However, the characteristics of construction work should be also considered when building the structure of the model. Compared with other high-risk industries, working conditions for construction workers are loosely defined, and their work processes are too varied to be covered by specific rules. Therefore, when confronted with hazards, workers highly rely on their own observation and experience. Hence, (1) workers’ observations are mostly reflected in the first stage, obtaining information and thus, this stage

<table>
<thead>
<tr>
<th>Common stages</th>
<th>Cognitive models</th>
<th>Human information processing model</th>
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<tbody>
<tr>
<td>Obtaining information</td>
<td>Activation</td>
<td>Information preprocessing</td>
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<td>Observation</td>
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<td>Identification</td>
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<td>Understanding information</td>
<td>Interpretation</td>
<td>Diagnosis and decision-making activities</td>
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<td>Evaluation</td>
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<td>Selecting response</td>
<td>Goal selection</td>
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<td>Procedure selection</td>
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<tr>
<td>Taking action</td>
<td>Activation</td>
<td>Action execution processes</td>
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should be a key stage in the model; and (2) since young workers without much experience might not know safety options between the stages of understanding information and selecting response, another stage, perceiving responses, should be added between them. According to Reason (1990), errors and violations originate from different cognitive causes. One kind of error is due to lack of knowledge, which means workers do not know how to respond safely; while a violation means workers know how to respond safely but they deliberately choose an unsafe response. Therefore, adding the stage of perceiving responses is necessary. Moreover, in contrast to other high-risk industries, such as nuclear power, the hazards in the construction industry are relatively obvious and easy to be discovered. Workers can recognize hazard information through their eyes or ears rather than facilities, such as reading boards. Therefore, compared with obtaining information, perceiving responses, and selecting response, the stages of understanding and processing hazard information are not the key.

Based on the preceding analysis, the CM-CWUB should consist of five stages: (1) obtaining information, (2) understanding information, (3) perceiving responses, (4) selecting response, and (5) taking action. The following parts of this section will describe the basic elements, their functions, and other aspects of these stages respectively.

Obtaining Information

Obtaining information is the first stage in the CM-CWUB. This stage represents workers’ searching and detecting of potential hazards in the outside environment, with the help of their own experience, but limited by some constraints. Only the successfully obtained information can be further processed in the following stages. As follows, basic information processing elements are included in the CM-CWUB.

Working Memory and Long-Term Memory

Working memory (hereinafter referred to as WM) is the mental workspace to store and process information (Reason 1990). Both storage and processing share and compete for the WM capacity (Rafaeli et al. 2012; Rasmussen 1990). In the CM-CWUB, WM is where workers’ cognitive processes mostly happen. WM organizes all the incoming information, releases unnecessary information, and submits the processing result to the next cognitive stage. In addition to WM, there are other types of memories, such as intermediate memory and knowledge base (Ashcraft 1989). The CM-CWUB adopts the concept of long-term memory (LM) to represent all long-period memory repositories except WM, such as intermediate memory and knowledge base (Posner 1989; Reason 1988). Workers’ LM stores all the relevant experience and knowledge that have been previously obtained.

Attention Resources

Attention, as a cognitive resource allocated to cognitive activities, is not infinite (Salvendy 2012), which is the reason for why dual tasks are very likely to cause a decrease in task performance (Vancouver and Tischner 2004). Additionally, attention is difficult to maintain, due to its requirement of physical and mental effort (Barnes et al. 2002; Kirwan 1994). People tend not to exhaust their energy, which means cognition is less likely to be rational (Bruner and Austin 1986). Both the two features of cognition, bounded rationality and relucance in rationality, indicate that workers cannot be absolutely rational and thus it is impossible to eliminate cognitive failures completely.

External Filter and Internal Filter

Information can be detected intentionally and nonintentionally. The process of obtaining information is to some extent a process of filtering (Reason 1990). The cognitive process adopts a two-step mechanism to guarantee the quantity and quality of information entering WM. The first step is the external filter, which functions before information being perceived by sense organs (Chang and Mosleh 2007a). Typical external filters include noise and view obstruction (Salv endy 2012). After passing through the external filter, if the information is obtained intentionally, it will go straight into WM to be processed; if it is obtained nonintentionally, it has to pass through a second filter, the internal filter. Typical internal filters include selective attention, limited information processing capability, low information importance, etc. After passing through the internal filter, information obtained nonintentionally will finally enter WM.

