Master of Science in Engineering

Cognitive Process Model for Construction Safety Management using System Dynamics

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Cognitive Process Model for Construction Safety Management using System Dynamics

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Abstract

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Finding the causes of unsafe behaviors by construction workers is important for preventing construction accidents; 80 percent of such accidents occur because of workers' unsafe behaviors. Therefore, this research aims to investigate possible reasons for workers' unsafe behaviors based on their cognitive process models using system dynamics. This study is based on two related cognitive processes: hazard perception and failure of hazard perception. Based on previous research, this study develops causal loops to explain workers' cognitive processes: habituation by staying out of accidents, safety learning by experience, failure of hazard perception, and attitude changes by accidents. The interactions between the loops developed provide managerial insights for safety managers aiming to reduce workers' unsafe behaviors. Safety managers should increase workers' hazard perception through safety education and maintain workers' positive safety attitudes. Additionally, safety managers should direct first-line supervisors to eliminate workers' unsafe behaviors directly. This research allows us to better understand the causes of and solutions for ending workers' unsafe behaviors from a cognitive perspective.

Keywords: System Dynamics, Cognitive Process, Human Behavior, Accidents, Construction Management

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Chapter 1. Introduction

This chapter deals with the current safety management problems in the construction industry and the needs for this research. To solve the problems, research objectives are established. Then, research process to attain the objectives effectively are addressed.

1.1 Research Background and Objectives

Construction sites remain one of the most dangerous workplaces over recent decades in many countries, including the United States, Korea, and China (Mearns et al. 1995; Mitropoulos et al. 2005; Choudhry et al. 2007; Lee et al. 2011; Chi et al. 2012; Kim et al. 2013; Shin et al. 2014; Jiang et al. 2014; Fang et al. 2016). In Korea, for example, 1,810 workers lost their lives in work-related accidents; 27.2% (493 person) of them were working in the construction industry (Korea Ministry of Employment and Labor 2015) as shown in fig 1.2. In the United State, 20.5% of all fatalities in private industry occurred in the construction industry in 2014 (United States Department of Labor 2014). Despite various efforts to reduce such accidents, construction accidents are a continuing threat to workers' safety (Tixier et al. 2014).

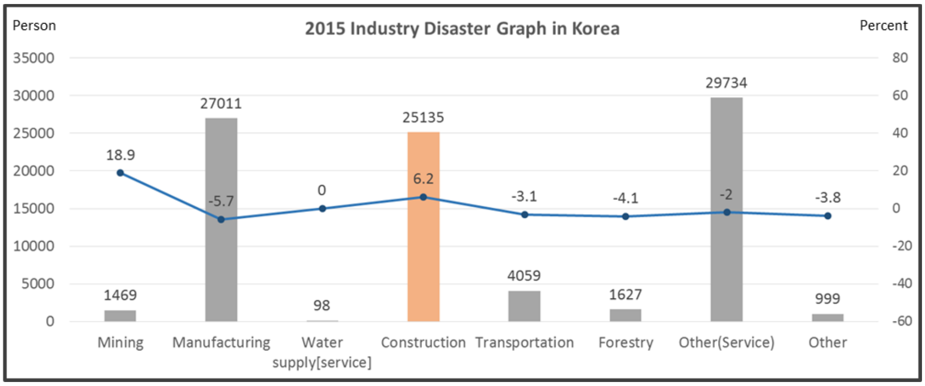


Figure 1.1 Industry Disaster Graph in 2015 at Korea

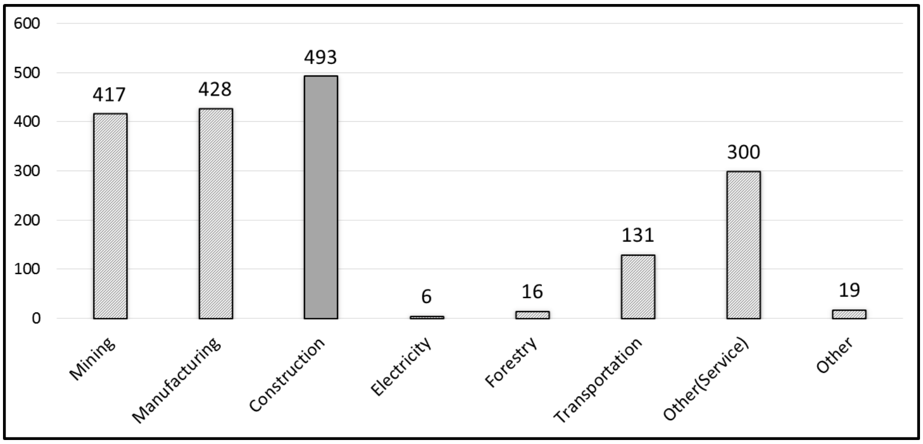


Figure 1.2 Industry Mortality Accident Graph in 2015 at Korea

Previous research has emphasized that workers' unsafe behaviors and unsafe conditions are major root causes of construction accidents (Heinrich 1959; Svenson 2001; Chi et al. 2012; Shin et al. 2014). An unsafe condition is a hazardous physical condition or situation that can directly lead to accidents. For example, providing inadequate guards or protection for, or defective tools to, workers can trigger unsafe conditions at construction sites (Heinrich 1980; Langford et al. 2000; Abdelhamid et al. 2000; Chi et al. 2012). Unsafe behaviors are defined as inappropriate actions in a potentially dangerous situation, such as violations of safety procedures or the removal of personal protective equipment (Mitropoulos et al. 2005).

Unsafe conditions can be discovered visually by workers and managers, allowing them to easily eliminate potential hazards at construction sites (Gould et al. 2009; Shin et al. 2014). However, the sources of unsafe behaviors at construction sites remain ambiguous, because workers' unsafe behaviors are transient and depend on individuals' cognitive processes (Donald et al. 1996). Unsafe behavior by workers accounts for 88% of construction accidents. Thus, understanding the reasons for performing unsafe behaviors is significant (Heinrich 1980; Abdelhamid et al. 2000).

The execution of unsafe behaviors by construction workers can be categorized by whether the worker is aware of a potentially dangerous situation that can induce accidents. Construction sites have many potential hazards owing to their complex nature, and workers are susceptible to working without awareness of all hazards (Lee et al. 2011; Tixier et al. 2014; Namian et al. 2016). Significant research effort has focused on workers' intended behaviors with regard to hazard perception. However, these researches may not fully reflect the dangerous circumstances of unsafe behaviors because accidents can be caused not only by safety violations, but also by poor hazard perception (Tixier et al. 2014; Namian et al. 2016). This study, therefore, includes workers' unintentional unsafe behaviors.

In addition, workers' cognitive processes have various feedback effects (Shin et al. 2014; Jiang et al. 2014). For example, accidents are often caused by workers' unsafe behaviors, and the results of accidents influence workers' behaviors through their cognitive processes. Furthermore, applying safety management strategies to workers' cognitive processes could induce side effects because workers might get biased attitude from the situation which did not occur accidents. For these reasons, system dynamics modeling is an appropriate methodology for understanding feedback effects.

This study attempts to develop a cognitive process model for workers using the concept of hazard perception, and proposes effective management strategies that can reduce workers' unsafe behaviors. The scope of this study focuses on workers' knowledge and attitude because workers' safety-related experience and knowledge is one of the main sources for hazard perception and decision-making (Namian et al. 2016).

1.2 Research Process and Assumptions

The research aims to develop workers' cognitive process model toward safety issues at construction sites, and find out causes of workers' unsafe behaviors in presented model. Finally, this study suggests managerial implications.

The research process is as follows.

(1) To develop worker's cognitive process, this research reviews previous researches: safety management, unsafe behavior, hazard cognitive model, and hazard identification.

(2) Factors regarding the cognitive model are extracted based on the literature reviews, and causal links are established.

(3) After modeling through System dynamics approach, the research analyze the effects of controllable factors, and suggests managerial implications. The research process can be illustrated as Figure 1.3.

Since this study focused on workers' cognitive (mental) process, workers' individual statues such as age, characteristic, health conditions and so on are assumed same. Furthermore, it is assumed that there are only two types of behaviors which workers' can conduct; safe behaviors and unsafe behaviors.

