Impact of the Dynamicity of Workgroup Changes on Social Influence of Construction Workers' Safety Behaviors

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ABSTRACT

Recently, researchers have paid increased attention to the social and cognitive aspects of workers' safety behaviors. In the same vein, researchers have begun modeling the socio-cognitive process of workers' safety behaviors. However, an inquiry into the impact of workgroup changes on social influence remains limited. Workgroups in a construction project dynamically change because workers enter and leave according to the project schedule. Considering that changes in workgroups affect the social network of the project, and the transmission of the social norms occurs through the social network, workgroup changes should be considered. In this paper, an agent-based model is developed to investigate how the dynamicity of workgroup changes affects the socio-cognitive process of workers' safety behavior. Three experiments examining the effect of the dynamicity of workgroup changes (i.e., static (no turnover), mildly dynamic (modest turnover), and highly dynamic (high turnover) change) in three site risk conditions (i.e., low, modest, and high site risk conditions) were conducted. The results indicate that while the incident rates for the static and mildly dynamic changes are significantly higher than the highly dynamic changes in the modest and high-risk condition, the differences in the incident rates for the three dynamicity changes are not significant in the low-risk condition. The findings provide construction practitioners with insight into the development of safety management interventions by exploring the interaction between the workgroup changes and site risk conditions. Also, this study contributes to the body of knowledge of construction safety by testing the importance of the workgroup changes in the socio-cognitive process of workers' safety behaviors.

INTRODUCTION

Despite advancements in technologies and managerial practices, safety remains a significant concern for successful construction management. Previous studies have reported that workers' unsafe acts are attributable to more than 80% of construction accidents (Heinrich et al. 1980). Given the importance of workers' safety acts, increased attention has been paid to the socio-cognitive process of workers' safety behaviors. Such efforts have suggested cognitive process models of workers' safety behavior such as Generic Error Modeling System (GEMS) (Reason 2000), Step Ladder

Model (SLM) (Rasmussen 1986), Cognitive Model of Construction Workers' Unsafe Behaviors (CM-CWUB) (Fang et al. 2016), and so forth. Although there are some variations in details, risk perception, risk assessment, and decision-making are emphasized in all the models. Also, a number of empirical studies have demonstrated that informal social controls such as safety climate, safety norms, and safety culture are critical determinants of construction workers' safety behaviors (Lingard et al. 2011).

Based on the previous studies on the socio-cognitive process of workers' safety behaviors, researchers have recently been adopting computer simulation models to enhance our understandings. These efforts have employed agent-based modeling where behavioral rules for the individual agent are created and used to investigate how the socio-cognitive process can affect workers' safety behavior (Choi and Lee 2017; Liang et al. 2018). The previous works simulated an artificial construction project where all workers stayed on the project during the entire duration of the project and explored how the socio-cognitive process interacts with the environment, such as site-risk conditions as well as diverse safety management interventions (e.g., frequency, strictness and cohesiveness of safety feedback and stimulation of project identity).

KNOWLEDGE GAPS AND RESEARCH OBJECTIVES

Although the previous works deepen our understanding of the socio-cognitive mechanism of workers' safety behavior, they are not without limitations. In the previous works, all the agents (i.e., workers) were created at the beginning of the simulation, and there were no changes in workers during the simulation. In other words, the organizational structure in the previous works is similar to the permanent organizations. However, workgroups in many construction projects can dynamically change because workers enter and leave (i.e., worker turnover) according to the project schedule. Considering that the structure of workgroups affects the social network of the project, and the transmission of the social norms occurs through the social network, workgroup changes should be considered in modeling the socio-cognitive process. As such, the impact of workgroup changes on the socio-cognitive process of workers' safety behaviors remains unclear.