Calling Conditions

WM has no direct access to information stored in LM; however, WM can retrieve information by manipulating calling conditions or evoking stimulus (Baars and Gage 2010; Reason 1990). The basic mechanisms for retrieving are similarity-matching and frequency-gambling (Reason 1990), which are consistent with other notions (the representativeness and availability heuristics) provided by Tversky and Kahneman (1974). Similarity-matching means that the experience or knowledge that matches well with calling conditions will be easily activated. Frequency-gambling controls how much of this information enters WM. More-frequently-used experience or knowledge will eventually enter WM and assist to current cognitive processes.

Start Modes of Obtaining Information

Information in workers’ cognition can be obtained from both inside and outside. Workers first obtained information of potential hazards from the outside environment, and during information processing, workers retrieved information from LM. Thus, obtaining information starts from gathering information from the outside environment. Specifically, the start can be classified into two modes: intentional search and nonintentional search. Similar classifications can be found in Kontogiannis (1997), Thompson et al. (1997), and Smidts et al. (1997). In intentional search, information from the outside environment enters WM through the external filter; while in the latter mode, it enters through both external and internal filters.

Intentional search starts when workers realize potential hazards and keep an active mind for searching for hazards and watching the environment. The environment is complicated, and workers need the direction of situation models to conduct targeted searching. A situation model (i.e., mental model) is an understanding of current special circumstance and can help individuals make predictions of the beginning and evolution of circumstances. For example, experienced workers often know where the hazards are and how to find them, while inexperienced workers usually have no idea of what to look for.

Understanding Information

After WM has obtained the relevant information, the process of cognition will move to the second stage of understanding information. In this stage, workers form a certain cognitive response in WM, which can translate hazard information into problems or goals (Chang and Mosleh 2007b). Workers estimate the hazards and understand its characteristics. For example, if a worker discovers an opening without protection, by understanding this information, the worker will realize that the opening is dangerous and should be avoided.
Sometimes, due to the complexity of the problem, WM continuously decomposes it into subproblems (Bruner and Austin 1986), until the subproblems become basic enough to be solved immediately (Chang and Mosleh 2007b).

**Perceiving Responses**

In this stage, WM will focus on solving the problem resulted in the previous stage. If the problem cannot be solved and is detected as complex, a selected strategy will be assigned to it, which decides how to decompose the problem further. The selection of strategies is largely influenced by personal experience (Chang and Mosleh 2007b). The two stages of understanding information and perceiving responses are a cyclical process. The process of cognition will not go to the next stage until some potential responses are proposed to solve the problem.

**Selecting a Response**

After WM has worked out one or more responses to the problem after the first three stages, a certain response will be selected in the fourth stage (if there is only one response, the stage will be skipped). Selection is based on the evaluation of which response best satisfies the workers’ current motivation. Motivation, having roots in psychology, behavior, cognition, and society, is the inner driver for the people to behave in a particular way; therefore, it can be interpreted as a physiological cause of a certain behavior. There are basically two types of motivations upon which the selection can be made: safety-only motivation or comprehensive motivations.

**Selecting Response in Safety-Only Motivation**

When the cognitive process advances to the selecting a response stage, workers have perceived the potential hazard and have started to solve the problem; otherwise, the cognitive process has already ended in failure. Once the potential hazard has been perceived, workers’ safety motivation is activated. The best response is the one that can best satisfy this safety motivation.

**Selecting a Response in Comprehensive Motivations**

In reality, workers have other motivations in addition to safety, such as motivations for high work speed and for good relationships with coworkers, which are very common on construction sites. The theory of planned behavior (TPB) illustrated in Fig. 1 with reference to Ajzen (1991), describes how people select from such different motivations under conscious control, and this theory is adopted to explain how to select a response in comprehensive motivations. Details will be discussed in the next section.

**Taking Action**

Taking action is the end of the entire cognitive process. The result of the cognitive process, a response, is carried out at this stage. Taking action includes signal transmission and physical expression, which is beyond the focus of this study and will not be discussed further.

Based on the above theoretical development, the whole CM-CWUB is demonstrated in Fig. 2, with the left-hand blocks representing the five stages and the flow chart illustrating the processes. According to the classification of accident causation model by Lehto and Salvendy (1991), CM-CWUB concerns human error and unsafe behaviors, and thus describes the root cause of workers’ error (Arboleda and Abraham 2004).