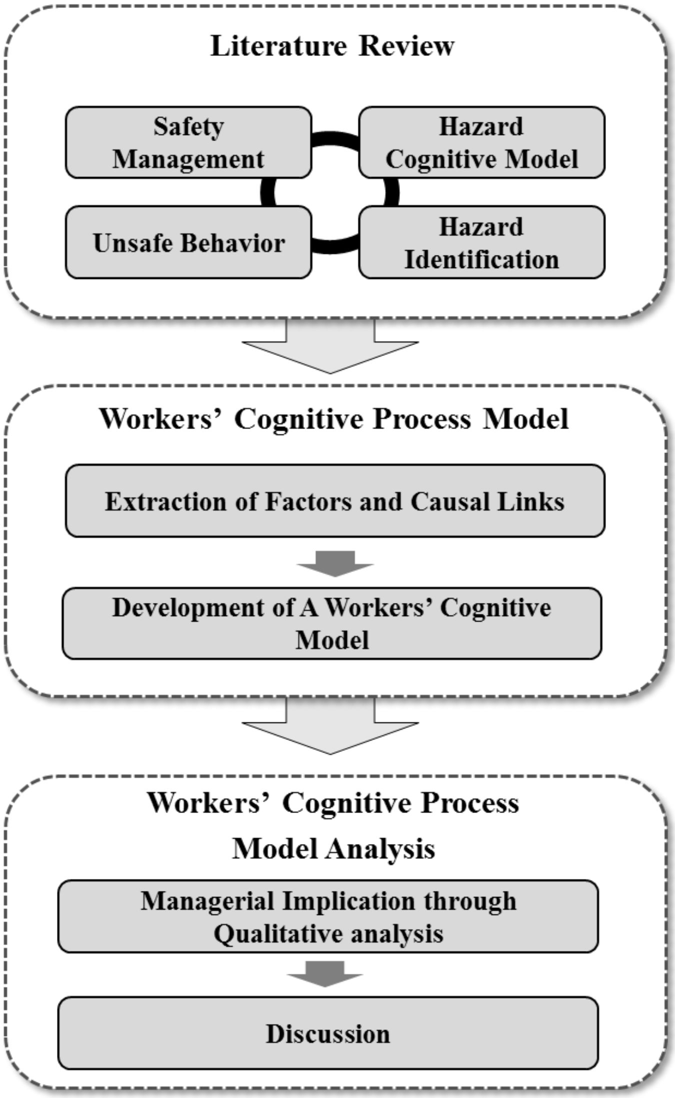


Figure 1.3 Research Process

Chapter 2. Preliminary Study

This chapter reviews previous researches and cognitive process models to extract factors from them and causal links which are meaningful for explaining how workers make decisions.

2.1 Different Perspectives on Workers' Safety Management

Workers' behaviors are influenced by safety management strategies; hence, it is necessary to understand different perspectives on safety management tactics. As shown in Fig. 2.1, safety management strategies have changed in recent decades and significant efforts have been made to elucidate the root causes of accidents (Gordon et al. 1996; Goetsch 2009; Tam et al. 2011; Health and Safety Executive 2015).

Previous study has focused on unsafe conditions at construction sites from a hardware perspective (Goetsch 2009). Some mechanical equipment employed in construction sites prior to the modern era, such as fall protection devices and personal protective equipment, were not effective in preventing accidents (Donald et al. 1996). Thus, these devices have been increasingly improved by environment-based management (Chi et al. 2012). For instance, some past construction sites used natural materials, such as bamboo without protective devices, for fall protection, which have since been replaced by special scaffolding (Lingard et al. 1994; Chung et al. 2002). Consequently, environment-based management is a basic management method for eliminating accidents.

After the hardware era came the employee era. During this period, the causes of accidents were considered to be human errors rather than environmental failures (Gordon et al. 1996). This argument has been supported as technological capabilities have continued to improve, and accordingly, accidents related to failures of technology have gradually decreased, while those related to human error have increased. Thus, the blame and responsibility for accidents was attributed to individuals (Gordon et al. 1996). The third era is that of organizations, which explains that accidents are not caused by human or environmental errors, but by organizational influence (Zohar 1980; Langford et al. 2000).

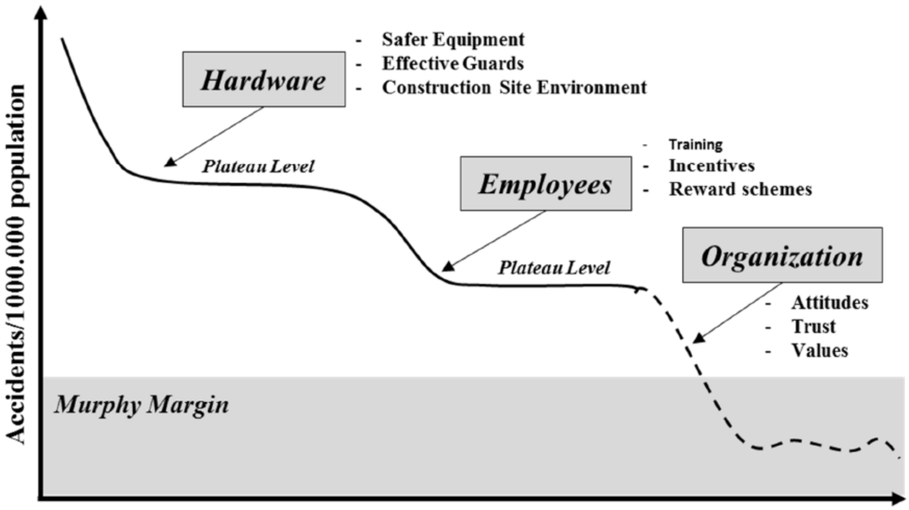


Figure 2.1 Studies of Long-term Safety Development

2.2 Unsafe Behaviors

Prior studies on unsafe behaviors can be classified as behavior-based, culture and climate-related, and cognitive-related safety management studies (Fang et al. 2016). Behavior-based studies aim to introduce various management measures, such as incentives, education, and training, which can be helpful in reducing workers' unsafe behaviors (Reber et al. 1990; Choudhry et al. 2007). However, such methodologies do not adequately explain the effectiveness of management measures for controlling unsafe behaviors (Fang et al. 2016). Culture-related studies, which adopt the perspective of a safety culture or climate, neither reflect the status of individuals nor establish exact concepts of safety culture (Dejoy 2005). Furthermore, there has been disagreement among scholars upon the definition of safety culture (Mearns et al. 1995; Choudhry et al. 2007).

As an alternative, to help overcome the limitation of behavior-based and culture-related studies, the cognitive-based approach is used to investigate into how humans process information (Miller 2003). Specifically, cognitive-based study can provide clearer explanations of how organizations influence individuals and vice versa, in the niche between the microscopic approaches, which addresses the behaviors of individual workers, and a macroscopic methodology, investigating overall organizational culture, as shown in Fig. 2.2 (Dejoy 2005; Fang et al. 2016).

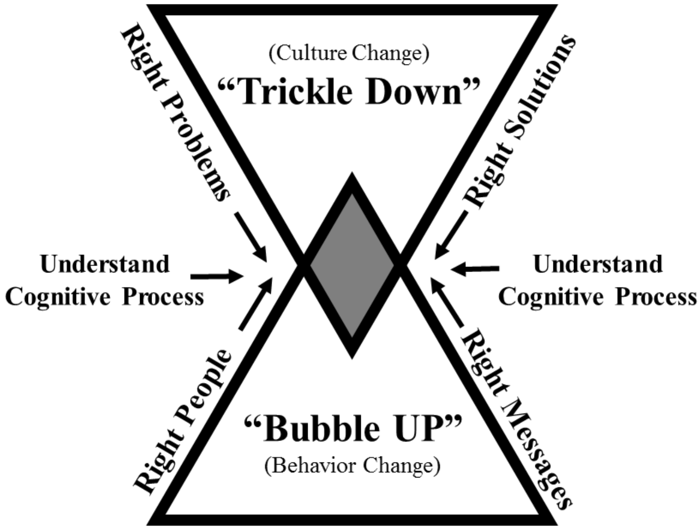


Figure 2.2 Approaches to Reduce Workers' Unsafe Behaviors

(Modified from Dejoy 2005)

2.3 Previous Cognitive Process Models

Cognitive processes refer to psychological processes, such as interpreting and perceiving the surrounding environment. Thus, workers' hazard cognitive processes are the process of interpreting insecure elements at construction sites.

