Master of Science in Engineering

Mental Process Model for Human-based Safety Management in Construction Industry

by

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Abstract

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Safety management parts can be classified into Environment-based Safety Management (ESM) and Human-based Safety Management (HSM). To attain a desired safety level, improving both parts is required. The current safety management, however, is conducted focusing mainly on the ESM, not on the HSM. In order to conduct balanced safety management, a mental process to support the HSM is required to be identified. Thus, this study presents a mental process model which explicates how a worker makes a decision on safe behaviors. The model consists of three sub-models: Model for Worker's Decision-Making on Safe Behavior, Model for Optimistic Recovery, and Model for Habituation. Model for Worker's Decision-Making on Safe Behaviors explains how a worker makes a decision based on his/her risk perception and expected utility of safe behaviors.

Model for Optimistic Recovery explains how the effect of accidents on a worker dwindles and how the worker recovers from the effect of accidents. Model for Habituation explains the behavioral inertia due to habituation.

Based on the quantified mental process model, three strategies were suggested.

(a) Allocate most of the incentives to the early stage if giving incentives is considered.

(b) Encourage workers to share information of accidents.

(c) Help workers to believe the shared accidents as what can happen to them.

This study has provided a better understanding and a logical basis for the HSM. In addition, the HSM strategies proposed in this study can be meaningful alternatives to decision-makers.

Keywords: Mental Process Model, Safety Management, Safety Attitude, Risk Perception, System Dynamics

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Chapter1. 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, assumptions and research process to attain the objectives effectively are addressed.

1.1 Background

Over the past few decades, the construction industry has ameliorated its safety. According to the Korea Occupational Safety and Health Agency (KOSHA, 1974-2010), Accident Frequency Rate (AFR) of the construction industry in South Korea, as shown in Fig. 1-1, has largely diminished since 1974. However, if its half-life considered, period 1 (the first half-life) and period 2 (the second half-life) were about 14 years and about 7 years, whereas period 3 (the third and most recent half-life) has not been achieved yet over 15 years. In sum, improvement in construction safety appears to have reached a plateau recently.

One of the major causes for the plateau is thought to be the current biased safety management. Safety management can be divided into two: Environment-based Safety Management (ESM) and Human-based Safety Management (HSM). The ESM is based on the idea that accidents are less likely to occur under various circumstances if all the physical conditions around a worker are safe. Therefore, the ESM focuses on how to improve safety physical conditions such as safety helmets, safety harnesses, and safety nets. The HSM, on the other hand, regards a worker's unsafe behavior as a main cause of an accident and thus emphasizes management over worker's behaviors by safety programs or notifications. The industry typically has emphasized the ESM rather than the HSM. However, due to the fact that there remain few things to improve in terms of safety physical conditions, the further improvement in safety can be hardly made (Donald and Young, 1996). Therefore, in order to overcome the recent plateau in safety management, the construction industry is required to focus on the HSM more.

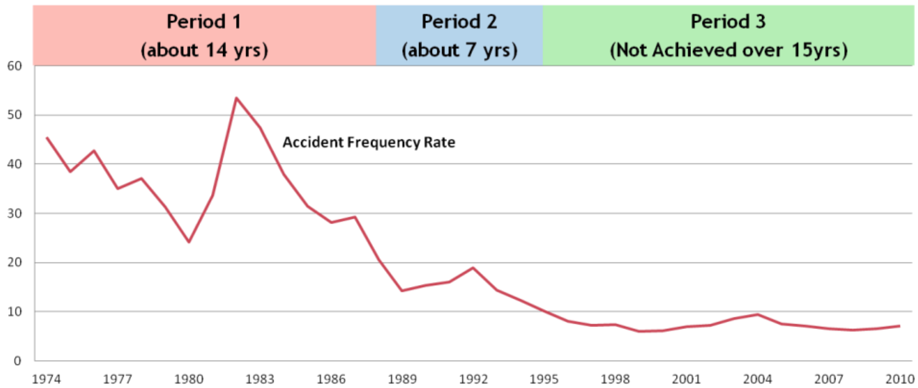

Fig.1-1 Accident Frequency Rate of Construction Industry in South Korea (KOSHA, 1974-2010)

1.2 Objectives and Basic Framework

Prior to suggesting HSM strategies, it is required to develop a model for explicating how workers make decisions on their safe behaviors. Because HSM is to correct workers' behaviors, it is important to understand and manage workers' mental process to behaviors. In addition, an explicative model can provide a better understanding and a logical basis for which management programs and initiatives to select (Cheyne et al, 1998). Although many researchers such as Anderiessen (1978), Purdham (1984), Paul Slovic (1990), Pligt (1996), Reyna (2004), Langford et al. (2000), Mohamed (2002), O'Toole (2002), and Siu et al. (2003) made significant works on safe behaviors and factors affecting the behaviors, there have been a paucity of studies on models which integrate the factors and explain a worker's mental process to behaviors logically. Therefore, this research is to develop a mental process model which can explain how workers' safe behaviors are determined in the construction industry and to suggest HSM strategies from the model.

1.3 Assumptions and Research Process

Since this study focuses on workers' behaviors, site hazards are considered as an external factor. Furthermore, it is difficult to regard that the workers in the construction industry think and make decisions disparately from those in other industries. Therefore, it is assumed that researches on human factors and accidents from other industries can be applied for explicating causal links in the model.

To simplify the model, it is also assumed that most of the behaviors are intended through a certain decision-making process and there are only two types of behaviors which a worker can conduct; safe behaviors and unsafe behaviors. There are no behaviors that belong to neither safe nor unsafe behaviors.

To develop a mental process model, this research reviews previous researches and previous mental process models which are pertinent to the research objective and extracts meaningful factors and lessons. Based on the factors and lessons from the previous researches, this study develops a mental process model for explicating safety attitudes and accidents. After quantifying the model, the research analyzes the effect of controllable factors. Based on the results of the analyses, the research suggests HSM strategies from the model. The research process can be illustrated as Fig. 1-2.

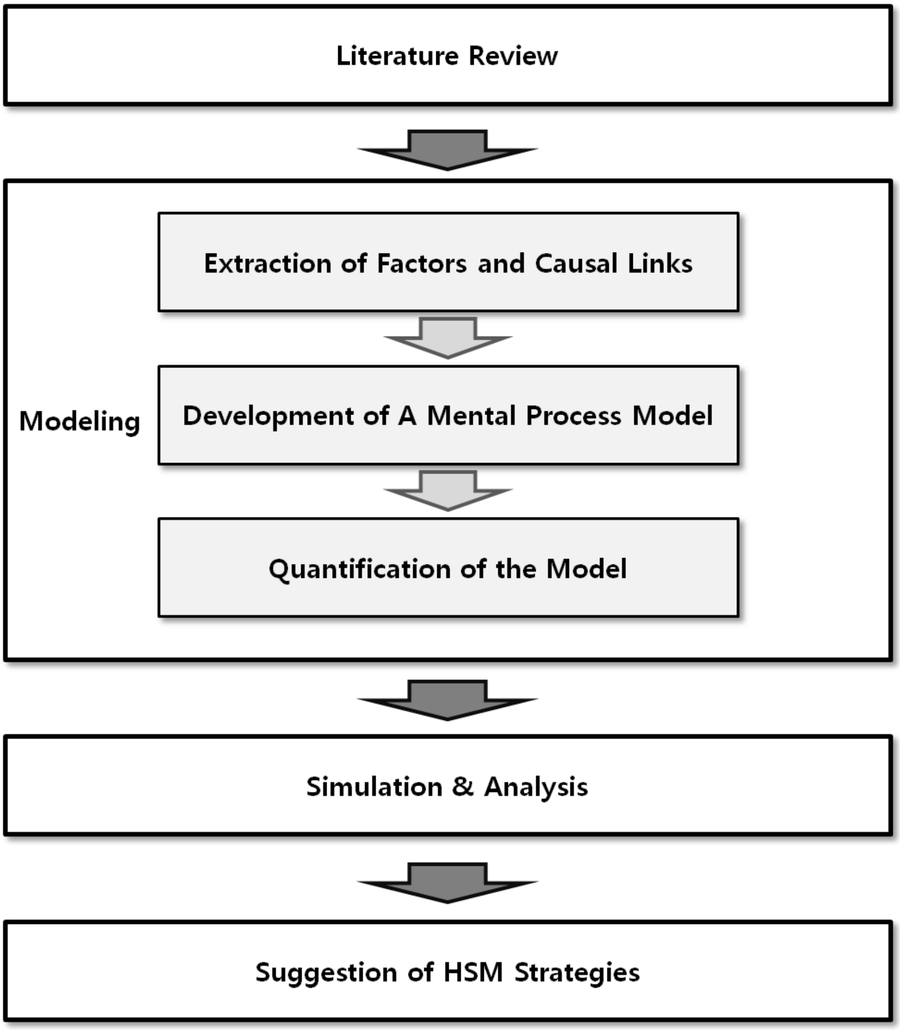

Fig.1-2 Research Process

Chapter2. Preliminary Study

This chapter reviews previous researches and mental process models to extract factors from them and causal links which are meaningful for explaining how workers make decisions. This chapter also provides definitions for the factors. Then, this chapter addresses why system dynamics is effective in explicating the mental process.

