Impact of the Strictness and Cohesiveness of Management Feedback on Construction Workers' Safety Behavior
Agent-based Modeling and Simulation

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Abstract: Although workers' unsafe behaviors are the main causes of accidents in construction projects, there is a noticeable lack of research addressing the mechanisms of workers' safety behavior. In this paper, an agent-based model that integrates the cognitive process of safety behavior and workers' interactions with the environment –including coworkers, management, and site condition– has been constructed. Then, model experiments were conducted to investigate the effects of the strictness and cohesiveness of management feedback on safety behavior. The results indicated that while strictness has significant impacts on reducing workers' unsafe behaviors, the impacts become limited in specific conditions; 1) lenient feedback in the modest-risk condition; 2) whole range of the strictness in the low-risk condition except for very strict feedback; and 3) very strict feedback in high-risk conditions. Also, it was found that construction managers should achieve at least a medium level of cohesiveness in feedback in order to prevent the negative impacts of the low cohesiveness of management feedback. This paper contributes to the body of knowledge on construction safety as well as simulation literature by developing the socio-cognitive process model of workers' safety behavior that examines how the socio-cognitive process interacts with management and the site condition.

1 INTRODUCTION

The construction industry has been notorious for its poor safety record not only in the U.S., but also in many other regions including EU, Asia, and Australia (Lingard et al., 2011; Choi and Lee, 2016). Although continuous efforts have been made to reduce the number of accidents at construction sites, the safety in the construction still lags behind other comparable industries (Kim et al., 2013). In the U.S., for example, 894 fatal occupational injuries were reported from the construction industry in 2014, which accounted for 18% of the total fatal occupational injuries across all industries (BLS, 2016a). Also, non-fatal injury rate of the U.S. construction industry is 1.4 times greater than national average of all industries (BLS, 2016b).

Accident investigations have shown that accidents are caused by the interaction between unsafe conditions (i.e., a physical hazard in work environment) and unsafe acts (i.e., behavior that deviates from safety rules and procedures) (Heinrich et al., 1950). Traditionally, safety management in construction has centered on eliminating unsafe work conditions on a construction site, and these efforts have resulted in significant improvements in work conditions on construction sites over the past decades (Choi et al., 2017). However, given that more than 80% accidents are attributable to workers' unsafe behaviors (Salminen and Tallberg, 1996), increased attention has been paid to the improvement of workers' safety behaviors.

In this regard, there have been continuous efforts to identify factors affecting workers' safety behavior. Such research efforts have noted that that workers' safety behaviors are under the influence of social controls such as safety climates, safety norms, and safety culture. Safety climate is defined as "employees' shared perception of organizational safety policies, procedures, and practices" (Zohar, 1980). Also, the social norm is defined as "shared understandings of what is acceptable behavior and what is not acceptable behavior for a group" (Anderson et al., 2014). A number of previous studies have empirically shown that workers' shared perception of safety (i.e., safety climate and safety norm) plays a paramount role in shaping their safety behavior at construction sites (Mohamed, 2002).

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2 RESEARCH OBJECTIVES

Although previous studies have provided ample evidence on the influence of social factors on workers' safety behaviors, few research efforts have been made to uncover the mechanism of social influence on workers' safety behaviors. Since most of the previous studies have attempted to identify a covariation between workers' shared perceptions and their safety behaviors at a single point (i.e., cross-sectional survey, variable-based approach), it 's hard to uncover underlying mechanism of group behaviors emerging from individuals' interactions in an organization with this methodology (Smith and Conrey, 2007). Furthermore, the previous studies are limited to investigate how individuals in an organization will react and which group-level phenomena will emerge when management's policies /interventions are implemented (Ahn and Lee, 2015).

To address these limitations of the variable-based approach, this study adopts agent-based modeling and simulation because it has strength in generating complex social phenomena emerging from the interaction of individuals in an organization (Macy and Willer, 2002). The agent-based model consists of multiple agents (i.e., abstraction of workers in this paper) that interact with each other and/or with the environments and make their own decision over time based on a set of theoretically or empirically postulated behavioral rules (Hughes et al., 2012). The modeler can observe dynamic changes in agents' behaviors at the individual as well as group level emerging from the behavioral rules by running simulation with the model. Therefore, the agent-based model provides "generative or mechanistic explanation of observed phenomena by postulating or set of mechanics, that generates the phenomena" (Smith and Conrey, 2007). The generative explanations from agent-based model reveal how the observed phenomena from the variable-based approach emerge in populations of heterogeneous individuals.