The cognitive process for workers' safety at construction sites can be divided into four stages as shown in fig. 2.3. Workers obtain site information through their sensory organs, perceive hazards, make decisions regarding subsequent actions based on these perceived hazards, and act in accord with their decision (Shin et al. 2014; Jiang et al. 2014; Fang et al. 2016).

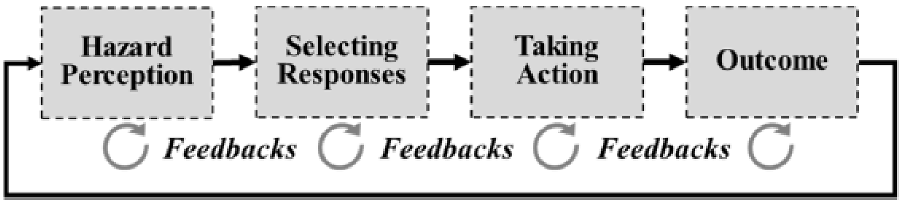


Figure 2.3 Workers′ Cognitive Processes (with perception)

Shin et al. (2014) have developed a model that includes workers' perceptions and attitudes toward hazards, including feedback processes concerning workers' habituation and the occurrence of accidents. However, this model cannot fully reflect the influence of safety management on individual perception. It is also limited by its inability to reflect failures of hazard perception. Fang et al. (2016) explain a decision-making flow for an unsafe behavior from a cognitive perspective. The authors describe the types of errors that can be made in workers' cognitive processes by combining a variety of social science theories. The limitation of this work is that it cannot explain feedback effects between management and individual workers. Jiang et al. (2014) represent the interactions between individual, environmental, and management condition. However, they do not consider individual differences and failures of hazard perception in dangerous situations. Previous studies' overall cognitive process are presented as such shown in fig. 2.4

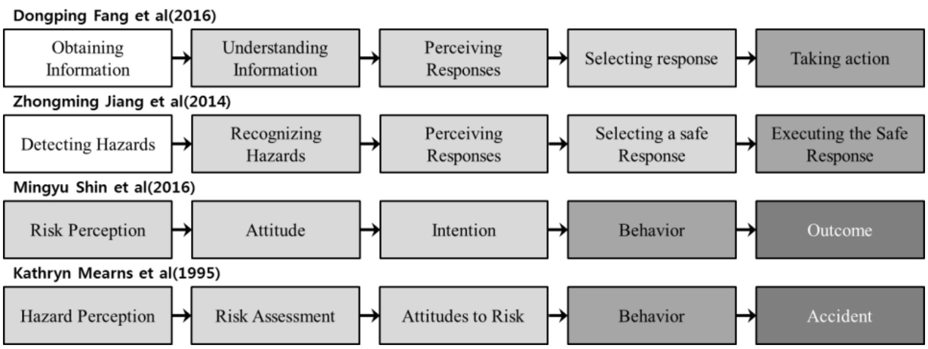


Figure 2.4 Previous Workers' Cognitive Process

Previous cognitive studies concerning unsafe behaviors do not fully consider failures in workers' hazard perception in dangerous situation. Workers' misperception of hazards occurs occasionally (Haslam et al. 2005; Namian et al. 2016); the misunderstanding of construction site hazards and cognitive overload caused concurrently by the construction environment have been demonstrated in studies. Per Chi et al.'s work, 32.1% (Table 2.1)of all construction accidents in the United States between 2002 and 2011 were related to the misjudgment of hazardous situations or a failure in hazard perception, confirming that failures of hazard perception have a large effect on unsafe behavior (Choudhry et al. 2008; Chi et al. 2012).

Table 2.1 Accident Statistics related to Perception Error.

Items	Contents
Risk Factor	Worker Behaviors
Category	Judgment or Perception
Observation	Misjudgment of hazardous situation or distracting action by others
Frequency	3,008
Percent (%)	32.1
Fatality (%)	35.2
Hospitalized (%)	53.6
Non-hospitalized (%)	11.2

2.4 Hazard Identification

Construction sites are a dynamic work environment (Lee et al. 2011). Workers must complete their assigned daily tasks at job sites that change from moment to moment (Lee et al. 2011). Furthermore, each construction project's characteristics are different, causing novel, unexpected situations each day (Lee et al. 2011). For these reasons, precise hazard recognition is a significant and fundamental requirement for preventing accidents and workers' unsafe behaviors (Carter et al. 2006).

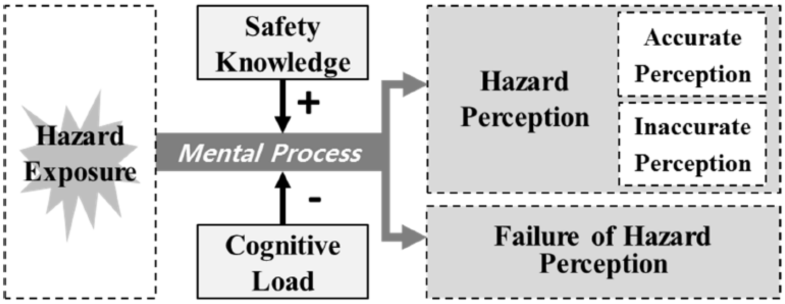


Figure 2.5 Workers' Hazard Perception Process

As shown in Fig. 2.5, when workers are exposed to hazardous situations, there are two possible reactions: hazard perception and failure of hazard perception. Hazard perception can be further divided into accurate and inaccurate perception (Namian et al. 2016). Even when workers are accurately aware of a hazard, they may not properly defend against risks because their behaviors depend on intentions in their cognitive processes.

Meanwhile, proper safety controls are sometimes connected to accidents. Moreover, improper safety controls may not lead to accidents, because accidents occur when multiple errors occur (Reason 1990) as shown in fig 2.6 according to the Swiss Cheeses Theory.

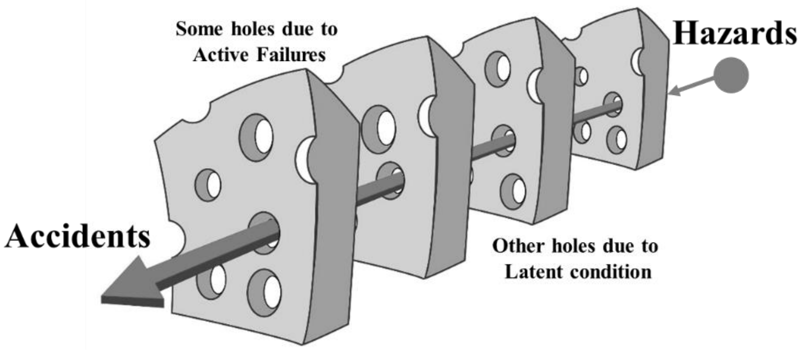


Figure 2.6 Swiss Cheeses Theory (Modified from Reason 1990)

Therefore, if other workers fail to control hazardous situation, accidents that affect other workers may occur. A more detailed explanation of this process is provided in the model development section of this paper. Similarly, when workers fail to recognize a hazard, there is insufficient time in which to prepare for risks, which can also result in accidents (Namian et al. 2016). Thus, it is important for workers to know how to perceive hazards.

Workers generally use their knowledge and experience to perceive hazard, in which case accurate information leads to the correct judgment toward hazards (Carter et al. 2006). Knowledge can be divided into explicit and tacit types (Hadikusumo et al. 2004; Hallowell 2011); explicit knowledge is formal information and is easily transferred to workers via safety management training and education (Nonaka 2008; Sherehiy et al. 2006). In contrast, tacit knowledge is commonly generated by a worker's own experience or communication with other workers (Hallowell 2011). Both knowledge types are important for understanding hazards; however, tacit knowledge, such as experience, should be carefully verified (Choudhry et al. 2008). To illustrate, knowledge gained through communication with coworkers is often inapplicable in specific situation because worksite conditions are always different and changing. Moreover, workers occasionally share wrong information, which provokes inaccurate perception and failures of hazard perception (Geller 2016). Therefore, this research focuses on workers' correct safety knowledge gained by experiential learning and safety education.