2.1 Basic Concept

In order to develop a worker's mental process model, a basic framework is needed to be identified first. Behaviors which lead to accidents are intentional (Donald & Canter, 1993), and attitudes are one of the key factors to predict intentions on behaviors (Ajzen, 1991). Moreover, attitudes depend on how people perceive risks (Fisher et al, 1988). A traumatic event may make people perceive loss of safety or increased risk (Foa et al., 1989), and previous experience of accidents influences attitudes towards accidents (Canter, 1980). Thus, the process can be summarized as follows. First, a person perceives risks combining information the worker has. Second, the person establishes his/her attitude toward a safe behavior based on the risks he/she perceived. Third, the person makes a decision to do it or not based on his/her attitude. Fourth, the person executes the decision. Fifth, the person faces the result of the behavior. Sixth, the outcome influences how the person perceives. This process is a basic framework for a worker's mental process to behaviors and can be demonstrated as Fig. 2-1. The basic framework consists of five factors and six causal links between them. The three causal links between the first four factors and the link from outcome to perceived risk are objects to be managed through HSM whereas the link from behavior to outcome is an object to be managed through ESM. Since a mental process model in this research is developed to suggest HSM strategies, the model is required to focus mainly on the five causal links and to present the causal links and feedback loops effectively.

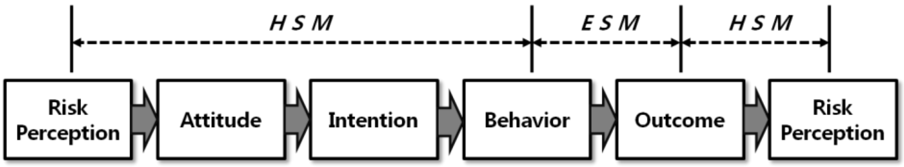

Fig. 2-1 Framework for Mental Process Model

2.2 Main Factors

The factors of the framework are considered as main factors composing the mental process model. As shown in Fig. 2-1, the factors are Risk Perception, Attitude, Intention, Behavior, and Outcome.

Risk perception is defined as a person's subjective judgment on a risk (Lavino and Neumann, 2010). Hence, perceived risks may vary from worker to worker even when workers are addressing a same risk. Whereas an objective worker may perceive a risk as it is, a cautious worker or a bold worker may perceive a bigger risk or a smaller risk than it really is according to the worker's perceiving tendency. In addition, it is worthy of notice that people tend to overestimate their ability and think accidents are controllable, which misleads the people into underestimate risks (Lichtenstein et al., 1978). This fact may explain why workers conduct unsafe behaviors.

Attitude is defined as "a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor" and the evaluation can be cognitive, affective, or behavioral (Eagly and Chaiken, 1993). Attitude is addressed in an individual worker's level whereas similar concepts, safety culture and safety climate, are addressed in an organizational level (Guldenmund, 2004). In this research, two types of attitudes are addressed: one is attitudes toward risks, and the other is attitudes toward behaviors. As mentioned above, attitudes toward risks tend to be optimistic, but be changed to be pessimistic when a person experiences a traumatic event or an accident. If the accident is not severe, it is assumed that the worker's attitude toward risks will become pessimistic at first but recover gradually to the optimistic state as the worker forgets about the accident. Attitudes toward behaviors, on the other hand, are closely connected with expected utility of behaviors. Expected utility is a combination of expected benefits and cost, which influences people's intention (Raiffa, 1968). There has been an effort to explain a driver's attitudes toward safe behaviors (Blomquist, 1986). According to the research, a driver makes a decision whether to conduct a safe behavior or not based on value of expected risk reduction and inconvenience of the safe behavior.

Intention is a decision on whether to execute a behavior or not. However, although a worker intends to execute a safe behavior, the worker may fail to execute the behavior due to his/her habits against the intention.

A worker's behaviors are either safe or unsafe, and unsafe behaviors are considered as a main cause of accidents in this study. The concept, unsafe behavior, is a subset of human error. Human error is "A set of human actions that exceeds some level of acceptability" as Rigby (1970) defined, and can be classified into two types according to Reason (1990); "Slip: an unintended error in execution of an otherwise correct plan" and "Mistake: an intentional act that involves incorrect choice of action." Since most of the unsafe behaviors are assumed to arise from unsafe intentions, most unsafe behaviors are equivalent to mistakes. Slips are assumed to be made only by the worker's habits against the intention in this research.

Outcomes are results of behaviors and can be classified into successful outcomes and unsuccessful outcomes. The unsuccessful outcomes include accidents and incidents which are incurred either by the worker or other workers. An accident is a sequence of events leading to undesirable consequence, and an incident is a sequence of events which was triggered but stopped before leading to the undesirable consequence (Svenson, 2001). In order to simplify the model, an incident is not considered in the model.

2.3 Previous Mental Process Models

Through reviewing the previous researches that have been conducted to explain people's mental process, this study can identify key factors, causal links, and limitations to overcome. There are two models that are persuasive and meaningful to this study. One model was suggested by Eagly and Chaiken in 1993, and the other was suggested by Mearns and Flins in 1995.

One of the most persuasive mental process models for behaviors is a model by Eagly and Chaiken (1993) as shown in Fig. 2-2. The model can demonstrate how behaviors are formed with regard to attitudes. Attitude toward behavior influences intention, and intention induces behaviors. There are five factors affecting attitude toward behavior. Among the factors, habit plays an important role by affecting three other factors, which are attitude toward target, attitude toward behavior, and behavior. Although the model is simple, it can explain various mental processes to behaviors. However, the model does not deal with cognitive processes and attitudes toward risks and underestimates the possibility that the outcomes of behaviors can impact on the attitudes again.

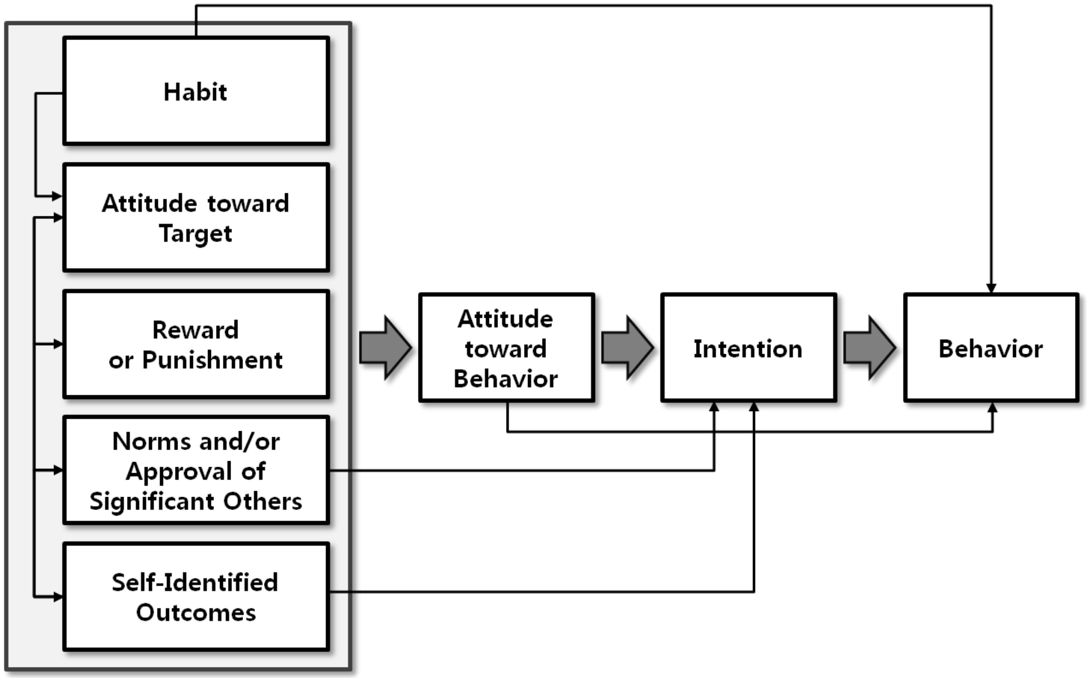

Fig. 2-2 Attitude Formation Process Model
(Adapted from Eagly and Chaiken, 1993)

Another mental process model is a model by Mearns and Flin (1995) as shown in Fig. 2-3. The model emphasizes risk perception and thus deals with social and cognitive factors. Since the model by Mearns and Flins has more variables than the model by Eagly and Chainken, the model has advantages in explaining various paths to behaviors over the model by Eagly and Chainken. For example, the model can explain how a worker’s knowledge or mastery influences the worker’s mental process. Nevertheless, the model still does not present the feedbacks from the outcomes and does not deal with the possibility that others’ outcomes influence a person’s attitudes toward risks.