To fill the knowledge gap, the purpose of this study is to investigate how the dynamicity of workgroup changes affects the socio-cognitive process of workers' safety behavior. Specifically, this paper aims to answer the following questions: 1) does the dynamicity of workgroup changes have an impact on workers' safety behavior, and 2) if so, how does the dynamicity of workgroup changes affect workers' safety behavior under scenarios of different site risk conditions? To achieve the objectives, this paper has adopted behavioral rules in Choi and Lee (2017), and the model structure has been ameliorated to reflect workgroup changes during the simulation. Further, to investigate how the dynamicity of workgroup changes interacts with different site risk conditions, "thought experiments" will be conducted using the developed model.

MODEL DEVELOPMENT

The agent-based model simulates workers (i.e., agents) in an artificial construction site, and the artificial site is an environment where the agent interacts with. In the model, the agent makes a decision with respect to safety behavior and performs safe or unsafe behavior based on the behavioral rules at every time step. The behavioral rules in this model consider workers' interaction with coworkers, managers, and site risk. The model is initialized by creating an artificial construction site. The site has three attributes; project schedule, site risk, and strictness of management feedback on unsafe behavior. The project schedule determines how workgroups and workers are added to and remove from the project, and it also includes the size of each workgroup. The previous works (Choi and Lee 2017) did not take into account the project schedule, and all the workers are created at time zero and exist until the project conclusion. On the other hand, workers only for the first activities are created at time zero in this model, and workgroups for following activities will enter and leave the project based on the schedule. The site risk represents the degree of hazard of the project with a range between 0 and 1, and it includes the probability that workers encounter unsafe situations and the risk severity of the unsafe condition. The strictness of management feedback refers to the risk tolerance of the management. The strictness is operationally defined as 1 – risk tolerance of the management, and thus little risk tolerance refers to high strictness, which means the management does not ignore a little risk.

At every time step, all workers in the model are exposed to safe or unsafe work conditions based on the site risk. If the workers are in a safe condition, they practice safe behavior. On the other hand, in the case of the unsafe condition, workers determine response to the unsafe condition (i.e., safe acts or unsafe acts) by comparing their risk acceptance and the severity of the perceived risk. If the perceived risk is greater than workers' risk acceptance, they will practice safe acts and vice versa. The perceived risk and risk acceptance is the result of workers' socio-cognitive process. First, individuals' perceived risk includes subjective judgment of the actual risk, and it may not be the same as the actual risk (Rodríguez-Garzón et al. 2014). Some workers can overestimate the actual risk, and others can underestimate the actual risk, and the individuals' tendency to over/underestimate the risk is defined as risk perception coefficient (Shin et al. 2014). As such, each worker's perceived risk in the model is the product of actual risk and the worker's risk perception coefficient. As aforementioned, the site risk determines the severity of the actual risk at every time step. Also, workers' risk perception coefficient is affected by workers' risk attitude. For example, risk-seeking workers' risk perception coefficient will be below 1.0 because they underestimate risk and overestimate their ability to control the situation. Risk acceptance is defined as a function of risk attitude, workgroup norm, management norm, and project identity using the result of Choi et al. (2017b) as follows:

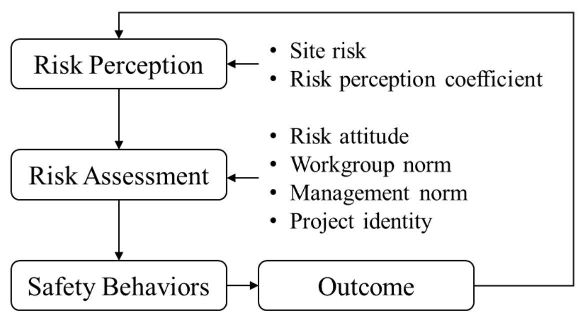


Figure 1 Agents' Decision-Making Process under Unsafe Condition

$$RA_i(t) = (1-s)AT_i(t) - s((1-PI_i)WN_i(t) + PI_iMN_i(t)) + \varepsilon \qquad (1)$$

where, $RA_i(t)$ is worker i's risk acceptance at time t, $AT_i(t)$ is worker i's risk attitude at time t, $WN_i(t)$ is worker i's workgroup norm at time t, $MN_i(t)$ is worker i's management norm at time t, PI_i is worker i's project identity, and s is weight on the social influence.