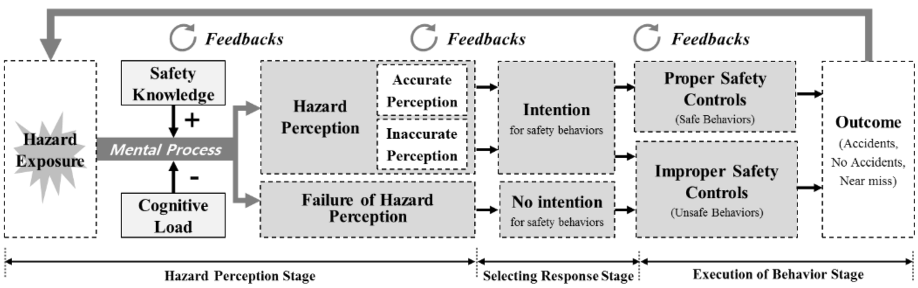


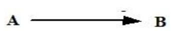
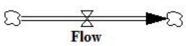
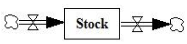
Figure 2.7 Workers' Hazard Perception and Occurrence of Accidents

2.5 System Dynamics

System dynamics (SD) is an approach to understanding the behaviors of complex systems over time. Since it was developed in 1961 by Jay W. Forrester at the Massachusetts Institute of Technology, it has been widely used to analyze industrial, economic, social, and environmental systems. SD deals with internal feedback loops and time delays affecting a whole system. It also maintains the negative (balancing) loop, which causes stable system operation, and the positive (reinforcing) loop, which perpetuates the system (Forrester 1961; Park et al. 2009; Kim et al. 2016). The basic schematic representation of the SD model is shown in Table 2.2 (Sterman, 2000; Park et al., 2009).

Table 2.2 System Dynamics Legends

(Modified from Sterman, 2000; Park et al., 2009)

<table>
<tr><th>Legends</th><th colspan="2">Explanation</th></tr>
<tr><td>
</td><td rowspan="2">when other conditions are the same</td><td>When factor A increases(decreases), factor B increases(decreases)</td></tr>
<tr><td>
</td><td>When factor A increases(decreases), factor B decreases(increases)</td></tr>
<tr><td>
</td><td colspan="2">Define the rate of change in system states and control quantities flowing into and out of stocks</td></tr>
<tr><td>
</td><td colspan="2">Define the state of a system and represent stored quantities</td></tr>
</table>

Since worker behaviors are influenced by the complex environment of the construction site and the worker's psychological condition, previous studies have been conducted to represent their understanding of safety using SD (Cooke 2003; Jiang et al. 2014; Shin et al. 2014). These studies focus on the cognitive processes concerning workers' unsafe behaviors at hazardous construction sites. By studying the workers' cognitive process through an SD approach, the various feedback loop relationships can be more clearly understood.

2.6 Summary

This chapter consists of contends on different perspectives on workers' safety management, previous researches concerning unsafe behaviors, hazard cognitive models, and hazard identification. Through these previous researches, the much reasons of unsafe behaviors were identified, and variety of safety management methods were suggested. Nevertheless, construction accidents occur consistently due to workers' improper acts in hazard situations. One reason is that suggested workers' cognitive processes has been focused on workers' violations. However, it may not fully reflect workers' unintended behaviors which is acts in failure of hazard perception.

Therefore, failure hazard perception should be included in workers' cognitive process to better understand workers' unsafe behaviors. This concept can make us to find not only different perspective's causes of unsafe behaviors but also fundamental management methods.

Chapter 3. Cognitive Process Model Development

This chapter provides definitions for factors. Then, this chapter addresses why system dynamics is effective in explicating the mental process. Also, cognitive process is represented by multiple feedback loops between factors against a complex phenomenon, and each factors consistently give a mutual influence each other. System Dynamic is also used in various fields and a number of researcher use System Dynamic to understand construction workers' safety. Therefore, in this chapter, cognitive process model is developed using System dynamics approach.

3.1 Cognitive Process Model Concept

Each causal process is constructed considering the variables that can affect unsafe behaviors at construction sites, which provide the basis for identifying and managing the causes of workers' unsafe behaviors. The basis of the causal process, based on previous research, is as follows:

1) Hazard Exposure → Hazard Perception → Intended Behaviors → Proper Safety Control → Outcome.

2) Hazard Exposure → Hazard Perception → Intended Behaviors → Improper Safety Control → Outcome.

3) Hazard Exposure → Failure of Hazard Perception → Unintended

Behaviors → Improper Safety Control → Outcome.

Cognitive models focus on 2) and 3), because this model mainly deals with workers' unsafe behaviors. Additionally, model variables were extracted, then were identified based on previous research, to develop workers' cognitive model (Fig. 3.1). Ultimately, workers' cognitive models were developed with the following process: (1) causal process building, (2) extracting and identifying the relationships between the model variables, (3) developing detailed partial models, and (4) summarizing variables and suggesting managerial implications

	Variables and relationships (affects/affected by column to row)							
	HP	FHP	I	UB	NAE	SK	WAS	A
HP			+/			/+		
FHP				+/		/-		
I	/+			-/			/+	
UB		/+	/-		+/			+/
NAE				/+			-/	/-
SK	+/	-/						/+
WAS			+/		/-			/+
A				/+	-/	+/	+/	

Note: HP=Hazard Perception; FHP=Failure of Hazard Perception; I=Intention for Safety Behaviors; UB=Unsafe behaviors; NAE=No Accident Experience with Unsafe Behaviors; SK=Safety Knowledge; WAS=Workers' Attitude toward Safety; A=Accidents

Figure 3.1 Analyses of Variables and Relationships

3.2 Factors Identification

To understand workers' cognitive processes toward unsafe behaviors, this section defines each term and explains their casual relationships.

Hazard exposure represents dangerous situations arising from environmental aspects of construction sites (Mitropoulos et al. 2005; Fang et al. 2016).

Hazard perception is the process by which workers identify hazardous situation based on information obtained about construction sites (Mearns et al. 1995; Fang et al. 2016). If the information is obtained, workers identify hazards with their safety knowledge and working memory (Baddeley 1992; Gerrig et al. 2011; Reason 1990). Human working memory has limited information storage and processing capacity (Fang et al. 2016). Data that exceed working memory capacity remain unprocessed or cause cognitive overload (Sweller 1994).

Safety knowledge can be expressed as the amount of accumulated knowledge necessary for workers to perceive hazards (Jiang et al. 2014). Workers with extensive safety knowledge can perceive information related to unstable conditions more quickly and correctly (Choudhry et al. 2008). Workers' safety knowledge can be increased by learning from past incidents and by safety education provided by managers (Namian et al. 2016). However, a high level of knowledge does not always help workers, because they must sometimes make decisions in dynamic construction workplaces (Mitropoulos et al. 2005). In other words, they cannot acquire enough situational information to use their knowledge and may make mistakes even if they have safety-related knowledge (Rasmussen 1997; Mitropoulos et al. 2005).

Intention means workers' intention to cope with hazards that they have perceived (Shin et al. 2014). In other words, intention is motivation regarding actions. Early behavior theories considered that workers' attitudes always match their actions (Ajzen et al. 1997). However, the theory of planned behavior maintains that intention for action is determined based on a combination of attitude, subjective norms, and perceived behavior control (Reason 1990; Ajzen 1991; Jiang et al. 2014; Fang et al. 2016).

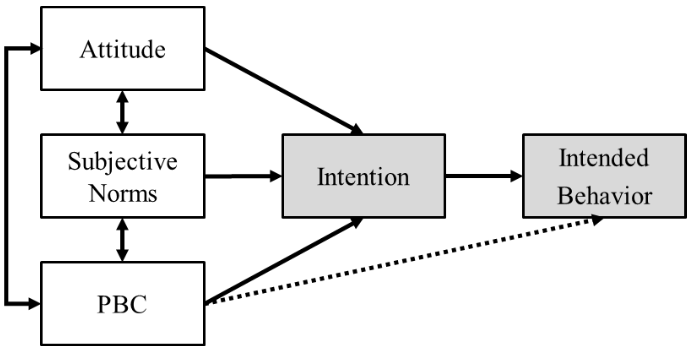


Figure 3.2 Theory of Planned Behavior (Modified from Ajzen 1991)

Attitude is the assessment of beliefs and convictions that individuals uphold for safety behaviors. Factors affecting workers' safety attitudes on construction sites can be divided into three types, as follows (Tixier et al. 2014; Fang et al. 2016): The first type is safety-related beliefs, which hold that attitude can change due to the relationship between a low probability of accidents and unsafe behavior (Fang et al. 2016). The second type is personal-comfort-related beliefs, which relate to the wearability of personal protective equipment (Bohm et al. 2010; Shin et al. 2014). Lastly, operation-pace-related beliefs depend on working speed (Fang et al. 2016). This research focuses on workers' cognitive changes resulting from the occurrence of accidents; thus, workers' cognitive process models reflect only safety-related beliefs.