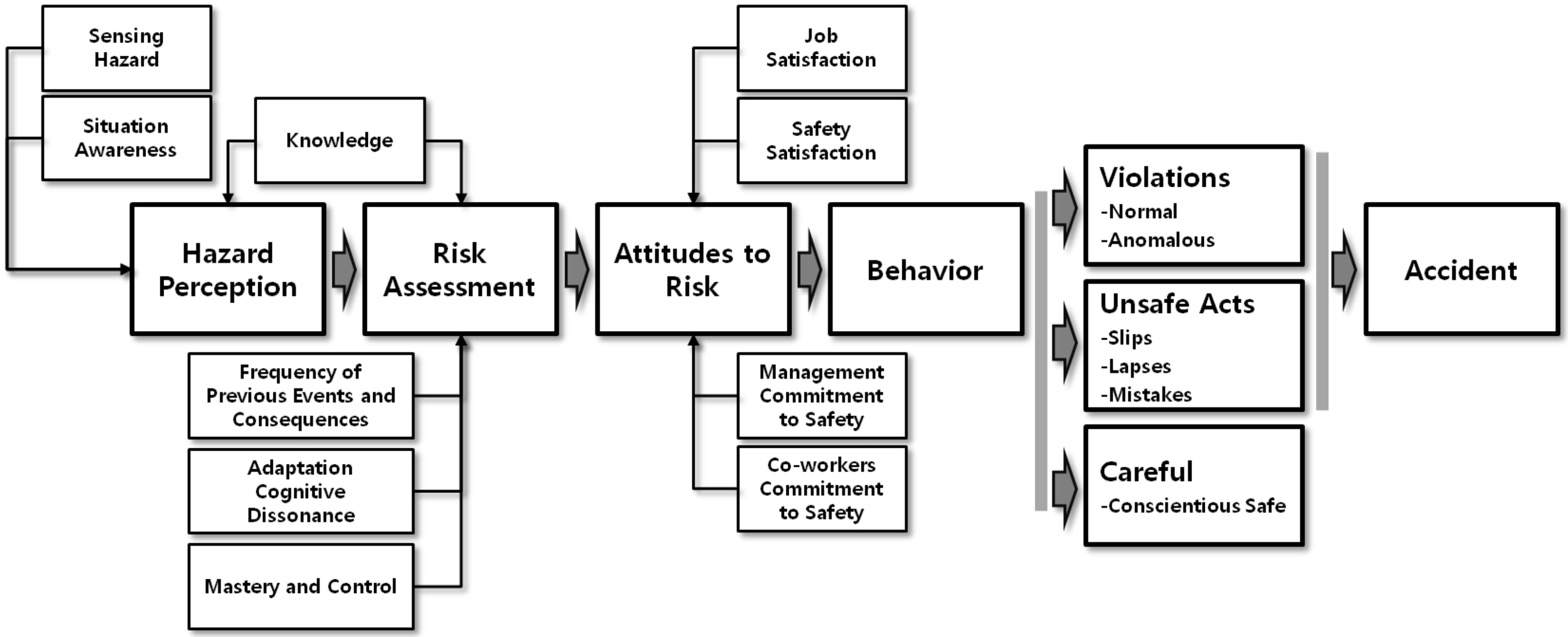

Fig. 2-3 Risk Perception Process Model (adapted from Mearns and Flin, 1995)

2.4 System Dynamics

System dynamics is a sort of modeling methods that have the advantage in presenting and understanding complex and dynamic system which contains various interactions and feedbacks (Sterman, 2000). Since safety management copes with a complex and dynamic system, numerous researches have been conducted for better understandings of safety using system dynamics (Cooke, 2003; Abdelhamid and Howell, 2005; Cooke and Rohlede, 2006; Minami and Madnick, 2009; and Han, Lee and Peña-Mora, 2010). Moreover, for the reason that this research focuses on a worker's mental process which is more unpredictable and dynamic compared to researches dealing with the ESM, the system dynamics is thought to be an appropriate method to satisfy the research objective. For a similar reason, system dynamics was applied on a research to investigate how people make decisions on personal protective underuse when spraying pesticide (Feola et al., 2011). Therefore, this study also employs system dynamics to explain various causal relationships.

2.5 Summary

Prior to developing a worker's mental process model, a basic framework was suggested. The basic framework consists of five factors and six causal links between them. The five factors are perceived risk, attitude, intention, behavior, and outcome. Among the factors and causal links, the model is required to focus on how behaviors are made and how outcome influences worker's behavior.

In addition, two models that are persuasive and meaningful to this study were reviewed in this chapter. One model was suggested by Eagly and Chaiken in 1993, and the other was suggested by Mearns and Flins in 1995. The two models have several limitations, and system dynamics is considered an appropriate methodology to improve the limitations.

Chapter3. Worker’s Mental Process Model

In this chapter, a mental process model is developed based on the factors and causal links identified in the previous chapter. Furthermore, the model is required to present advantages over the previous mental process model.

3.1 Model for Worker’s Decision-Making on Safe Behavior

A worker perceives risk of accidents based on how dangerous the site is. However, as noted earlier, perceived risk is a subjective concept and thus can differ from worker to worker even in addressing a same risk. Such subjective perceiving tendency is named perceiving coefficient in this study. The perceiving coefficient is defined as “ratio of perceived risks to objective risks”, thus, if the perceiving coefficient is one, the worker perceives risk as it is. In contrast, if the perceiving coefficient is two, the worker overestimates the risk of accidents at the moment. Despite the possibility that some people may evaluate risks abnormally small or big, it is assumed that the perceiving coefficient is approximately in the range of 0.5 to 2.

Another concept of importance when it comes to risks is acceptable risk. Even if two workers perceived same amount of risk, it is uncertain whether the two workers’ acts are same or not. It is because some workers are willing to take the risk while other workers are averse to take it. In other words, their acceptable risks are different. Therefore, when judging on risks, workers need two types of risks. One type is perceived risk the other type is acceptable risk.

Based on the perceived risk and the worker's acceptable risk, the worker evaluates the utility of safe behaviors to make a decision on his/her attitude toward safe behaviors. Besides the evaluation on risks, how much incentive the worker can expect and how much inconvenience the worker has to endure are the factors affecting the utility of safe behavior. If the utility of safe behavior is calculated, the utility induces how the worker intends and acts, and how the worker acts influences the probability of accidents on the construction site.

If an accident occurs on the construction site, information about the accident will be diffused across workers, but the diffusion rate depends on how much or how often workers communicate on accidents. The perceived accidents have an effect on the worker's attitude toward risks as the worker recognizes the necessity for modifying how the worker perceives risk of accidents. In this process, how sensitively the worker responds to the accident is a critical factor to determine the change of the worker's attitude toward risks. In other words, the worker would not respond to the accident seriously if the accident is thought to be irrelevant to the worker. Finally, the modified perceiving coefficient changes the worker's perception on risks. This loop is a balancing loop (B1) as shown in Fig. 3-1.

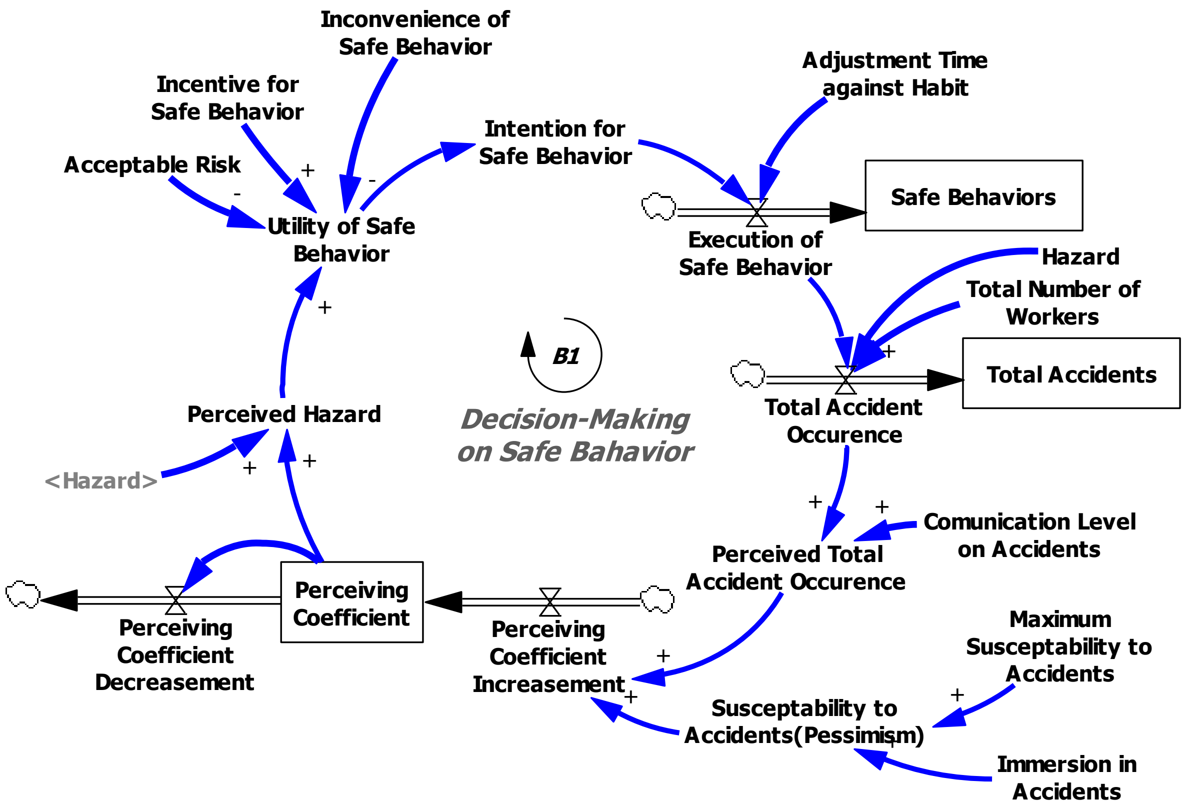

Fig. 3-1 Model for Worker's Decision-Making on Safe Behavior

3.2 Model for Optimistic Recovery

As described above, workers tend to overestimate themselves, which can be described as their perceiving coefficients are less than one. Although such tendency is punctuated by accident occurrences, a worker is assumed to recover from the pessimistic perceiving tendency as the worker forgets about the accidents. Therefore, as some amount of time goes by, the worker gets back to the state that the worker overestimates him/herself in. This loop is a reinforcing loop (R1) as shown in Fig. 3-2.

Nonetheless, a worker who has experienced or witnessed several accidents cannot fully recover from the effect of the accidents as if the worker had not experienced or witnessed any accident. Thus, a worker's maximum optimistic level is regarded to dwindle as accidents accumulate. This loop is a balancing loop (B2) as shown in Fig. 3-2.