With this background, this study aims to develop an agent-based model of construction workers' safety behavior based on previous theoretical and empirical findings regarding workers' safety behavior. The developed model is expected to provide a deeper understanding of the mechanism of social influence on workers' safety behavior. Further, to investigate how workers react to different safety management interventions and provide insight into the development of effective safety management policies/strategies, "thought experiments" are conducted using the developed model. Before preceding the next section, the authors would like to note that the model in this paper is guided by Choi and Lee (2017), but model assumptions have been re-evaluated. Also, while Choi and Lee (2017) explore the impact of the strictness of management feedback on workers' safety behavior in the modest level of site risk, this paper additionally considers different site conditions and the cohesiveness of management feedback in the experiment. However, this paper is limited to the impacts of the strictness and cohesiveness of management feedback on workers' safety behavior. The results of more comprehensive experiments that include additional safety management interventions (e.g., different frequency of management feedback and stimulation of workers' project identification) and interactions between the safety management interventions will be presented in the future journal paper.

3 LITERATURE REVIEW

Considering that workers' safety behavior is a response to potential hazards in the workplace, workers' unsafe behavior is in line with risk-taking behavior. The theory of risk homeostasis (Wilde, 1982) provides an explanation of the cognitive process of risk-taking behavior. According to the theory, perceived risk and acceptable risk is two main dimension to determine risk-taking behavior, and individual takes the risk only when the perceived risk is smaller than an internal threshold (i.e., acceptable risk). In other words, an individual perceives the risk (i.e., risk perception) and assesses the risk based on his/her acceptable risk (i.e., risk assessment) to determine his/her response to the risk. The concept of perceived risk and risk acceptance have been also applied to explain various types of risk-taking behavior such as finance and health risk behavior. Also, risk perception and risk assessment have been included in numerous studies on the causes of workers' unsafe behaviors (Chi et al., 2013).

Since construction workers are working in a social context, the cognitive processes and safety behaviors would be influenced by interaction with others. In a construction site, interaction happens not only between workers but also between workers and management. Construction workers create the perception of coworkers' risk acceptance based on their observation of coworkers' safety behavior (i.e., workgroup norm). Also, workers learn risk acceptance of management based on the management feedback on unsafe behaviors (i.e., management norm). If a worker receives feedback from the management on a specific unsafe behavior, the worker realizes that the unsafe behavior is not acceptable in the current project. Construction workers establish their internal standard regarding safety behavior based on own risk attitude as well as the two norms. In the same vein, recent studies have suggested multi-level social influence model that consists of organization and workgroup levels and showed the separate impact of the two levels (Clarke and Ward, 2006).

The process of social influence on an individual's behavior can be explained by social identity theory. Social identity is defined as "a part of an individual's self-concept which derives from his knowledge of his/her membership in a social group (or groups) together with the value and emotional significance attached to that membership" (Tajfel, 1978). The social identity theory posits that the strength of influence of group norms on an individual's behavior is determined by the salience of the group membership in his/her self-concept. In this regard, Choi et al., (2016) investigated the effects of workgroup norm, management norm, as well as project identification on workers' safety behavior. The results showed that construction workers' safety behaviors are influenced by workgroup norm and management norm, and workers' project identification intensifies the relationship between management norm and safety behavior and attenuates relationship between workgroup norm and safety behavior.

4 MODEL DEVELOPMENT

The agent-based model in this paper integrates the cognitive process and social influence process of workers' safety behavior. A theoretical model of the cognitive process and empirical findings regarding social influence from Choi et al., (2016) are incorporated into the model to establish behavioral rules in the model.

Figure 1 shows a structure of the model. The model simulates construction workers (i.e., agent) who are working on an artificial project. When the model is initialized, a site condition and all workers in the project are created and stored initial values of the site condition and workers. The site condition has two attributes; site risk and strictness of management feedback. The site risk refers to the hazard level of the project with a range between 0 and 1. It includes the probability, that workers in the project are exposed to unsafe work condition, and the severity of the risk that workers are exposed. The strictness of management feedback refers how strictly management regulates to workers' unsafe behavior and is defined as *1-risk acceptance*. As such, high strictness (i.e., low-risk acceptance of management) implies that management does not tolerate a small risk at the project.