**Mechanism of Workers’ Unsafe Behaviors**

In order to fundamentally prevent accidents from happening, the mechanism of unsafe behaviors should be understood. This section focuses on the analysis of the mechanism of on-site unsafe behaviors, based on the CM-CWUB proposed earlier, stage-by-stage, respectively.

The assumption of the analysis is that a failure at any cognitive stage would lead to an unsafe behavior. Cognitive failure can be defined, according to Simpson et al. (2005), as “cognitive-based errors on simple tasks that a person should normally be able to complete without fault.” In the context of construction work, when confronted with potential hazards, a worker should normally be able to take safe behaviors to avoid accidents or near misses. However, if a cognitive failure happens at any stage, workers will not be able to achieve or will deviate from the goal of guaranteeing safety.

Because construction work does not require the same rigorous and long-term thinking as nuclear plants and aviation operations, construction workers have no chance to correct their errors in subsequent stages. Consequently, they fail to achieve safe behaviors, which possibly result in bad outcomes (i.e., accidents and near misses).

**Cognitive Failure in Obtaining Information**

There are two distinct start modes of obtaining information, i.e., intentional searching and nonintentional searching.

**Intentional Searching**

In this start mode, the whole cognitive process starts from an idea of searching the external environment. Then, as mentioned before, workers need the direction of situation models to conduct a targeted searching. Situation models have a direct relationship with workers’ on-site experience. If workers are familiar with their surroundings, they are more likely to recognize potential hazards.

Information obtained by intentional search, before entering WM, should pass through the external filter, which means that the information must be perceived by sense organs. On-site workers perceive hazard information mainly through sight and hearing. Therefore, hazard information not passing through the external filter are probably due to visual or acoustic obstruction, such as hidden hazards because of site disorganization, loud on-site noise that prevents workers from noticing the hazard, hazards being small, and large blind spots resulting from bad design in some equipment. Hinze and Teizer (2011) pointed out that most visibility-related fatalities are associated with the use of equipment, especially when equipment is operating in a reverse direction. In addition, from the subjective perspective, limitations in workers’ sense organs also lead to the failure of the intentional search, such as the physical difficulty of staying alert due to fatigue, and certain hazards.
(e.g., structural damages of carrying tools) not being detected by the naked eye.

As the process of intentional search, WM continuously produces calling conditions that automatically and unconsciously retrieve related knowledge stored in LM, in order to support the analysis of hazard information. If, based on similarity-matching and frequency-gambling, calling conditions cannot retrieve appropriate information from LM to support the analysis of hazard information,
the cognitive process might fail. These two automatic retrieval mechanisms are regarded as the root of many errors (Reason 1990), for example, workers’ lack of related knowledge and low frequency in using of the knowledge. In addition to retrieving knowledge from LM, workers can also obtain information through exploring the external environment. However, the intentional search needs more attention resources to support it; therefore, the cognitive process tend to use retrieving instead of exploring, in order to remit the burden on attention resources (Reason 1990). For example, Hinze and Teizer (2011) mentioned that reversing alarm is very effective at the early beginning of the project; however, once reversing alarm becomes routine and is perceived as annoyance, it is no longer effective, and workers are lazy to analyze the situation when the alarm sounds.

**Nonintentional Searching**

Nonintentional searching for information may be happening every second. In contrast with direct and reliable intentional searching, nonintentional searching is inefficient because there is no search target. Therefore, adopting this start mode has the potential to lead to cognitive failures. However, nonintentional searching requires fewer attention resources than intentional searching, which can be regarded as an advantage.

The information obtained by nonintentional searching should pass through both filters before entering WM. Besides being perceived by sense organs, the information should also not be blocked by the internal filter. The internal filter largely originates from the limitation on the capability of cognitive processes, such as the limited span of WM, limited attention resources, and low relevance to the current cognitive process. Inadequate attention resources can be attributed to distraction (e.g., a truck driver was listening to a two-way radio and didn’t pay attention to the steering wheel and the road (Hinze and Teizer 2011)) or lack of alertness resulting from fatigue and sleep deprivation.

Like intentional searching, nonintentional searching also has a corresponding retrieval process, and therefore the same potential of failure may exist.