Subjective norms represent the extent of workers' perceptions towards the opinions of reference group (Ajzen 1991). In addition, perceived behavior control is a circumstantial element of safety behavior. In this study, however, the model was set by defining workers' subjective norms and perceived control as a control variable to model the relationship between workers' attitudes and their behavior.

Intended behavior represents a stage at which workers who perceived hazards and intend to act begin to put such intention into action. Workers whose safety intentions are positive are more likely to engage in safe behaviors; those with negative intentions are more likely to engage in unsafe behaviors (Shin et al. 2014).

Failure of hazard perception arises from workers' inadequate knowledge with respect to hazards and cognitive overhead hindering the processing of hazard-related information (Jiang et al. 2014; Fang et al. 2016; Namian et al. 2016). Workers who do not perceive potential hazards fail to cope with them proactively and are exposed to hazards defenselessly (Namian et al. 2016). Work at construction sites involves less repetition and more intersection with other work, unlike works in other industries. Thus, hazards at construction sites are not only tricky to predict but also manifest rapidly, requiring expeditious judgment by workers. If workers fail to determine hazards beforehand, unintended unstable behavior may result.

Regarding unintended behavior, workers who fail to perceive hazards in the work environment will have no intention to deal with such situations. Usually, construction work is not covered by detailed manuals and is performed in accordance with a modus operandi (method of work) that varies depending on work environment. Failure to perceive hazards in such situations may increase the risk of fatal accidents (Namian et al. 2016). Workers' behaviors lead to accidents, near-misses, or no accidents, and have a feedback effect on organizations and individuals.

3.3 Partial Loops of Cognitive Process Model

3.3.1 Habituation by Staying out of Accidents

In the "Failure of Hazard Perception" loop (B2), workers starting their work without detecting hazardous situations results in the failure to perceive hazards. Failure of hazard recognition normally leads to unsafe behaviors. New workers, who have relatively less safety knowledge, are particularly unaware of hazards. However, failures in hazard identification are not limited to new workers. Even skilled workers may fail to perceive a hazard when under cognitive load (e.g., stress, limitations, excessive workload, and unfavorable weather). Furthermore, construction sites are dynamic work sites. Work performed without hazard detection may constitute unsafe behavior, which is hazardous even when workers exhibit their usual behaviors. Therefore, in this study, the model insists that failure of hazard perception increases the chance of unsafe behavior by workers.

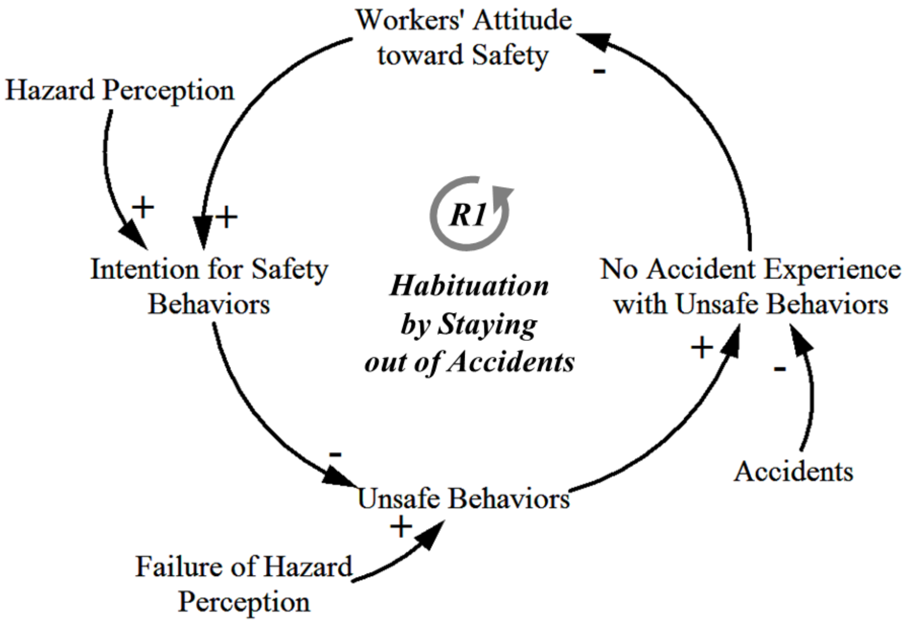


Figure 3.3 Habituation by Staying out of Accidents Loop

3.3.2 Safety Learning by Experience (with perception)

Workers build up safety knowledge through lessons learned from previous accidents. As safety knowledge increases, the "Probability of Hazard Perception" factor also increases. Workers become aware of hazards, intend to act, and put their intention into safe actions. Finally, the probability of accidents decreases. However, if an accident does not occur, workers' working memory diminishes as a forgetting curve. Therefore, this loop acts as a balancing loop.

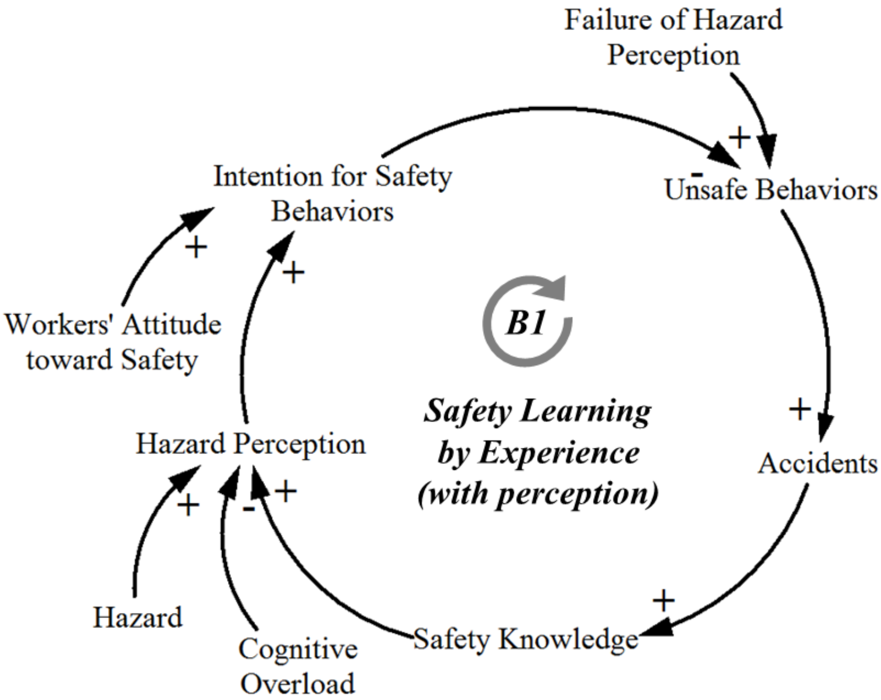


Figure 3.4 Safety Learning by Experience (with perception) Loop

3.3.3 Failure of Hazard Perception

In the "Failure of Hazard Perception" loop (B2), workers starting their work without detecting hazardous situations results in the failure to perceive hazards. Failure of hazard recognition normally leads to unsafe behaviors. New workers, who have relatively less safety knowledge, are particularly unaware of hazards. However, failures in hazard identification are not limited to new workers. Even skilled workers may fail to perceive a hazard when under cognitive load (e.g., stress, limitations, excessive workload, and unfavorable weather). Furthermore, construction sites are dynamic work sites. Work performed without hazard detection may constitute unsafe behavior, which is hazardous even when workers exhibit their usual behaviors. Therefore, in this study, the model insists that failure of hazard perception increases the chance of unsafe behavior by workers.