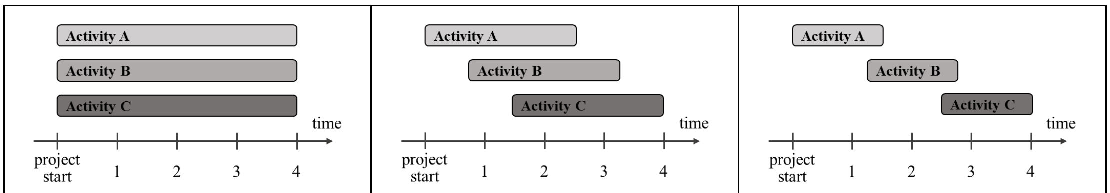
The workgroup norm in the model refers to a worker's perception of his/her coworkers' risk acceptance and is established by observing coworkers' safety behaviors. If a worker detects a coworker's unsafe acts under the unsafe condition, the worker's perception of the coworker's risk acceptance is greater than the actual risk where the coworker is currently exposed. In the model, the worker's perception of the coworker's risk acceptance is randomly selected between the actual risk and 1.0. In the model, each agent has a 95% chance to observe his/her workgroup members' safety behavior (i.e., clique) and a 5% chance to observe other workgroup members' safety behavior (i.e., sparse network) (Anderson et al. 2014). The management norm is defined as workers' perception of the management's risk acceptance and is formed based on the feedback from the management on their unsafe acts. If a worker receives safety feedback on his/her unsafe acts, he/she conceived that management in this project does not tolerate the current risk. In the case of not receiving any safety feedback, the worker interprets that the management in the current project accepts the current risk, which means the worker's management norm is greater than the perceived risk. Workers in the model are able to store 15 days' coworker's safety behaviors and safety feedback from the management.

Based on the result of the risk assessment, workers carry out safe or unsafe behaviors, and workers' unsafe behaviors can bring about near misses or accidents. On the other hand, it is also possible that nothing occurs to the workers. The probability of occurrence of the near-miss or accident is determined by the severity of the actual risk, which is derived from the site risk. The consequence of unsafe behaviors leads to adjusting workers' risk attitude. If a worker suffers a near miss or accident, he/she becomes more risk-averse because he/she actually discerns the possibility of an accident. However, if the worker does not experience anything, he/she becomes more risk-seeking because he/she gradually obliterates the possibility of the accident (i.e., optimistic recovery). In addition, worker's unsafe behavior is a source of safety feedback from the management. If a worker carries out unsafe behavior and the current risk that the worker encounters is greater than risk acceptance of the management, the worker will receive safety feedback from the management and vice versa.

At every time step, all workers are provided with safe or unsafe work conditions and carry out safe or unsafe behavior based on the severity of the actual risk and behavioral rules described before. After simulating all the workers' safety behaviors, the model calculates and stores group-level behaviors such as unsafe behavior ratio or incident rate and proceeds to the next time step. The model iterates these processes until the predefined maximum time step.

EXPERIMENTS

To investigate how the dynamicity of workgroup changes interacts with the socio-cognitive process of workers' safety behavior. Three experiments examining the effect of the dynamicity of workgroup changes (i.e., static (no turnover), mildly dynamic (modest turnover), and highly dynamic (high turnover) change) in three site risk conditions (i.e., low, modest, and high site risk conditions) were conducted. Under the static scenario, all the workers are created at time zero and stay until the project conclusion as the previous works (Figure 2 (a)). For the other two dynamicity scenarios, schedule data collected from two construction projects were used to the input data of the model. The mildly dynamic scenario represents a project where there are significant overlaps in time spent on site with other workgroups (Figure 2 (b)). This scenario represents a large-scale building construction project (e.g., university research building). The total duration of the project was about twenty-two months, and each workgroup in the project stays on the site for several months and is significantly overlapped with workgroups of precedents and successors in the schedule. The highly dynamic scenario represents even more dynamic projects where the workgroup comes and goes from the site quite rapidly, and thus there are limited overlaps in time spent among the workgroups (Figure 3 (b)). The highly dynamic scenario represents small building construction projects (e.g., a small elementary school renovation project). The project took place about eleven months, and each workgroup in the project stays on the site within a few weeks and has limited overlaps with other workgroups.