At every time step, every worker is exposed to a safe or unsafe work condition. The probability of the unsafe condition is determined by the site risk.The worker performs a safe behavior if the worker is exposed to the safe condition and does not make a mistake. On the other hand, the worker is provided with the value of actual risk if the worker is under the unsafe condition. The value of actual risk is also determined by the site risk. For example, if the site risk is 0.75, there is a 75% chance that a worker is exposed to the unsafe condition, and the average of actual risk that a worker will encounter is 0.75. Previously, the actual risk was assigned based on the uniform distribution between *the average actual risk - 0.25* and *average actual risk + 0.25* (Choi and Lee, 2017). This modeling assumption has been re-evaluated and revised because there is zero probability that workers are exposed to the actual risk out of the uniform distribution range. For example, if a worker is under 0.75 site-risk condition, it is impossible for the worker to encounter the actual risk below 0.5. To address this issue, the actual risk is assigned based on the beta distribution which is defined as a continuum between 0 and 1 in this paper.

In the case of the unsafe condition, cognitive processes are activated to determine a reaction to the exposed risk. In other words, the worker perceives the risk (i.e., risk perception) and determines whether the perceived risk is acceptable or not (i.e., risk assessment). First, the risk perception refers to a worker's subjective judgment on the actual risk and thus perceived risk may vary from worker to worker even under the same actual risk (Shin et al., 2014). The subjective tendency to overestimate or underestimate the risk is defined as risk perception coefficient in the model, and the risk perception coefficient is associated with individual's risk attitude. For example, a worker who has a risk-seeking attitude tends to underestimate the actual risk and overestimates their ability to control the situation. As such, a risk-seeking worker's risk perception coefficient will be below 1.0.

After perceiving the risk, the worker assesses the risk and determines safety behavior (i.e., safe or unsafe behavior) by comparing the perceived risk and risk acceptance. The risk acceptance also varies from worker to worker because some workers are more open to take the risk while others are reluctant to accept the risk. In the model, the risk acceptance is determined using the empirical results from Choi et al., (2016). As shown in Equation (1), the risk acceptance is affected by risk attitude, workgroup norm, and management norm, Also, the relationship between safety norms (i.e., workgroup norm and management norm) and risk acceptance is moderated by