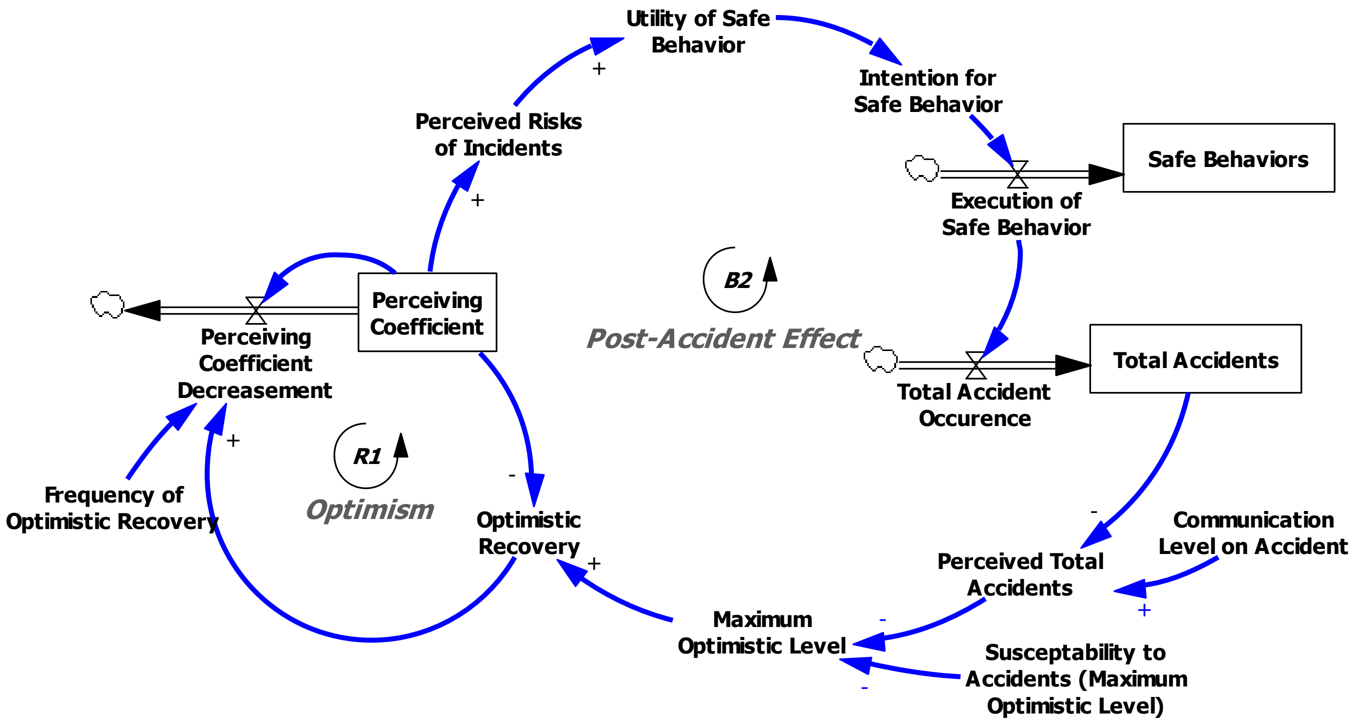

Fig. 3-2 Model for Worker's Optimistic Recovery

3.3 Model for Habituation

As Eagly and Chaiken (1993) demonstrated in their model (Fig. 2-2), a person's habits affect his/her attitude toward behaviors and execution of behaviors. In this context, when a worker is required to act more or less safely compared with what the worker has acted so far, the worker may confront a difficulty in establishing appropriate attitude or in executing what the worker intended to do owing to his/her habits. For instance, although a worker who acts safely two out of ten times suddenly set his rule to act safely nine out of ten times, there is little possibility that the worker achieves exactly what he intended to act because he may not be accustomed with the newly-set rule or may forget the rule. This is a reinforcing loop (R3) as shown in Fig. 3-3.

On the other hand, if a worker acts safely as a rule, then the worker may recognize less inconvenience from safe behaviors. Since inconvenience of safe behaviors is one of the important factors to determine the expected utility of safe behaviors, the worker is expected to establish favorable attitude toward safe behaviors. This is a reinforcing loop (R4) as shown in Fig. 3-3.

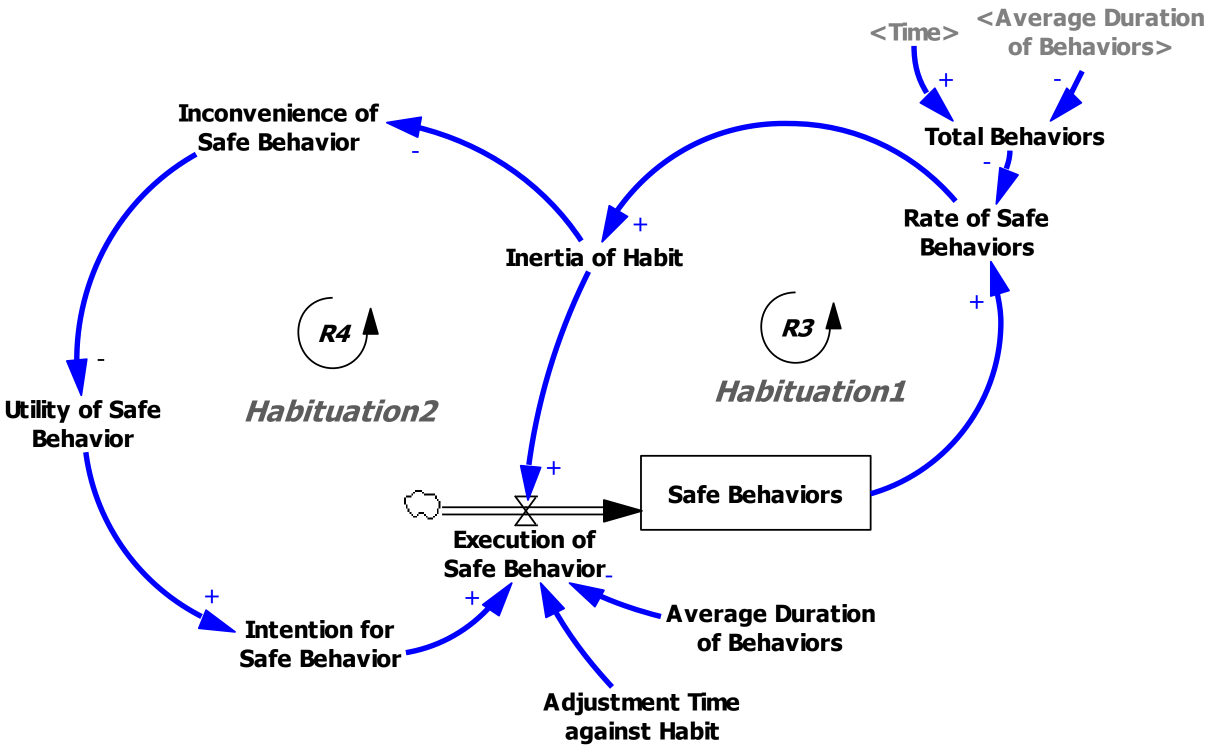

Fig. 3-3 Model for Habituation

3.4 Analysis

After quantification of the model with several values assumed (Final Time: 2000 Days, Time Step: 1 Day, Communication Level: 0.8, Immersion in Accident: 0.8, and Utility of Incentive for Safe Behavior: 0.3), analysis of the model was conducted. Leading indicators in the model are perceiving coefficient, total accidents, and rate of safe behaviors. The graph in Fig. 8 presents how a worker's attitude toward risks, which is presented as perceiving coefficient, changes. The worker has a minimum perceiving coefficient value of 0.5 as a maximum optimistic level and is predicted to have the value if the worker never perceives accidents. However, accidents happen and affect the worker's attitude toward risks. Thus, the soaring moments present the time when accidents occur. As noted earlier, a worker modifies his/her attitude toward risks when the worker confronts accidents, and thus the perceiving coefficient increases sharply. As the worker becomes insensitive to the accidents, the perceiving coefficient recovers to the value of 0.5 gradually.

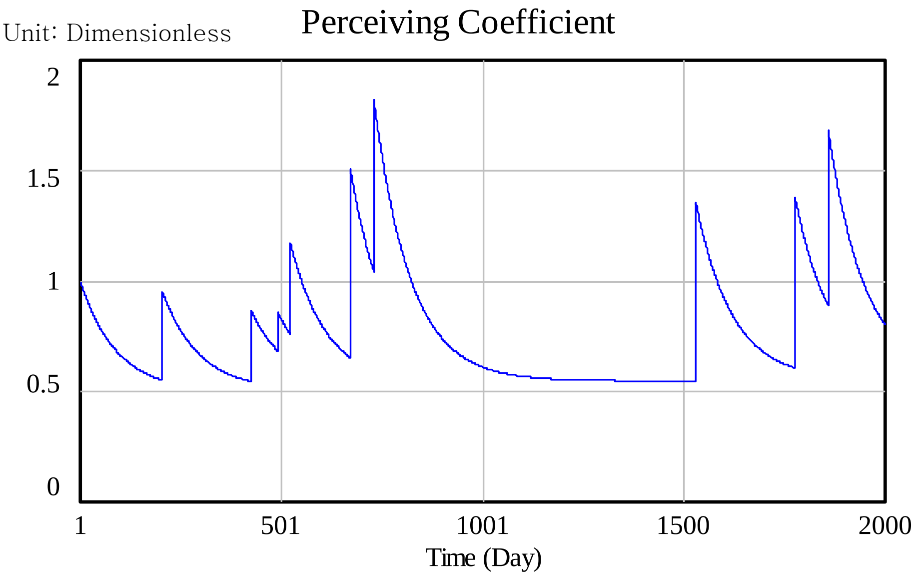

Fig. 3-4 Simulation Result (Perceiving Coefficient)
[Unit of the vertical axis is dimensionless. (The value of 1 means that actual risk equals perceived risk.)]