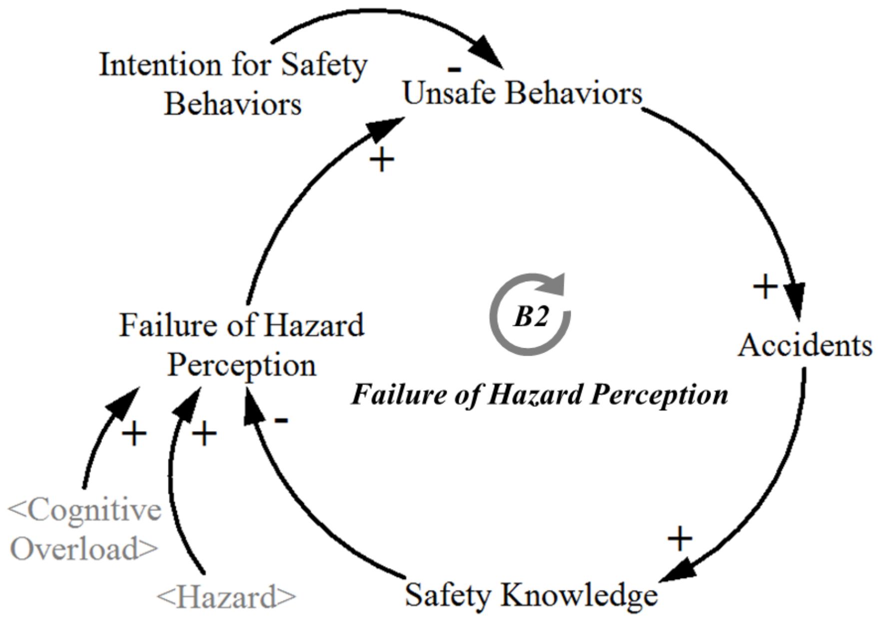


Figure 3.5 Failure of Hazard Perception Loop

3.3.4 Attitude Change by Accidents

Loop B3 explains workers' attitude changes resulting from accidents. Workers feel desirous of safety in the event of accidents and use caution to keep themselves safe (Shin et al. 2014). This inspires a positive attitude in the workers. Moreover, workers will obtain safety-related information directly and indirectly from accidents (as experienced either by themselves or by colleagues), increasing the likelihood that hazards may be perceived.

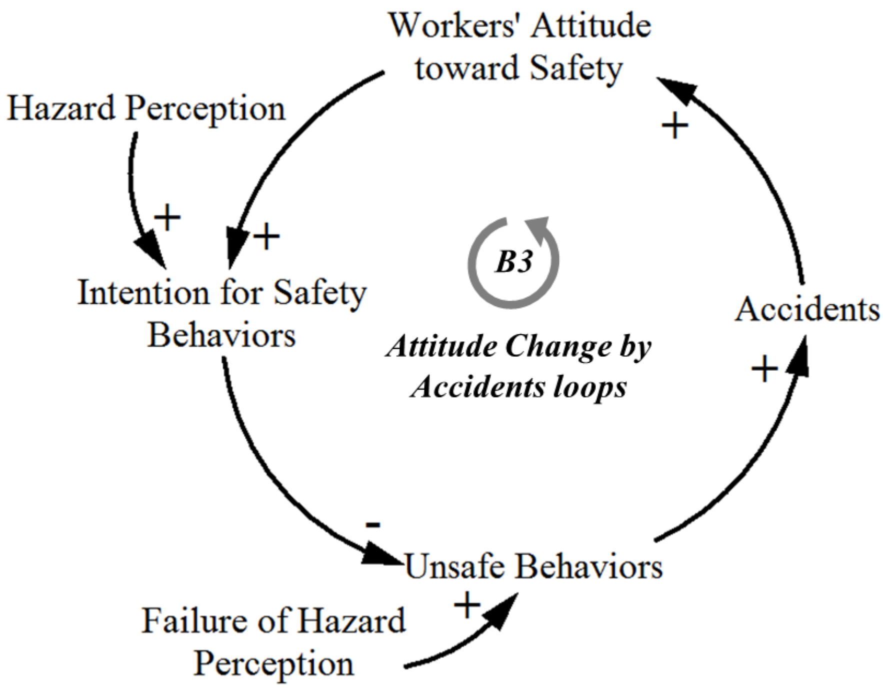


Figure 3.6 Attitude Change by Accidents Loop

3.4 Cognitive Process Model of Unsafe Behaviors

The objective of the workers' cognitive process model is to address multiple relationships associated with workers' mental processes. Workers recognize hazards through their foundation of safety knowledge. Perceived risk affects workers' intentions and results in the execution of behaviors. Workers' behaviors lead to an outcome. In contrast, workers' failure to recognize a hazard raises the probability of unsafe behavior. Based on these concepts, Fig. 3.7 proposes the workers' cognitive process with the five loops.

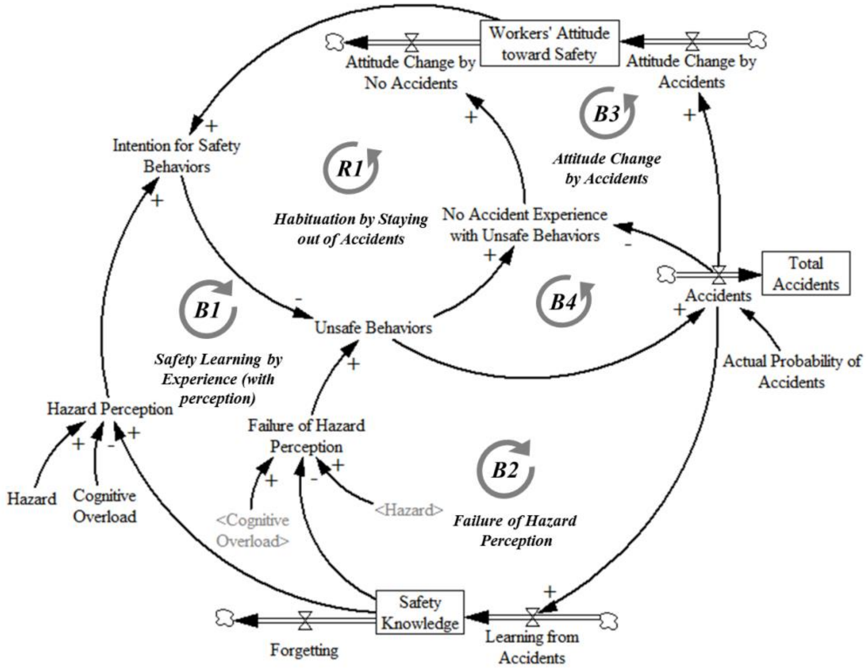


Figure 3.7 a Cognitive Process Model of Unsafe Behaviors

3.5 Cognitive Process Validation

The purpose of this study is to understand the cognitive process of unsafe behaviors by an SD model. However, since the proposed SD model expresses an individual's mental cognitive processes, it could not be verified by applying experimental observation and statistical analysis. Therefore, this study used a scenario-based verification method (Park et al. 2009) to confirm that the model behaves in accordance with the purpose of this study. The scenario validation method qualitatively tests whether actual cases matches the SD model. To verify the SD model, six accident cases were provided by the Korea Occupational Safety and Health Agency. The cases are classified into categories, including falls, conduction, collisions, and cutting. After summarizing the accident process in each case, it was applied to this model and its match with the modeled workers' cognitive processes was confirmed.

3.6 Summary

To develop the System dynamics model regarding workers' cognitive process, factors and causal links are identified based on previous researches. This model explain decision making about workers' acts in hazard situations, and the model consists of four sub-models.

One is habituation by staying out of accident which describe workers' safety attitude change associated with accidents.

Second is safety learning by experience (with perception) which deal with worker's perception and safety knowledge

Third is failure of hazard perception which can explain process about workers' unsafe behaviors due to the perception failure.

Last is attitude change by accidents. This loop elucidate workers attitude change because of the post-accident effect.

Chapter 4. Managerial Implications for Safety of Workers

Based on the model developed in Chapter 3, managerial implications are suggested in this chapter. Prior to suggesting strategies, identifying management strategies is required.

4.1 Safety Management and Worker's Cognition Process

Safety management strategies are important for preventing accidents at construction sites. Construction safety management has been devoted to two areas, as shown in Table 4.1: environment-based and human-based safety management (Shin et al. 2014).