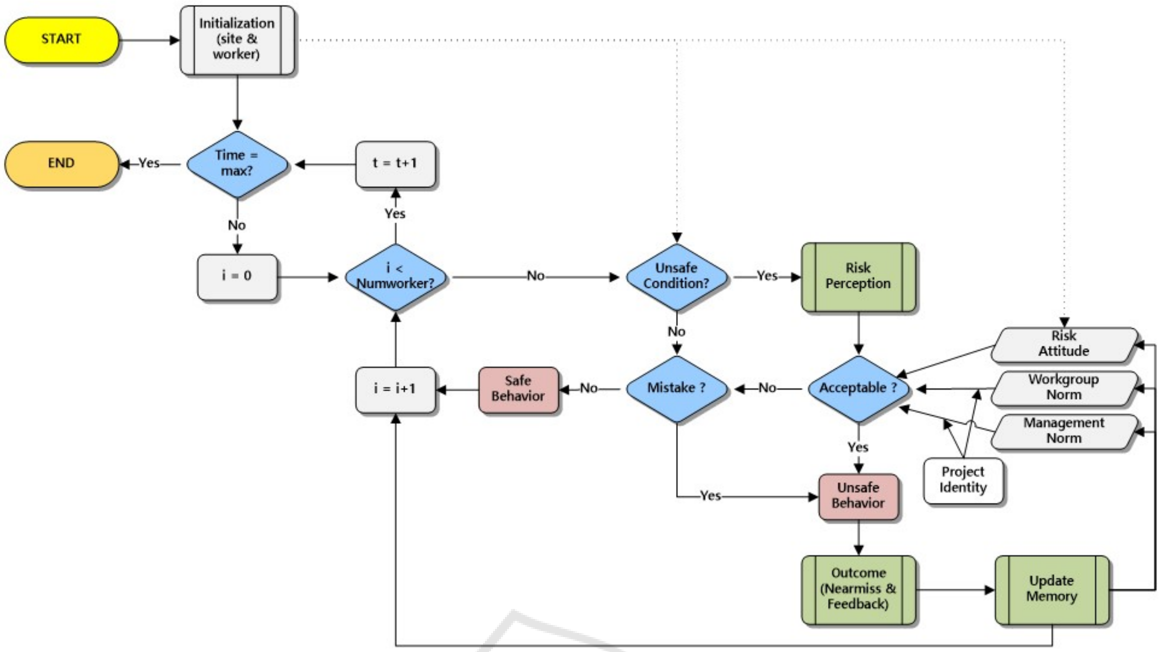

Figure 1: Flowchart of Model Structure.

project identification.

$$RA_i^t = (1 - w_i)AT_i^t + w_i((1 - pj_i)WN_i^t + pj_i MN_i^t) + \varepsilon \qquad (1)$$

where i = worker i; RA = risk acceptance; AT = risk attitude; WN = workgroup norm; MN = management norm; pj= project identification, w = weight on social influence, and t = current time step.

To determine the risk acceptance, the worker observes coworkers' safety behavior and perceives the workgroup norm. The workgroup norm in the model is defined as an individual worker's perception of coworkers' risk acceptance and is determined by coworkers' safety behavior. If the worker witnesses a coworker's unsafe behavior, the worker will assume that the coworker performs the unsafe behavior because his/her risk acceptance is higher than current risk. On the other hand, in the case of observing the safe behavior, the worker's perception of the coworker's risk acceptance will be lower than the current risk. Also, the management norm is defined as an individual worker's perception of management's risk acceptance at the current project. Likewise to the workgroup norm, a worker's management norm is determined by his/her experience of management feedback on the unsafe behavior. If a worker receives safety feedback from management on his/her unsafe behavior, he/she will conclude that the current risk is not acceptable to the management. In other words, his/her perception of risk acceptance of management (i.e., management norm) is lower than the perceived risk. On the other hand, if there is no feedback from management even if the worker performs an unsafe behavior, the worker will conclude that risk acceptance of the management is greater than the perceived risk. Finally, if the worker carries out a safe behavior, there will be no changes in the worker's management norm.

After assessing the perceived risk, the worker will try to perform a safe behavior if the perceived risk is higher than his/her risk acceptance. On the other hand, the worker will perform an unsafe behavior if the perceived risk is acceptable which means the perceived risk is lower than his/her risk acceptance. The worker's unsafe behavior can result in a near miss or accident. On the other hand, it is possible that nothing happens to the worker because all unsafe behaviors do not necessarily lead the near miss or accident. The probability of the near miss or accident occurring is determined by the actual risk which is assigned based on the site risk at the beginning of each time step. If the worker experiences a near miss or accident, he/she will become more risk-averse because he/she realizes the risk in the workplace. In the case of happening nothing, optimistic recovery makes the worker more risk-seeking (Shin et al., 2014).

Every time step, every worker has a chance to perform the safety behavior. The order of performing the safety behavior is randomly determined to avoid possible bias due to the order of performing safety behavior. After completing all workers, the model collects the group-level behaviors such as unsafe behavior ratio and moves on to the next time step. The model repeats the process until the time reaches the predefined maximum time step.

5 VALIDATION

Before conducting the experiment, the model validity is examined by testing whether the developed model is qualitatively consistent with empirical findings of the literature regarding construction workers' safety behavior based on the method suggested by Ahn and Lee (2015). First, the developed model successfully reproduces the effect of risk attitude on workers' safety behavior in previous studies (Cooper, 2000). Also, the model reaffirms the empirical findings of the separate effects of workgroup norm and management norm on workers' safety behaviors (Meli et al., 2008). Finally, the moderating effect of workers' social identification with the current project on the relationship between social norms (i.e., workgroup norm and management norm) and safety behavior (Choi et al., 2016) is also reproduced by the developed model.