The graph in Fig. 3-5 presents total accidents on the construction site. Under the assumed conditions, there happened ten accidents. It can be noticed that site hazard is overestimated in this study in order to facilitate an evaluation of influencing factors. Furthermore, the moments of accidents in the second graph correspond to the soaring moments in the first graph.

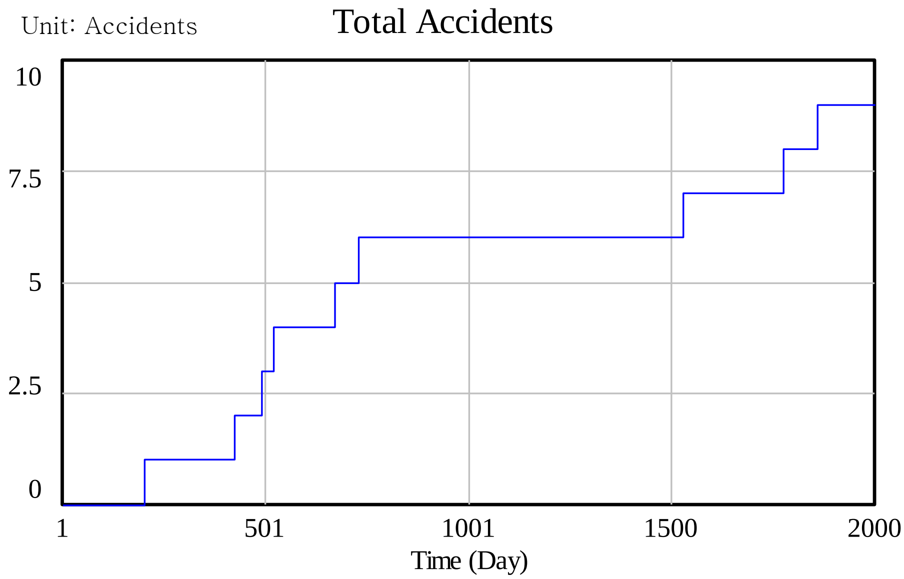

Fig. 3-5 Simulation Result (Total Accidents)

The graph in Fig. 3-6 presents how many safe behaviors a worker conducts out of the total behaviors. Under the conditions mentioned above, the worker acts safely about six out of ten times. The rate of safe behaviors tends to fluctuate more at the beginning stage, and there are two reasons for the fluctuation. First, the rate of safe behaviors is a value calculated by dividing safe behaviors by total behaviors. As the two factors get bigger, the rate of safe behaviors gets less sensitive to the change of the two factors. Second, habit is a factor that reduces fluctuations in the model but is not fully-established at the beginning stage. As the worker's behavior pattern becomes stable, the rate of safe behaviors also becomes stable.

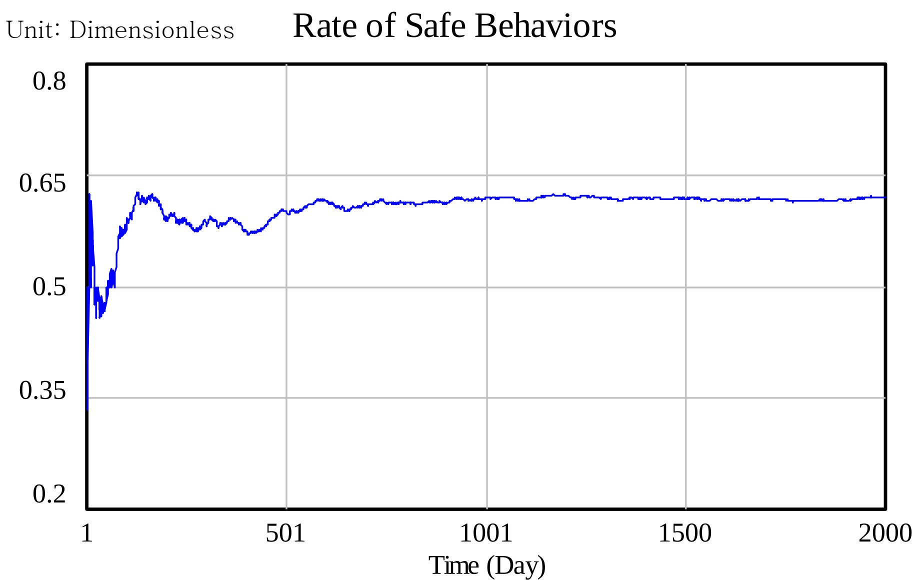

Fig. 3-6 Simulation Result (Rate of Safe Behaviors)

3.5 Summary

Based on the basic framework in Chapter 2, a mental process model to explain how a worker decides to act in terms of safety was developed in this chapter. The model consists of three sub-models.

One is Model for Worker's Decision-Making on Safe Behavior which deals with main process of decision-making.

Another is Model for Optimistic Recovery which describes workers' optimistic perceiving tendency and recovery process from the effect of accidents.

The other is Model for Habituation which explains how a worker's habit influences the worker's decision-making process.

The entire model which includes the three sub-models mentioned above is presented in Fig. 3-7. After quantifying the model, simulation was conducted to examine the logics of the model and to provide a standard.

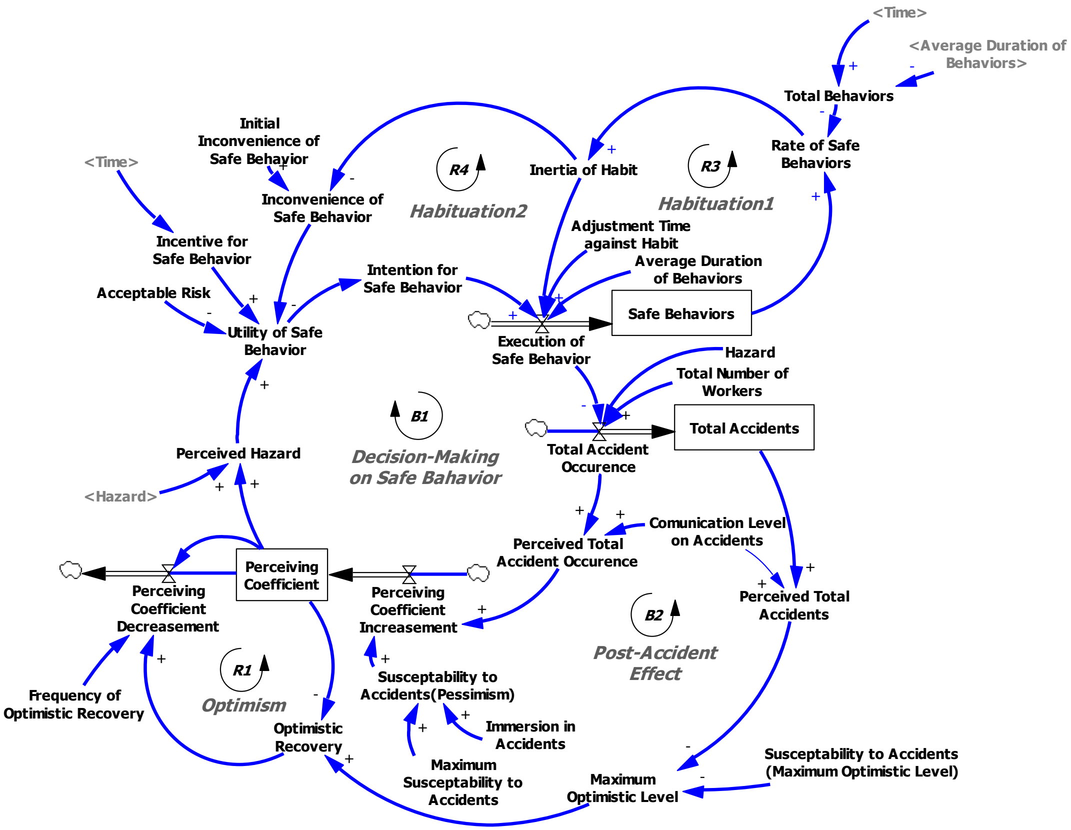

Fig. 3-7 Entire Mental Process Model

Chapter4. Strategies for Human-based Safety Management

Based on the model introduced in Chapter 3, HSM strategies are suggested in this chapter. Prior to suggesting strategies, identifying meaningful factors is required. Meaningful factors are controllable and effective.

4.1 Incentive for Safe Behavior

If giving incentives to workers who act safely is considered, allocating most of the incentives to the early stage is efficient according to the model. As shown in Fig. 4-1, incentive for safe behavior is a trigger factor for the R3 and R4 loops. An incentive for safe behaviors increases the utility of safe behaviors and the probability of safe behaviors. As a worker conducts a high possibility of safe behaviors, it grows into a habit. Although the incentive is abolished or reduced after the habit is built, the worker would still conduct more safe behaviors than other workers who do not have such habits. In this situation, the habit works as a factor which delays the reduction in the rate of execution. In contrast, if an incentive is launched in the middle of the construction project, a worker who has rarely acted safely for a long time needs enough time to change his/her habit due to the fact that this time the habit works as a factor dragging down the rate of execution.