(a) Static Change | (b) Mildly Dynamic Change | (c) Highly Dynamic Change

Figure 2. Conceptual Diagrams of the Three Dynamicity Scenarios

Each experiment runs three hundred times for each configuration of the dynamicity scenario (i.e., static, mildly dynamic, and highly dynamic change) and site risk condition (i.e., low (0.25), modest (0.50), and high site risk (0.75)). Common parameter settings for each experiment are represented in Table 1. The values for the parameters related to individuals' attributes (i.e., project identity, initial risk attitude, risk perception coefficient) are randomly assigned based on the uniform distribution to reflect the heterogeneity of individuals. Specifically, the mean of risk perception coefficient is set below 1.0 because workers tend to underestimate the risk of external conditions and overestimate their ability to control the conditions (Lichtenstein et al. 1978). The value of the weight of social influence is determined using the result of Choi et al. (2017b). Lastly, the mean of the strictness of management feedback is set greater than 0.5 because the management has a somewhat strict standard with respect to unsafe behaviors (Choi et al. 2017a).

Table 1. Common Parameter Settings for Simulations

Parameter	Setting
Strictness of management feedback	Uniform distribution [0.5, 0.9]
Weight on social influence	0.75
Project identity	Uniform distribution [0.1, 0.9]
Initial risk attitude	Uniform distribution [0.1, 0.9]
Risk perception coefficient	Uniform distribution [0.6, 1.2]

RESULT AND DISCUSSION

In total, 2,700 simulation runs were run to investigate how workers' socio-cognitive process of safety behavior, dynamicity of workgroup changes, and site risk condition interact with to influence workers' safety behavior. Statistical differences in the incident rate of static, mildly dynamic, and highly dynamic workgroup changes are examined in the three site risk conditions to identify the impacts of the interaction on workers' safety behaviors. Results from each simulation are analyzed using the Kruskal-Wallis test, which is one of the non-parametric mean comparison methods because the normality assumption for the parametric statistical test could not meet.

Figure 3 shows the effect of interaction between dynamicity of workgroup changes and site risk condition on the incident rate. The incident rates of each configuration of the dynamicity and site risk condition in the experiment are represented in Figure 3. In the low site risk condition, the dynamicity of workgroup changes does not have a significant influence on the incident rate ($H = 4.22$, $p > 0.12$, $df = 2$). The incident rates of each dynamicity do not significantly vary each other (*Mean* (Static) = 1.31, *M* (Mild) = 1.27, and *M* (High) = 1.26). Also, the incident rates in the low site risk condition are significantly lower than modest and high site risk conditions. On the other hand, the mean differences in the incident rates of each dynamicity are statistically significant in the modest and high site risk conditions. In the modest risk condition, the mean differences between static (*M* (Static) = 3.72), mildly dynamic (*M* (Mild) = 3.60), and highly dynamic (*M* (High) = 3.31) workgroup changes are statistically significant ($H = 41.11$, $p < 1.18 \text{ x } e^{-09}$, $df = 2$). Specifically, the mean differences between the high dynamicity and mild dynamicity (0.29) are greater than between mild dynamicity and static workgroup changes (0.12). Lastly, the incident rates are found to be significantly different for each level of dynamicity in the high site risk condition (*M* (Static) = 4.38, *M* (Mild) = 4.20, *M* (High) = 3.58, $H = 91.75$, $p > 0.12$, $df = 2$) as well. The incident rate increases as the dynamicity of workgroup change decrease. The mean differences in the incident rate between high and mild dynamicity (0.62) are greater than between mild dynamicity and static workgroup change (0.18). Also, the incident rates in the high site risk condition are significantly higher than modest and low site risk conditions.