6 SIMULATION EXPERIMENT

To investigate how workers' socio-cognitive process interacts with management and site condition, impacts of the strictness of management feedback on workers' safety behaviors are investigated in different site risk conditions. The impact of the strictness of management feedback is tested by applying different values in the model and comparing the results (i.e., parameter sweep). For this purpose, the mean of unsafe behavior ratio of all workers for each of the 150 simulated days is measured. The range of the strictness of management feedback is determined from 0.1 to 0.9 because extremely lenient or strict management feedback do not reflect safety management practices. Also, the parameter sweeps are repeated in three different site risk conditions (i.e., low (0.25), modest (0.5), and high-risk (0.75) site conditions) to explore the effects of interactions between the socio-cognitive process, management feedback, and site condition.

In addition to the strictness of management feedback, effects of the cohesiveness of management feedback are investigated using another experiment. The impact of the cohesiveness of the management feedback is tested by applying different ranges of the strictness of management feedback with the same mean in the model and compare the unsafe behavior ratio. A wider range of the strictness means less cohesive management feedback. The mean of the strictness of management feedback is determined 0.7 because construction managers typically have a relatively strict standard regarding safety behavior (Choi et al., 2017). The simulation is repeated in three different ranges of the strictness of management feedback (i.e., high cohesiveness; Uniform distribution [0.7, 0.7], medium cohesiveness; Uniform distribution [0.55, 0.85], and low cohesiveness; Uniform distribution [0.4, 1.0]) in the modest-risk condition (0.5).

Common parameter settings for each simulation is described in Table 1. A 200-worker organization, which consists of 20 crews and each of crew has 10 workers, is simulated. Within each crew, every worker is able to observe coworkers' safety behaviors, while observation across crews is limited in the model (Ahn et al., 2013). At the beginning of the simulation, workers are initialized with the value of the risk perception coefficient and risk attitude which are randomly assigned based on the uniform distribution with the consideration of heterogeneity of the workers. Finally, the value of the weight of social influence in Equation (1) is determined based on the result of Choi et al., (2016).

Table 1: Common parameter settings for simulations.

Parameter	Setting
Number of workers	200 (20 x 10)
Simulation days	150
Within-crew connection probability	1.0
Outside-crew connection probability	0.03
Risk perception coefficient	Uniform distribution [0.6, 1.2]
Risk attitude	Uniform distribution [0.1, 0.9]

7 RESULTS & DISCUSSION

For the first experiment. the experiment runs 270 simulations for each value of the strictness of management feedback (from 0.1 to 0.9) and site risk (i.e., 0.25, 0.5, and 0.75) to produce a sufficiently large sample size. Statistical significance of the effect of the strictness of management feedback is examined using MannWhitney U test because the data could not guarantee the assumptions required for parametric statistical test (i.e., normality assumption). To examine the effect of the strictness, differences in the unsafe behavior ratio between the low (0.2) and medium level (0.5) of the strictness and between the medium

(0.5) and high level (0.8) of the strictness are tested in the three different site risk conditions. Since data in medium strictness are used in both of the comparisons, the results of MannWhitney U are corrected by Bonferroni correct to address multiple comparison issue.

Figure 2 shows the effect of the strictness on workers' safety behavior in the modest-risk condition. In Figure 2, the horizontal axis represents changes in values of the strictness, and the vertical axis refers to the unsafe behavior ratio. As shown in Figure 2, the strictness of management feedback contributes to reducing workers' unsafe behavior in the modest-risk condition. First, there are significant differences in the median of the unsafe behavior ratio between high strictness (Mdn = 0.355) and medium strictness (Mdn = 0.380), U = 865,140.0, $p = 2.38 \times e^{-63}$. Also, significant differences between medium strictness (Mdn = 0.380) and low strictness (Mdn = 0.395), U = 1,030,089.0, $p = 2.82 \times e^{-26}$ are found while the differences are are less than the previous comparison.

The significant effects imply that the strictness of management feedback is directly associated with workers' perception of management norm and reduces workers' unsafe behaviors. Workers are more likely to receive safety feedback from management and decrease their risk acceptance if management has stricter risk acceptance because the management will not ignore the small risk and give safety feedback toward unsafe behaviors. In addition, patterns of the effects of the strictness can be found in Figure 2. In very lenient management feedback situation (i.e., from 0.1 to 0.3), changes in the strictness have very limited impact on the unsafe behavior ratio. For example, differences in the median between 0.1 strictness (Mdn = 0.395) and 0.2 strictness (Mdn = 0.395) are not significant, U = 1,312,200.0, p = 0.499. However, the impact becomes significant as the strictness increases.