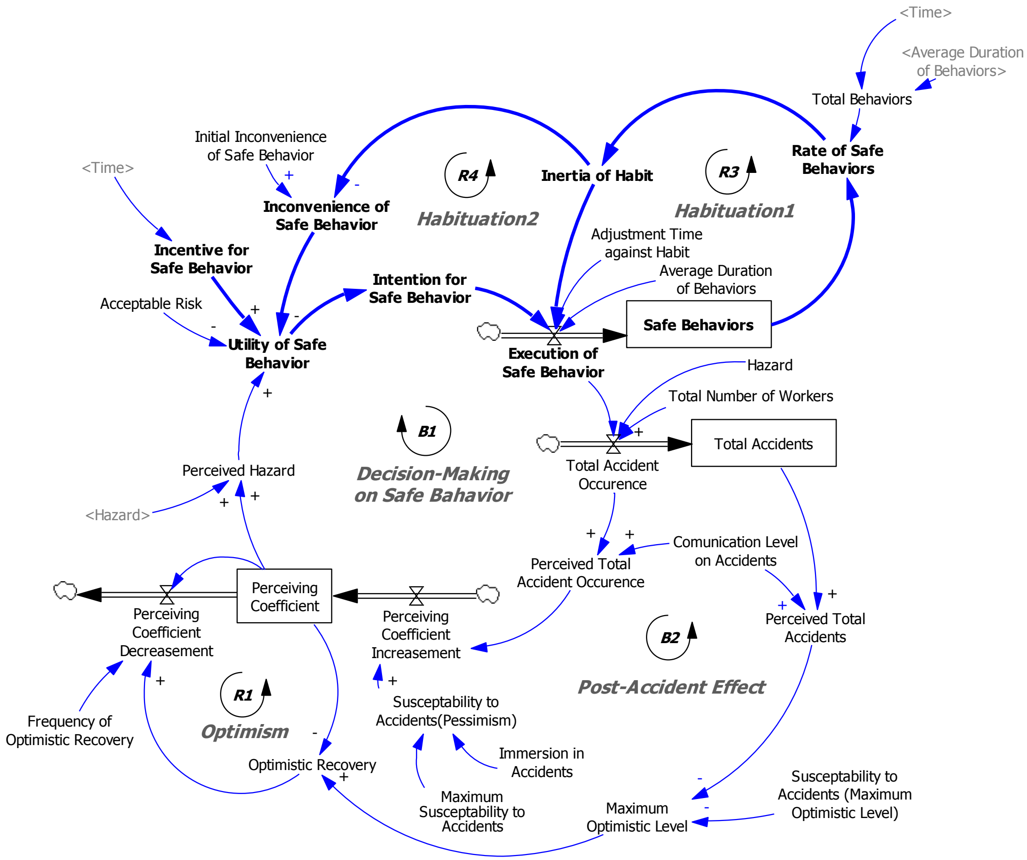

Fig. 4-1 Incentive for Safe Behaviors

The graphs in Fig. 4-2 and Fig. 4-3 present the simulation results conducted to identify the effect of incentive allocating in terms of time. One was conducted under the condition that 0.2 for day 1 to 1000 and 0.4 for day 1001 to 2000 were set, and the other was conducted under the condition that 0.4 for day 1 to 1000 and 0.2 for day 1001 to 2000 were set. The other conditions are same as those of the simulation in Chapter 3.4. The two graphs represent that each strategy of allocating more incentives in the early stage or the late stage with the same total amount of incentives. As presented in Fig. 4-2 and Fig. 4-3, the case that provides incentives concentrating on the early stage induces more safe behaviors and thus less accidents than the case concentrating on the late stage.

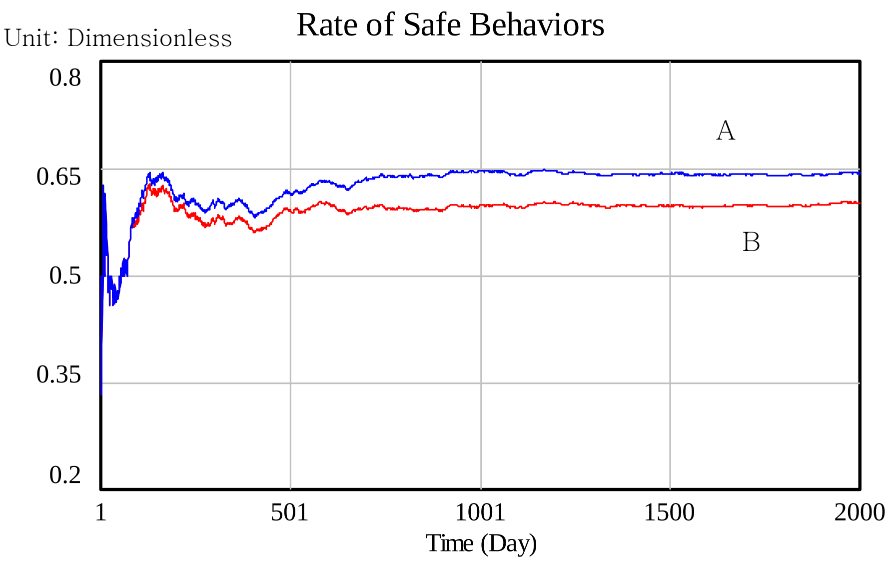

Fig. 4-2 Simulation Results (Rate of Safe Behaviors) - Sensitivity Analysis of the Effect of Incentive Allocating
Concentrating Incentives on the Former Half Stage (A) and Concentrating Incentives on the Latter Half Stage (B)

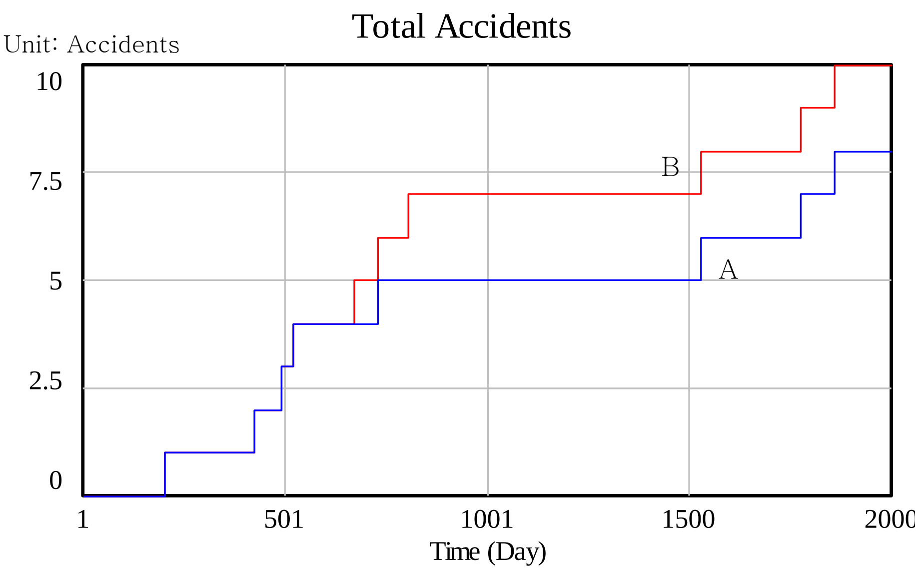

Fig. 4-3 Simulation Results (Total Accidents) - Sensitivity Analysis of the Effect of Incentive Allocating
Concentrating Incentives on the Former Half Stage (A) and Concentrating Incentives on the Latter Half Stage (B)

4.2 Communication Level

As shown in Fig. 4-4, attitude toward risk plays an important role in the worker's mental process model, and accident is a factor influencing the attitude toward risk. Hence, factors amplifying the impact can be important management factors. Communication level on accidents, for example, has an effect on the links between accidents and perceiving coefficient and thus can be a target to be managed. In other words, if workers communicate on accidents more, then more workers become aware of the accidents. If more workers become aware of accidents, then bigger change of perceiving coefficient is anticipated. Since accidents make workers pessimistic or sensitive to risks, high communication level will induce workers to act more safely. Furthermore, a worker's maximum optimistic level decreases.