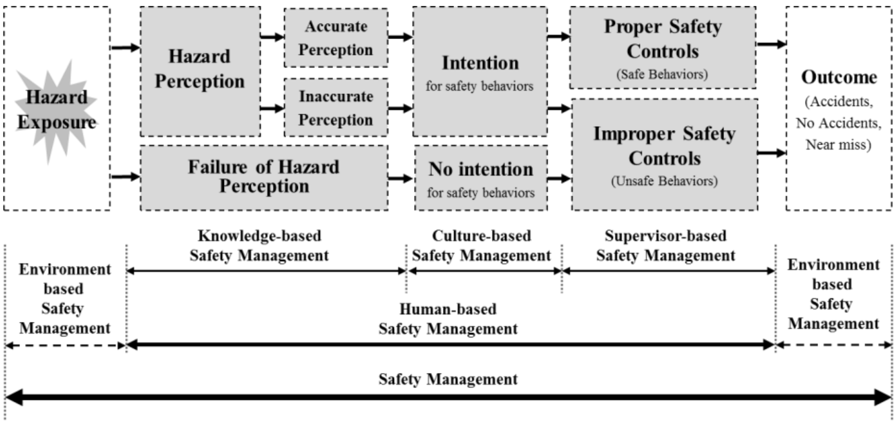


Figure 4.1 Interaction between Cognitive Process and Safety Management

Environment-based safety management (Fig. 4.3, number 1), means controlling the physical conditions of construction sites to preclude accidents. Human-based safety management can be divided into three parts, as shown in Table 4.1. First, supervisor-based safety management (Fig. 4.3, number 2) tends to be performed to prevent unsafe behavior by workers. In construction sites, work is carried out by teams; each team is led by a first-line supervisor, who has the most extensive expertise in a given construction task and takes on roles most likely to rectify workers' unsafe behaviors directly (Simard et al. 1994). This is known as the "intervention effect," and the head of a working group is called the "key person" for safety (Heinrich et al. 1980).

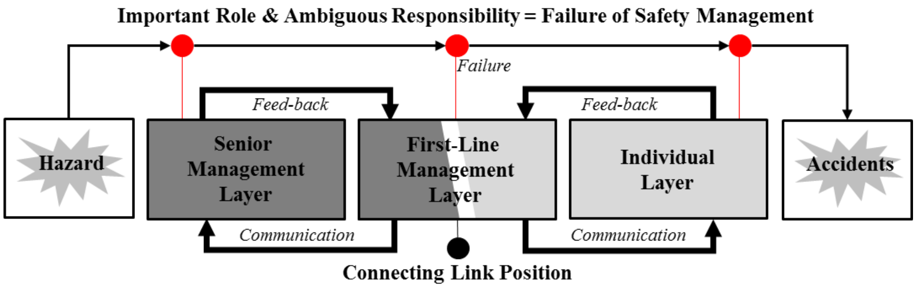


Figure 4.2 Concept of Supervisor-based Safety Management

Culture-based safety management (Fig. 4.3, number 3) has a direct or indirect effect on the level of awareness among workers and promotes positive safety attitudes. Although culture-based safety management does not produce instant results, it has a significant influence on workers' attitudes, so constant management is needed. Finally, knowledge-based safety management Fig. 4.3, number 4) is education and training for workers.

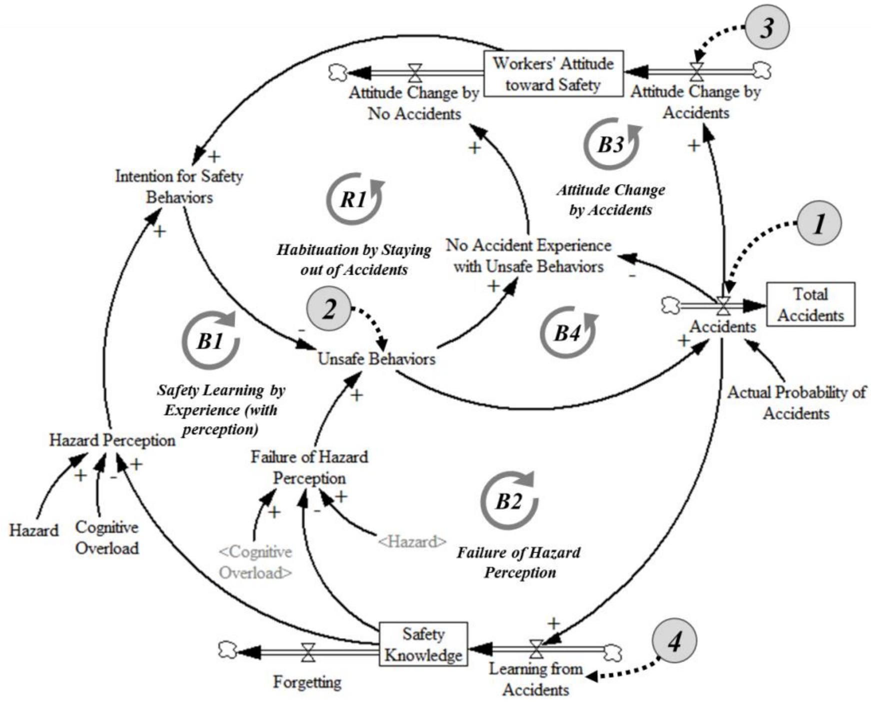


Figure 4.3 Effects of Safety Management

4.2 Effect on Human-based Safety Management

It is difficult for workers to acquire knowledge of safe working methods at construction sites because of the reluctance of workers to transfer their knowledge to others, as knowledge of construction work is their asset. Furthermore, this tacit knowledge is not always accurate. Therefore, it takes a long time for new workers to acquire correct knowledge of safe work procedures and job sites. Moreover, safety knowledge follows the forgetting curve; under these circumstances, workers eventually fail to perceive hazards. Therefore, number 4 in Fig. 4.3 indicates that managers must provide regular safety education that can help prevent workers from failing to perceive hazards.

Although workers accurately notice hazards, they can execute unsafe actions due to a negative attitude toward safety. Thus, culture-based safety management needs to change workers' attitudes from negative to positive.

Meanwhile, workers' unsafe behaviors should be prevented by behavior-based safety management. Thus, a person is needed to take on the role to restrain or prevent workers' unsafe behaviors. First-line supervisors may be best suited to this function, since first-line supervisors who fulfill their role well may help preclude workers' unsafe behaviors. Per Heinrich et al. (1980), this function was the primary reasons that first-line supervisors were compared to key persons.

4.3 Effect on Environment-based Safety Management

Environment-based safety management (Fig. 4.3, number 1) plays an important role in safety. Clearly, environment-based safety management should take precedence over other safety controls. Errors in mechanical equipment at construction sites should be minimized, and anti-fall and anti-slip facilities should be installed properly at places that pose hazards. Such environment-based safety management has not been carried out well at small-scale construction sites or in developing countries. Proper execution of environment-based management leads to a noticeable reduction in accidents (Cooke 2003).

4.4 Application Period of Safety Management Strategies

Although four strategies were applied to the SD model to eliminate workers' unsafe behavior, there can be side effects. As shown in Table 4.1, when safety managers focus only on environment-based safety management (strategy 1), the probability of accidents can be directly reduced. Nevertheless, this method can cause unpleasant results in the long term, because workers' safety attitudes are rapidly made negative. Additionally, workers cannot realize unsafe situations due to lack of safety knowledge, because workers and managers usually learn about construction safety from accidents or minor incidents (Jiang et al. 2014). Furthermore, workers temporarily slip in their safety knowledge, as depicted in a forgetting curve.

Environment-based safety is effective in preventing accidents; however, some construction site managers rely only on environment-based safety management strategies to reduce unsafe conditions. Biased safety management strategies can cause fatal accidents; therefore, safety managers should use this managerial strategy appropriately.