The effects of strictness of management feedback on safety behavior in the low-risk condition are represented in Figure 3. As shown in Figure 3, the strictness of management feedback has a relatively weaker impact on safety behavior than in the modest-risk condition. The effects of the strictness on safety behavior are significant only in very strict condition (from 0.7 to 0.9). Differences in the median of unsafe behavior ratio between low strict (Mdn = 0.280) and medium strict (Mdn = 0.280) management feedback are not significant, U = 1,309,279.5, p = 0.912. On the other hand, there are significant differences between medium strict (Mdn = 0.280) and high strict (Mdn = 0.275), U = 1,143,821.0, $p = 2.43 \times e^{-10}$.

Figure 4 represents the effects of strictness of management feedback on workers' safety behavior in

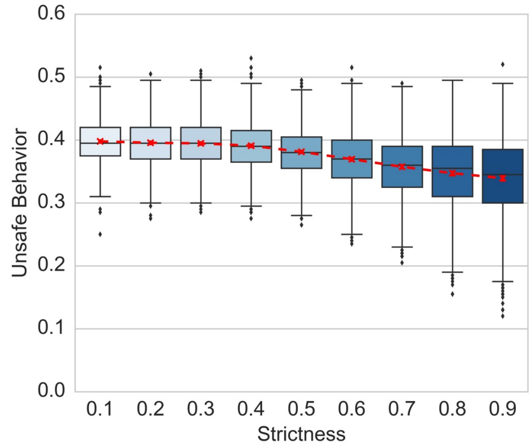

Figure 2: Influence of the Strictness of Management Feedback in Modest-Risk Condition.

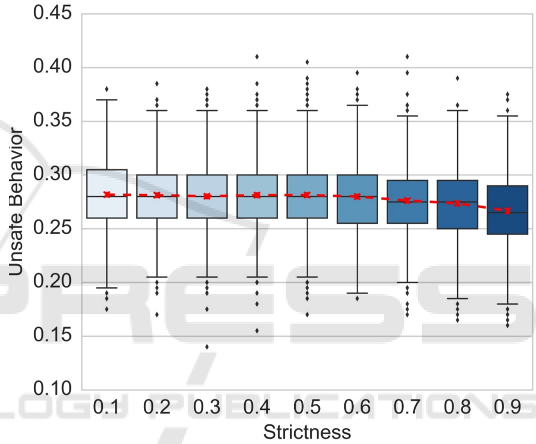

Figure 3: Influence of the Strictness of Management Feedback in Low-Risk Condition.

high-risk condition. As shown in Figure 4, the strictness of management feedback reduces workers' unsafe behavior in the high-risk condition. The median of the unsafe behavior ratio in low (Mdn = 0.400) and medium (Mdn = 0.350) strictness varies significantly and shows meaningful differences, U = 658,044.0, $p = 2.05 \times e^{-133}$. Also, there are significant differences between medium (Mdn = 0.350) and high (Mdn = 0.325) strictness in the high-risk condition, U = 1,032,552.0, $p = 8.12 \times e^{-26}$. Also, patterns of the effects can be found in Figure 4. While the strictness has significant effects on unsafe behaviors in the low and medium level of strictness, the effects become limited very strict condition (i.e., from 0.8 to 0.9). For example, differences in the median between 0.8 strictness (Mdn = 0.325) and 0.9 strictness (Mdn = 0.325) are not significant, U = 1,300,326.5, p = 0.328.

One possible explanation of the limited impact of the very strict management feedback is that the modest strict management feedback (i.e., 0.7 or 0.8) is already strict enough to cover the risk in the high-risk condition because workers in this condition are more likely to be at a high level of risk. Also, the line connects the mean of unsafe behavior ratio in each strictness value shows inverse "S" pattern. While slope of the line stays stable in lenient and strict condition, the slope becomes relatively steep in modest strict condition (from 0.3 to 0.7). It implies that construction managers should first have the medium level of management strictness to reduce workers' unsafe behavior in the high-risk condition. Then, the construction managers should find other ways to improve workers' safety behavior such as increasing the frequency of management feedback or promoting workers' project identification.