**Cognitive Failure in Understanding Information and Perceiving Responses**

The task of these two stages is to translate the information into a problem, decompose it into subproblems, and adopt strategies for them until the subproblems are basic enough to be solved immediately. The problems with which workers are confronted on construction sites are not as complicated as those in a nuclear plant or aircraft operations. Workers only need simple judgments and actions, instead of complex analysis and operation, to solve these problems.

The process of such two stages is a cycle of iteration, so a failure at one stage is related to the other stage. Lack of knowledge or experience related to decomposition or adoption leads to both cognitive failures in these two stages.

**Cognitive Failure in Selecting a Response**

As mentioned in the previous section, driven by safety motivation, workers will select the response that best guarantees safety. Then the single mission of selecting a response is to find out which one can best satisfy safety motivation. However, this is only an ideal situation. As a matter of fact, workers are usually under high production pressure and need to coordinate with others, and thus motivations other than safety motivation influence the cognitive process. Under such circumstance, safety is not always regarded as a priority over such production and social concerns.

Many researchers have found that even if workers realized a hazard situation and were aware of the potential dangerous consequences by the selected response, they still chose unsafe behaviors. Reason (1990) pointed out that such deliberate unsafe behaviors were mainly associated with a motivation of violation (James and Michael 1998). He proposed that three factors could lead to violation: attitudes, subjective norms, and perceived behavioral control. These three factors originated from TPB, which comprehensively takes into consideration individual and nonindividual factors and can explain why violations happens (Fogarty and Shaw 2010). TPB can predict behavior and explain the determinants of certain behavior.

**Cognitive Failure in Attitude towards the Behavior**

Attitude towards behavior (AB) refers to “the degree to which a person has a favorable or unfavorable evaluation or appraisal of the behavior in question, and to which this person is influenced by behavioral beliefs” (Ajzen 1991). It is assumed that a person might hold many beliefs (perceived outcomes or attributes) concerning a certain behavior, and the attitude toward the behavior is an overall evaluation of all the beliefs. Zohar and Erev (2007) pointed out that the negative outcomes of unsafe behaviors are often underestimated; in contrast, for some positive outcomes, the “frequent and immediate” benefits, such as faster work pace and greater personal comfort, are given higher weights. Based on the analysis of Zohar and Erev (2007), Table 2 lists these beliefs of safe and unsafe behaviors. If workers hold a positive attitude toward unsafe behaviors such as those behaviors being faster and more comfortable than safe ones, they tend to adopt unsafe behaviors.

Additionally, due to bounded rationality, individuals are inclined to focus narrowly on specific aspects of the task, therefore leading to underestimation of other aspects (Hofmann and Stetzer 1996).

### Table 2. Attitudes toward Safe and Unsafe Behaviors

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<thead>
<tr>
<th>Beliefs</th>
<th>Unsafe behaviors</th>
<th>Safe behaviors</th>
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<tbody>
<tr>
<td>Safety-related beliefs</td>
<td>Unsafe behaviors are with low-probability dangers</td>
<td>Safe behaviors cannot guarantee safety, e.g., PPE itself leads to accidents</td>
</tr>
<tr>
<td>Personal-comfort-related beliefs</td>
<td>Not wearing PPE is much more comfortable for workers (Bohm and Harris 2010)</td>
<td>Wearing PPE and following safety regulations are very uncomfortable, such as safety garment’s bad wearability (Hinze and Teizer 2011), seatbelt’s poor design (Bohm and Harris 2010), and inconvenience when following regulations (Shin et al. 2014)</td>
</tr>
<tr>
<td>Work pace-related beliefs</td>
<td>Unsafe behaviors would increase work pace and workers would get productivity bonus (Kines et al. 2010; Choudhry and Fang 2008)</td>
<td>It is time consuming to wear hearing protective devices (Edelson et al. 2009), gloves (Choudhry and Fang 2008), to wait for appropriate equipment (Lipscomb et al. 2008)</td>
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Note: PPE = personal protective equipment.
For example, if workers have high pressure to be on schedule, they will focus more on work pace than safety.

**Cognitive Failure in Subjective Norms**
Subject norms (SN) are the second determinant of intention, referring to the likelihood those important referent individuals or groups approve or disapprove of performing a given behavior (Ajzen 1991). The important individuals in workers’ daily work lives are managers and coworkers (Zhang and Fang 2013). If workers expect that managers and coworkers support a certain behavior, they will be inclined to select it.