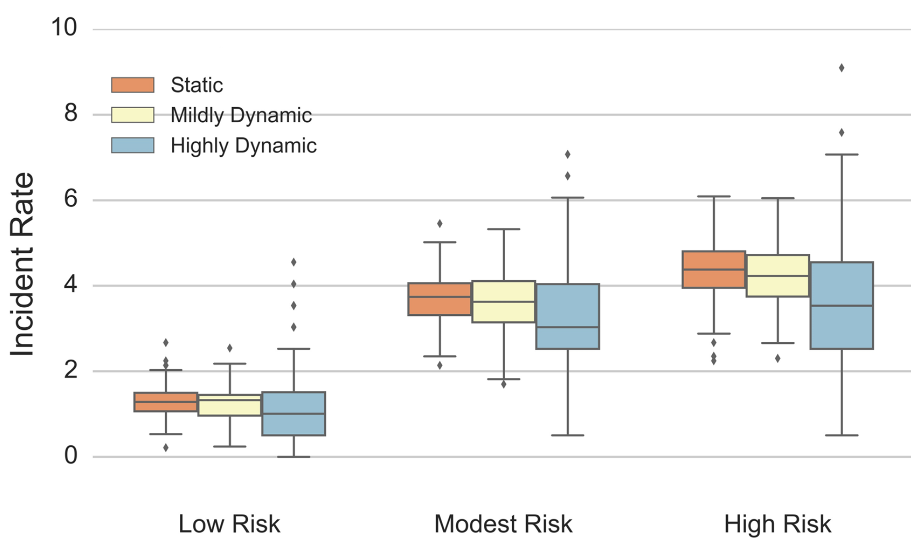


Figure 3. Interaction between Site Risk and Dynamicity of Workgroup Changes

The results of the experiment show a significant interaction between the dynamicity and site risk condition. While the dynamicity has no significant influence on the incident rate in the low site risk condition, more dynamic workgroup changes decrease the incident rate in the modest and high site risk condition. The result indicates how different types of social learning in construction projects affect the incident rate. Social interactions among the workers in the highly dynamic project are limited within the workgroup because there is a limited overlap in time spent with other workgroups. On the other hand, workers in the static and mildly dynamic projects may have more chances to interact across the workgroups. As such, the higher incident rates in the mildly dynamic and static workgroup changes imply that social learnings across the workgroup in the modest and high site risk condition have a negative influence on workers' safety behavior and ultimately increase the incident rate. In other words, workers who enter the project in the middle of a project may learn lenient safety norms from the workers who already worked for the project. However, workers in the highly dynamic project leave the project before they learn the negative safety norms from other workgroups because of their limited interaction with other workgroups and short tenure in the project.

CONCLUSION

In this study, an agent-based model is developed that simulates construction workers' safety behavior in order to examine how the socio-cognitive process of workers' safety behavior interacts with the dynamicity of workgroup changes and site risk conditions. The behavioral rules from Choi and Lee (2017) have been adopted to the model, and the model structure has been modified to reflect the schedule of the project. By running the simulation on the model with the different dynamicity of workgroup changes in different site risk conditions, it has been demonstrated that the incident rate in the highly dynamic situation is marked lower than the mildly dynamic and static situation in the modest and high site risk conditions. However, the dynamicity has no influence on the incident rate in the low site risk condition. This result indicates that interaction between the dynamicity of workgroup changes and site risk condition creates a harmful impact on workers' safety behavior. Considering that more construction projects have been adopting overlapping between the activities to reduce the total duration of the project, this finding provides important insights into the construction practitioners. Construction practitioners in the modest and high-risk project should pay more attention to establish positive safety norms and climates to prevent the harmful impact of the interactions. This study contributes to the body of knowledge of construction safety by testing the importance of the workgroup changes in modeling the socio-cognitive process of construction workers' safety behaviors

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