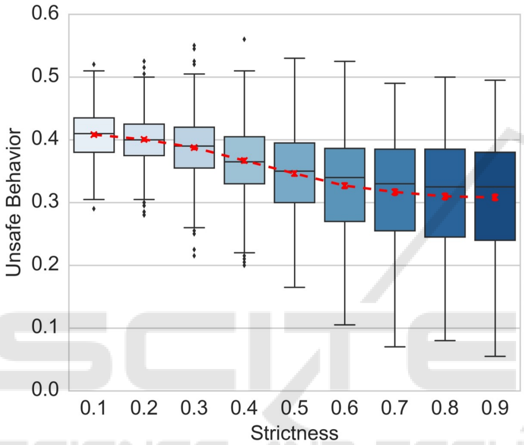

Figure 4: Influence of the Strictness of Management Feedback in High-Risk Condition.

The effects of the cohesiveness of management feedback on safety behavior are represented in Figure 5. As shown in Figure 5, while the cohesiveness contributes to reducing workers' unsafe behavior when the cohesiveness becomes medium level, the cohesiveness does not affect safety behavior after achieving a medium level of the cohesiveness. There are significant differences between low cohesiveness (Mdn = 0.355) and medium cohesiveness of management feedback (Mdn = 0.335), U = 3,624.0, p = 0.001.

This is because if the strictness of the management feedback has a wider range (i.e., low cohesiveness), management ignores the large risk when the strictness of management becomes very low (i.e., negative effect of low cohesiveness of management feedback). In such case, workers may perceive very low management norm, which increases workers' risk acceptance and unsafe behaviors. Although it might also be possible that management sometimes is sensitive to the small risk in the low cohesiveness condition (i.e., positive effect), the positive effects are limited to recover the negative effects. On the other hand, differences in the median of unsafe behavior ratio between medium cohesiveness (Mdn = 0.335) and high cohesiveness of management feedback (Mdn = 0.335) are not significant, U = 4,987.5, p = 0.976. It implies that management should achieve at least medium level of the cohesiveness of management feedback in order to prevent the negative impacts of the low cohesiveness of management feedback on workers' safety behaviors.

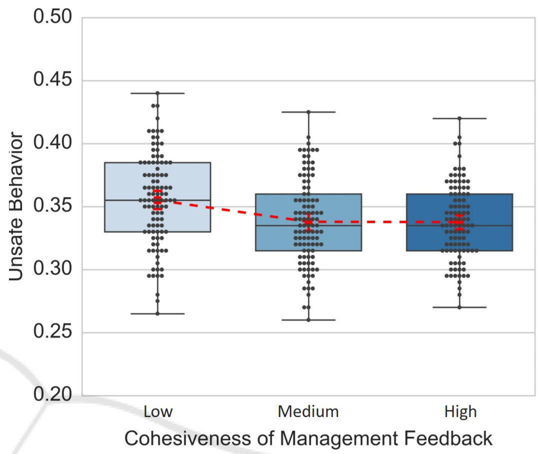

Figure 5: Influence of the Cohesiveness of Management Feedback.

8 CONCLUSIONS

In this study, an agent-based model has been developed to simulate workers' socio-cognitive process of safety behavior and its interaction with management interventions (i.e., strictness and cohesiveness of management feedback) and different site conditions (i.e., site risk). The theoretical model of a cognitive process (e.g., the theory of risk homeostasis) and empirical findings regarding social influence on workers' safety behavior (e.g., (Choi et al., 2016)) are incorporated to simulate workers' socio-cognitive process of safety behavior. By running simulations on the model with different strictnesses and cohesiveness of management feedback in different site risk, it has been demonstrated that (1) the strictness of management feedback has significant impact on reducing workers' unsafe behavior in the modest-risk condition, but the impacts are not limited in the lenient management feedback, (2) the strictness of management feedback only affects workers' safety behavior with very strict management feedback in the low-risk condition, (3) the effect of strictness of management feedback on workers' safety behavior is significant, but the impact of very strict management feedback becomes limited in the high-risk condition, and (4) construction managers should at least achieve the medium level of cohesiveness to avoid negative results. This paper contributes to the body of knowledge on construction safety as well as simulation literature by developing the socio-cognitive process model of workers' safety behavior that examines how the socio-cognitive process interacts with management and the site condition.

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