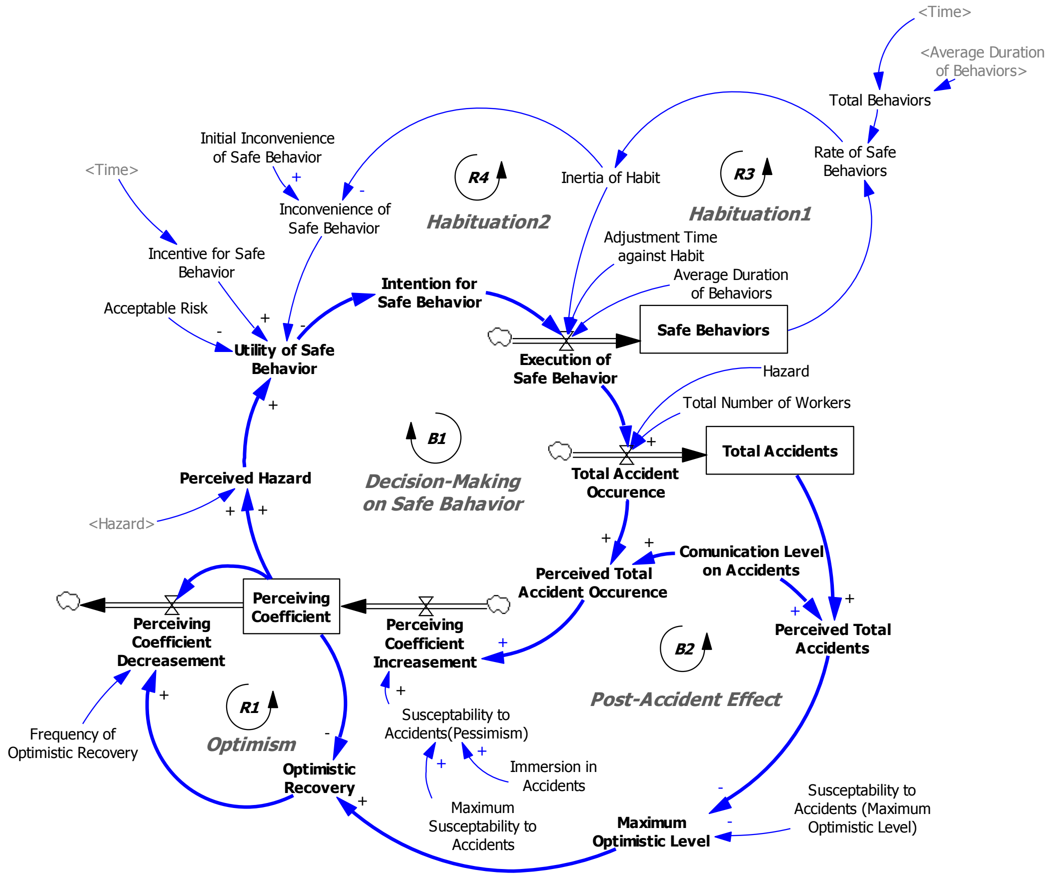

Fig. 4-4 Communication Level

The graphs in Fig. 4-5, Fig. 4-6 and Fig. 4-7 present the simulation results conducted to identify the effect of communication level on accidents. Each simulation was conducted with a value of 0.2, 0.5, or 0.8 as communication level on accidents. Communication level has a range from zero to one, and if the value is one, it means every worker on the site become aware of every accident. On the contrary, if the communication level has a value of zero, then it means that workers cannot be provided with information about accidents on the site. As anticipated earlier, the construction site where workers share information on accidents most has the least accidents among the three as shown in Fig. 4-7. This is because the most workers react to accidents when an accident occurs as shown in Fig. 4-5 (Since the perceiving coefficient is a value of an average worker, it can be interpreted as if simulation A has a bigger value of perceiving coefficient than simulation B, then more workers from A reacted to an accident than B). As a result, more workers strive to act safely as presented in Fig. 4-6, and it causes fewer accidents on the construction site.

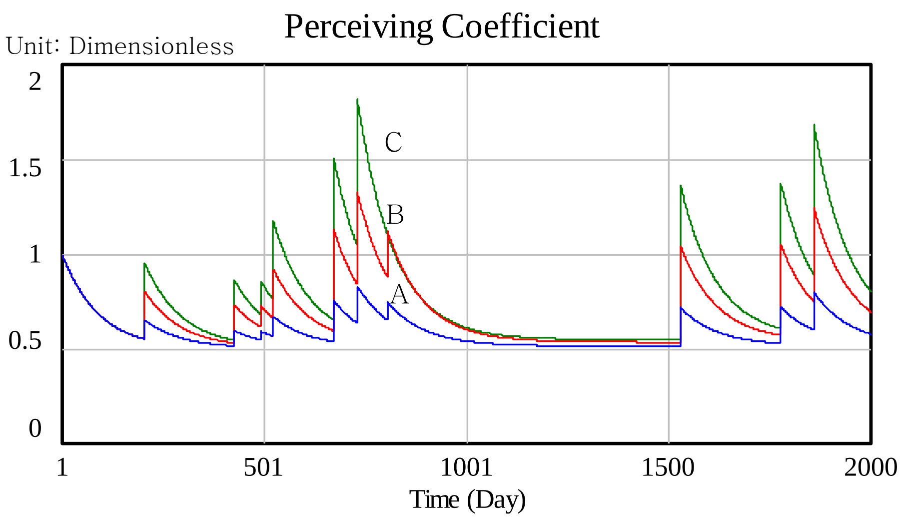

Fig. 4-5 Simulation Results (Perceived Coefficient) - Sensitivity Analysis of the Effect of Communication Level on Accidents: Low Communication (A), Middle Communication (B), and High Communication (C)

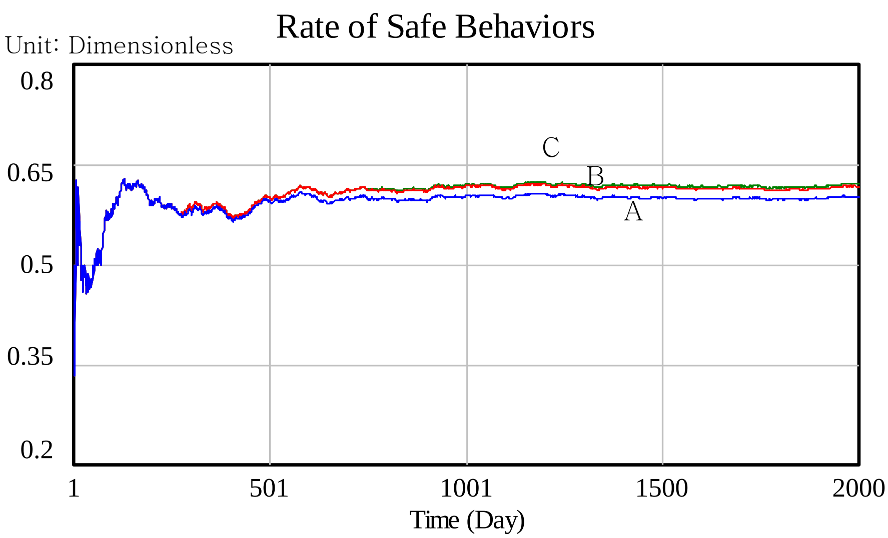

Fig. 4-6 Simulation Results (Rate of Safe Behaviors) - Sensitivity Analysis of the Effect of Communication Level on Accidents: Low Communication (A), Middle Communication (B), and High Communication (C)

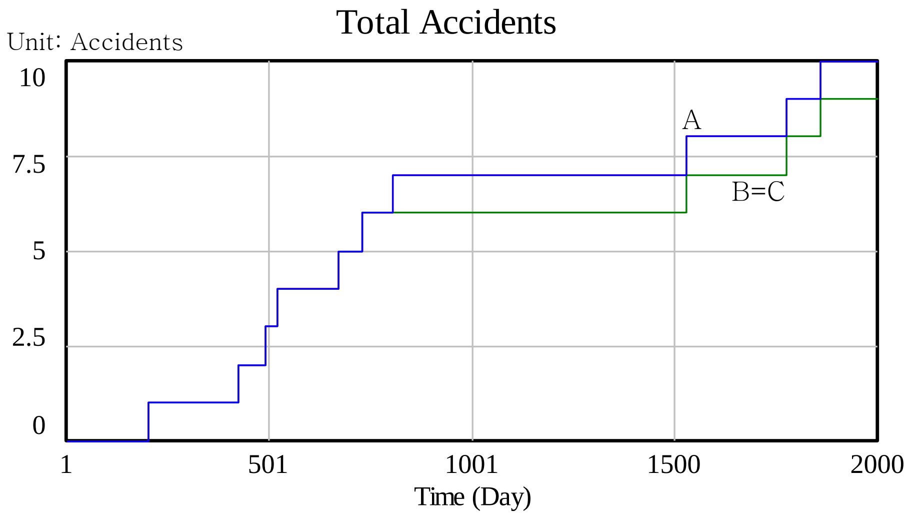

Fig. 4-7 Simulation Results (Total Accidents) - Sensitivity Analysis of the Effect of Communication Level on Accidents: Low Communication (A), Middle Communication (B), and High Communication (C)

In addition, this strategy can explain the importance of incident reporting. As noted earlier, site hazard in this study is overestimated to present the effect of strategies clearly. Therefore, safe management through enhancing communication on accidents may be unrealistic since accidents rarely happen on the real construction sites. On the contrary, incidents happen more and can play a similar role in the model, which is to increase workers' concern. However, the problem is that incidents are usually forgotten. As Chapman & Underwood (2000) mentioned, about 80% of car incidents tend to be forgotten after a delay. Thus, encouraging workers to report incidents and to share the reports over the construction site can be an effective strategy.

4.3 Immersion in Accidents

Even if a worker is informed of an accident, the worker would not consider it as important information if it is obvious that the accident will not happen to the worker. In other words, the worker does not immerse in the accident. Immersion is defined as how likely a worker perceives an accident is to happen. As shown in Fig. 4-8, immersion in accidents determines the effect of an accident. If a worker immerses in an accident entirely, then the worker becomes most sensitive to the accident. As a result, the worker is predicted to act more safely being adverse to accidents.

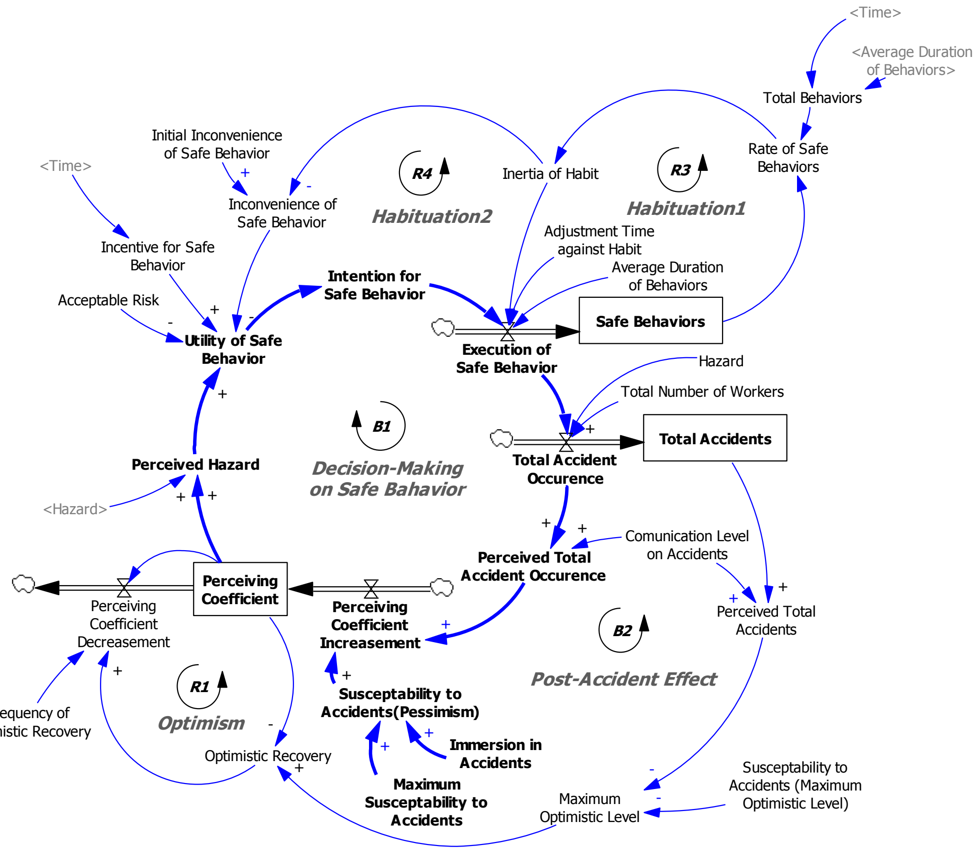

Fig. 4-8 Immersion in Accident

The graphs in Fig. 4-9 and Fig. 4-10 present the simulation results conducted to identify the effect of immersion in accidents. The factor has a value with a range from zero to one. Each simulation was conducted with a value of 0.2, 0.5, or 0.8 as immersion in accidents. As shown in the graphs, if workers perceive accidents unrealistic to them, the workers conduct fewer safe behaviors on site because the workers are less sensitive to the accidents. Consequently, there occur more accidents as shown in Fig. 4-10.