Managers. All levels of management, including high-level managers (such as clients, project managers, and general engineers), safety managers, safety supervisors, foremen, and even journeymen, direct and arrange workers’ production. Much research has confirmed that managers’ on-site behavior, attitude toward safety as well as their safety performance incentives have a great influence on workers’ safety.

While directing and supervising workers’ production, managers’ behaviors set standards for workers. Some carpenter apprentices said the journeymen who worked with them usually did not follow the safety practices learned from training courses; the journeymen even urged workers to do risky task (Lipscomb et al. 2008). In addition to behavior, managers’ attitudes toward safety issues also impact workers. This emphasis on safety can be achieved by several means, such as safety-related oral communication and safety performance incentives. Kines et al. (2010) argued that more safety-related oral communication between forepersons and workers does not affect production; instead, it significantly promotes workers’ safety. Safety performance incentives can also reflect leaders’ focus on safety issues. Common monetary incentives with high value are not always effective. Hinze (2002) suggested that good incentives do not have to be a massive undertaking, but should convey the belief that workers’ safe behaviors deserve to be recognized. Only if managers take safety issues seriously can a good safety climate be established on a construction site, so that everyone cares more about their own and others’ safety.

Coworkers. Safety-related knowledge is spread tactically by informal and oral means on a construction site. For example, workers’ work practices are passed down from more experienced workers. Though these practices are surely not adequate enough as training (Chi et al. 2009), varied procedures in the construction industry have made it very difficult for training to cover all aspects of training (Chi et al. 2009), varied procedures in the construction industry have made it very difficult to train workers on their own observations and experiences to identify hazards. Therefore, the first stage contains two different modes (intentional and nonintentional search) in order to fully reflect their searching processes and potential failures behind each process. In addition to independent observations, workers also have to make quick decisions to deal with hazards by their own. Influenced by production pressures, coordination with coworkers, managers’ attitudes, and other factors, the response that workers select may not ideally be the safest one. Hence, the fourth stage applies TPB and elaborates these factors of influence and explores potential failures due to them. The main benefit of developing such model from a cognitive perspective lies in that it can help further understand the causal mechanisms of unsafe behaviors, and help develop targeted management suggestions to effectively reduce unsafe behaviors.

**Cognitive Failure in Perceived Behavioral Control**
Perceived behavioral control (PBC) refers to the perception toward the ease or difficulty of conducting a certain behavior (Ajzen 1991); in other words, it represents the level of confidence in achieving a certain behavior. PBC not only includes volitional control, but also reflects the actual control over factors such as time, money, and other peoples’ cooperation (Ajzen 1991). Therefore, workers’ PBC consists of the assessment of external and internal factors. On one hand, workers may overestimate their ability to handle the potential hazard, which results in the selection of unsafe behaviors; on the other hand, workers may feel an inappropriate external environment, such as under an extremely tight schedule and lack of access to safety protection equipment, thus also leading to the selection of unsafe behaviors.

**Concluding Remarks**
Based on cognitive and social psychology theories, combined with existing accident causation models, this paper developed a five-stage CM-CWUB in order to describe construction workers’ cognitive processes when confronted with potential hazards on construction sites, as presented by Fig. 2. Different cognitive failures of each stage were then studied by the developed CM-CWUB. Compared with other cognitive models, on the basis of an adequate consideration of characteristics of the construction industry, CM-CWUB emphasizes and elaborates the first stage of obtaining information and the fourth stage of selecting response. Construction work is loosely defined and regulated, so workers highly rely on their own observations and experiences to identify hazards. Therefore, the first stage contains two different modes (intentional and nonintentional search) in order to fully reflect their searching processes and potential failures behind each process. In addition to independent observations, workers also have to make quick decisions to deal with hazards by their own. Influenced by production pressures, coordination with coworkers, managers’ attitudes, and other factors, the response that workers select may not ideally be the safest one. Hence, the fourth stage applies TPB and elaborates these factors of influence and explores potential failures due to them. The main benefit of developing such model from a cognitive perspective lies in that it can help further understand the causal mechanisms of unsafe behaviors, and help develop targeted management suggestions to effectively reduce unsafe behaviors.

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**References**