Table 4.1 Causal Relationship by Safety Management

Policy			Causal Relationship
①	Environment based Safety Management		①→ Accidents(↓)
②	Human based Safety Management	Supervisor based Safety Management	② → Unsafe Behaviors(↓) → Accidents(↓)
③		Culture based Safety Management	③ → Safety Attitude Increase(↑) → Intention for Safety Behavior(↑) → Unsafe Behaviors (↓) → Accidents(↓)
④		Knowledge Based Safety Management	④ → Safety Knowledge Increase(↑) → Failure of Hazard Perception(↓) → Unsafe Behavior(↓) → Accidents(↓) ④ → Safety Knowledge Increase(↑) → Hazard Perception(↑) → Intention for Safety Behaviors(↑) → Unsafe Behaviors(↓) → Accidents(↓)

Side Effects due to Management	Side Effects toward Safety Attitude	Side Effect(1): ① → Accidents(↓) → No Accident Experience with Unsafe Behaviors(↑) → Safety Attitude Decrease(↑) → Intention for Safety Behaviors(↓) → Unsafe Behaviors(↑) → Accidents(↑) Side Effect(2): ① → Accidents(↓) → Safety Attitude Increase(↓) → Intention for Safety Behaviors(↓) → Unsafe Behaviors(↑) → Accidents(↑)
	Side Effects toward Hazard Perception	Side Effect(3): ① → Accidents(↓) → Safety Knowledge Increase(↓) → Failure of Hazard Perception(↑) → Unsafe Behaviors(↑) → Accidents(↑) Side Effect(4): ① → Accidents(↓) → Safety Knowledge Increase(↓) → Hazard Perception(↓) → Intention for Safety Behaviors(↓) → Unsafe Behaviors(↓) → Accidents(↑)

4.5 Summary

Based on worker′s cognitive process model, four management factors are applied in this chapter. The four management factors are environment-based safety management, Supervisor-based safety management, knowledge-based safety management, culture-based safety management. These management methods can give positive effects in the model:

(1) Although environment-based safety management can reduce accidents rates immediately compared with other management methods, it can induce workers′ negative attitude toward safety.

(2) Knowledge-based safety management is necessary to reduce workers′ failure of hazard perception.

(3) Supervisors have a lot of chance to prevent workers′ unsafe behaviors directly.

(4) Workers′ attitude management is significant over the long run.

Chapter 5. Conclusions

This chapter deals with the results which are obtained from the worker′s cognitive process and contributions which this study makes.

5.1 Results and Discussions

This study developed an SD model for understanding the causation in construction workers' cognitive processes toward unsafe behavior. This model allows us to better understand the various influences and relationships between factors such as hazard perception, execution of unsafe behaviors, and managerial implications. Specifically, the "Habituation by Staying out of Accidents" loop (R1) shows that unsafe behaviors influence workers' attitudes, which can lead to accidents. The "Safety Learning by Experience (with Perception)" loop (B1) indicates that managing workers' knowledge is important for allowing workers to recognize potential hazards. The "Failure of Hazard Perception" loop (B2) expresses that failures of hazard perception lead directly to unsafe behaviors; even skilled workers may experience failures in hazard perception due to cognitive overload. Lastly, the "Attitude Change by Accidents" loop (B3) present workers' desire for security from accidents.

Based on the qualitative modeling, several managerial implications are proposed, including 1) management should increase the probability of workers' hazard perception through knowledge management; 2) if workers notice danger, management should maintain workers' attitude toward safety; and 3) management should control first-line supervisors, who have the best chance of eliminating unsafe behaviors. Lastly, although environment-based safety is fundamental in accident prevention, it can cause side effects, such as negative attitude and lack of safety knowledge. Therefore, it should be used with other management methods in appropriate situations.

5.2 Contributions

Safety management is highly important parts to achieve successful construction management. However, according to the recent statistics, construction accidents occur frequently in spite of various management methods. This is because safety management method should not be applied in right situations. Therefore, this study emphasize that environment-based management method and human-based safety management should be used in workers′ cognitive status.

On the other hands, in academic aspects, this research maintains that workers′ cognitive process should be included not only workers′ violation with hazard perception but also workers′ unsafety behaviors without hazard perception. Previous construction workers′ cognitive-related study tend to only focus on situation in which risk is recognized, however, workers′ usually could not recognize hazard while working, and it may induce serious accidents. Therefore, this research developed workers′ cognitive process including failure of hazard perception caused by lack of safety knowledge and cognitive load.

5.3 Further Study

This research represents workers′ cognitive process in individual aspects. However, this cognitive model is too broad to reflect specific workers′ conditions such as age, personal characteristic and so on. So, this model cannot express detailed managerial implication. Therefore, further study is required to address more specific cognitive process and detailed management tactics.

Moreover, this study used qualitative analysis techniques to examine managerial implications. However, combination of quantitative and qualitative inquiries plays an important role in research logic. Thus, considerations of additional methodologies such as expert survey and policy analysis reflecting accidents statistics are needed.

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Abstract Korean (국문 초록)

시스템 다이내믹스를 활용한 건설 안전 관리를 위한 인지과정모델

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건설재해의 직접적인 원인은 작업자의 불안전한 행동과 작업장의 불안전한 상태로 분류할 수 있다. 그러나 작업자의 불안전한 행동의 원인은 불안전한 상태에 비해 상대적으로 발견이 어렵다.

왜냐하면 불안전한 행동은 개인의 인지(정신)과정을 거쳐 순식간에 발생하기 때문이다. 따라서 본 연구의 목적은 작업자 인지과정모델을 통해 불안전한 행동의 원인을 밝히고 그 관리방안을 밝히는 것이다. 또한 작업자의 인지과정모델을 개발하기 위해 피드백 관계를 규명하기에 알맞은 시스템 다이내믹스 방법론을 사용하였다.

개발된 인지과정모델은 5개의 피드백 루프로 구성되어 있다. 각 루프에 대하여 요약하면, 무 재해에 의한 습관화 루프(R1)는 작업자의 불안

전한 태도를 설명한다. 안전경험습득 루프(B1)는 재해를 통한 작업자의 안전지식 수준의 변화를 설명한다. 위험 인식 실패 루프(B2)는 작업자의 위험 인식 실패과정에 대하여 설명한다. 안전 지식수준이 낮은 신입 작업자가 겪기 쉬우나 숙련 작업자도 인지 과부하가 걸리게 되면 인식실패를 할 수 있다. 태도변화 루프(B3)는 건설 재해로부터 작업자들의 안전에 대한 태도 변화를 설명한다,

통합된 모델은 작업자가 위험을 인식하지 못하는 상황 자체의 위험성에 대하여 강조하였으며 작업자가 위험을 인식 하였더라도 인지부하로 인해 불안전한 행동을 할 수 있음을 나타냈다. 또한 불안전한 행동이 바로 사고로 이어지지 않는다는 습관은 작업자의 안전에 대한 부정적 태도인 태도로 이어진다는 점에 대해서도 규명하였다.

또한 작업자의 불안전한 행동의 가능성을 줄이기 위해 안전관리방안을 분류하여 정리하고 모델에 적용하였다. 정성적인 SD모델링 분석을 기반을 통해 4개의 관리적 방안이 제시되었다.

1) 관리 레벨은 작업자의 위험 인식을 안전교육을 통해 상승시켜야 한다.

2) 만약 작업자가 위험 인식률이 상승하게 되면 안전관리자는 작업자의 안전에 대해 태도관리를 관리해야 한다.

3) 안전관리자는 일선 관리자가 작업자의 불안전한 행동을 직접 개

선할 수 있도록 유도해야 한다.

4) 현장 환경 안전관리를 하더라도 하나에 편향된 안전관리는 작업자의 부정적인 안전태도나 얕은 안전지식을 부작용으로 불러일으킬 수 있다. 따라서 모든 안전 관리 방안은 적절한 시기에 올바른 방식으로 사용되어야 한다.

앞서 서술 되었듯 작업자의 인지상태는 다양한 원인과 함께 시간에 따라 변화하고 이는 불안전한 행동을 유발하기도 한다. 본 연구에서는 작업자가 위험을 인식하지 못하는 그 상황 자체의 위험성에 대하여 강조하였으며 작업자가 위험을 인식 하였더라도 불안전한 행동을 할 수 있음을 나타냈다. 또한 불안전한 행동이 바로 사고로 이어지지 않는다는 습관은 작업자의 안전에 대한 부정적 태도인 태도로 이어진다는 점에 대해서도 규명하였다.

이러한 분석은 건설현장의 안전관리자가 작업자의 인지상태를 관리하는데 도움이 될 것이다.

주요어: 시스템 다이내믹스, 인지과정, 불안전한 행동, 재해, 건설관리

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