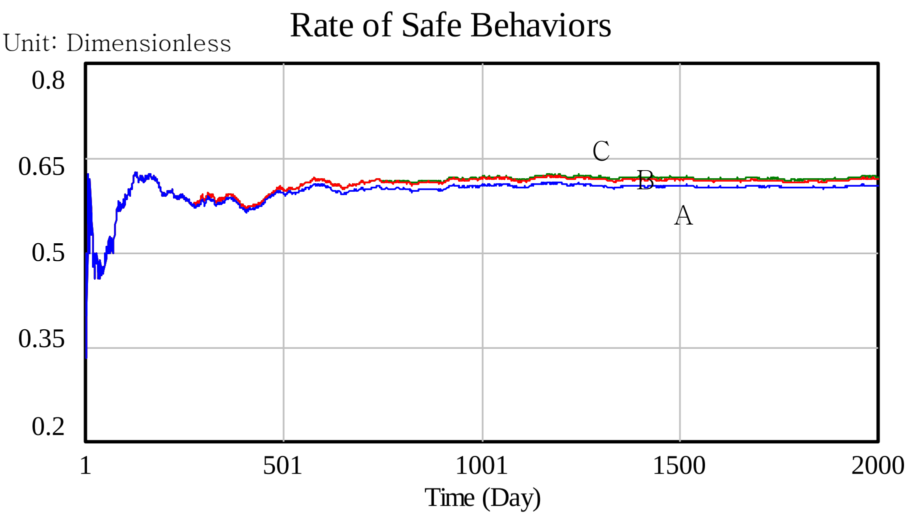

Fig. 4-9 Simulation Results (Rate of Safe Behaviors) - Sensitivity Analysis of the Effect of Immersion in Accidents: Low Immersion (A), Middle Immersion (B), and High Immersion (C)

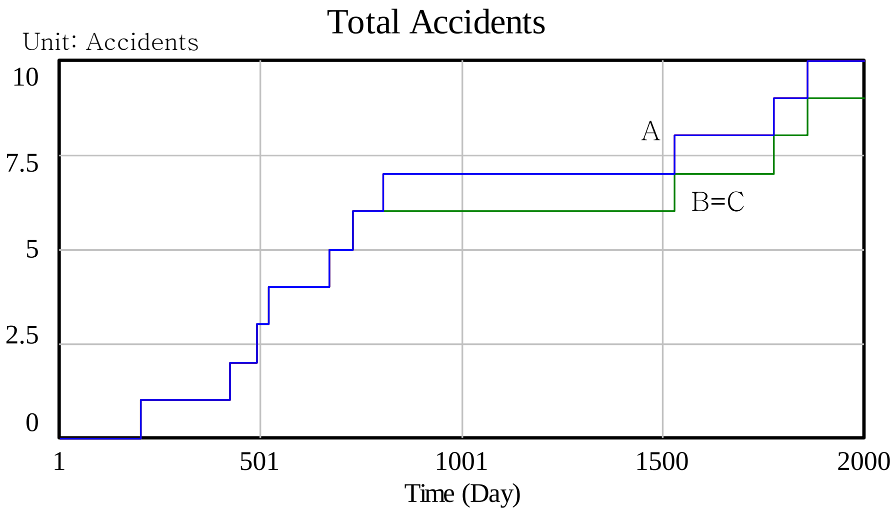

Fig. 4-10 Simulation Results (Total Accidents) - Sensitivity Analysis of the Effect of Immersion in Accidents: Low Immersion (A), Middle Immersion (B), and High Immersion (C)

4.4 Summary

Based on the proposed mental process model, three management factors were identified in this chapter. The three factors are Incentive for Safe Behavior, Communication Level, and Immersion in Accident.

After simulating the sensitivity of each factor, three strategies were proposed.

(a) Allocate most of the incentives to the early stage if giving incentives is considered.

(b) Encourage workers to share information of accidents.

(c) Help workers to believe the shared accidents can happen to them.

Chapter5. Conclusions

This chapter deals with the results which are obtained from the newly-suggested mental process model and contributions which this study makes.

5.1 Results and Discussions

The present safety management, Environment-based Safety Management which emphasizes physical conditions reveals its limitations and causes the plateau in improving safety in the construction industry. To solve the problems, Human-based Safety Management which focuses on workers and their behavior is demanded. Although a plethora of researches on HSM have been conducted, there has been little effort for developing a mental process model to support HSM. For this reason, this study suggested a mental process model to explicate how a worker make a decision on safe behaviors based on the factors and causal links that were identified by the previous researches. Since the model was required to deal with several feedbacks, system dynamics was employed as a methodology to describe the relationships. Based on the proposed mental process model, the following three strategies were suggested.

(a) Allocate most of the incentives to the early stage if giving incentives is considered.

Habituation is one of the important factors to consider in terms of HSM. An incentive encourages a worker to act safely and to make it a habit. Once a habit is established, the habit works as a factor which delays the reduction in the rate of execution.

(b) Encourage workers to share information of accidents.

Workers tend to overestimate themselves and underestimate the possibility of accidents. However, accidents give a chance to modify their optimistic perceiving attitudes to the workers, and communication level on accidents determines the impact. Since accidents rarely happen, encouraging incident reporting and sharing the reports are also effective HSM strategies.

(c) Help workers to believe the shared accidents can happen to them.

When sharing information of an accident, workers determine the meaning of the accident based on how realistic the accident is. Therefore, to make workers immerse in an accident, sharing information as in detail as possible or providing a chance to experience the accident indirectly based on various senses is a good strategy.

5.2 Contributions

Safety management is one of the important parts in the construction management. However, various statistics are presenting that the present safety management, Environment-based Safety Management, has limitations in making a further improvement of the construction industry. Therefore, Human-based Safety Management is required to be applied more.

This study has provided a better understanding and a logical basis for HSM through suggesting a mental process model to support HSM. The model has several advantages over the previous model in explicating a worker's mental process.

Furthermore, the three HSM strategies proposed in this study can be meaningful alternatives to decision-makers.

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국 문 초 록

안전관리는 작업자를 둘러싼 물리적 조건을 개선/제어하는 환경 중심의 안전관리와 작업자의 인지 및 행동을 제어하는 인간 중심의 안전관리로 나눌 수 있다. 최적의 안전관리를 위해서는 이 두 관리를 균형있게 적용하는 것이 요구된다. 본 연구는 현재 관심이 부족한 인간 중심의 안전관리의 논리적 바탕을 제시하고 이해개선을 도모하기 위해 작업자의 안전행동에 대한 판단 과정을 설명할 수 있는 모델을 제시한다.

기존 행동/판단 모델의 고찰과 인간 중심의 안전관리에 대한 연구의 고찰을 통해 주요 요소와 각 인과관계를 도출하고 이를 바탕으로 모델을 제시한다. 모델은 크게 의사결정 모델, 낙관회복 모델, 습관화 모델로 나뉜다. 의사결정 모델은 위험인지와 효용성에 기반을 두고 작업자가 어떻게 안전한/위험한 행동을 선택하는지를 설명한다. 낙관회복 모델은 작업자가 어떻게 사고에 의해 조심성이 증가한 상태에서 낙관적인 본래 상태로 회복되는지를 보여준다. 습관화 모델은 습관에 의한 작업자의 행동적 관성의 영향을 보여준다.

정량화한 모델을 바탕으로 도출된 세 가지 관리 전략은 다음과 같다.

(a) 안전한 행동에 따른 인센티브를 제공한다면 초기에 더 많이 할당하여 작업자의 습관화를 돕는 것이 효율적이다.

(b) 사고가 발생하였을 때, 현장에서 사고에 대한 정보교환을 활성화하여 안전한 행동의 효용을 높여서 작업자의 안전한 행동을 유도한다. 이는 아차사고(Near Miss)에 대한 작업자의 보고를 높이고 이 정보를 교환하는 방법으로 활용될 수 있다.

(c) 사고에 대한 정보는 작업자가 충분히 몰입할 수 있도록 최대한 자세히, 다양한 감각을 이용하여 접할 수 있도록 한다.

이 연구는 균형적 안전관리의 필요성 인식 및 활용에 도움을 줄 수 있고 도출된 전략들은 안전관리를 위한 의사결정에 기여할 수 있다.

주요어: 판단과정모델, 안전관리, 안전태도, 위험인지, 시스템 다이내믹스

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