Framework for a resilience system in safety management: a simulation and visualization approach

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Abstract

Because workers’ behavior and attitudes toward safety are crucial factors affecting the likelihood of construction accidents, traditionally, surveys have been taken or field observations conducted at a site to measure the safety climate. Although most accidents are directly or indirectly related to persons’ unsafe acts, such traditional methods have practical limitations for periodic application at a site in terms of workers’ participation, the efficiency of observation, and the absence of an expert. Thus, safety management could be improved if workers’ behavior could be monitored and analyzed automatically and if the measured result could be used to predict future risk. This paper presents a conceptual framework for a resilience system that uses a simulation and visualization approach to manage safety behavior. A computer vision technique capable of motion detection is introduced to monitor workers’ behavior with video cameras and to automatically analyze their level of unsafe acts. The procedures for and pace of activities are assumed to change under progress pressure, so any change may represent the amount of pressure workers perceive that may lead them to engage in unsafe acts. By detecting workers’ motions related to back injury, their attitudes toward safety can also be measured, based on the assumption that their attitudes should be managed if they repeatedly use unsafe poses after receiving education about back injuries. A system dynamics model was established from the perspective of resilience engineering to represent the safety culture at a site, and as the results are input, the organization’s level of safety is simulated to examine potential threats and restore safety to an acceptable level. This framework is expected to illustrate the applicability of a computer vision technique for safety climate measurement and to demonstrate the usability of a system dynamics model for a resilience system.

Keywords: safety, system dynamics, resilience engineering, visualization

1 Introduction

Workers’ behavior and attitudes toward safety are crucial factors affecting construction accidents; approximately 80 to 90% of accidents are directly or indirectly related to persons’ unsafe acts or to their unsafe behavior (Heinrich et al. 1980; Helen and Rowlinson 2005). Therefore, to measure a safety climate implicating workers’ behavior and attitudes, surveys have been taken or field observations conducted at a site. Certain characteristics of the construction industry, however, create practical limitations for periodically applying such traditional methods at a site, namely, (1) how actively workers will participate in a survey each time; (2) how efficiently an observer or surveyor can measure workers’ behavior and attitudes; and (3) who will analyze the measurement at a site. In
In this respect, any efficient and practical methodology for monitoring and analyzing workers’ behavior would play an important role in improving safety management.

This paper presents a conceptual framework for a resilience system that uses a simulation and visualization approach for safety behavior management. A resilience system for safety management was proposed to predict future risk and prevent it in advance with a simulation model using leading indicators as inputs (Han et al., 2009). In this paper, first, the literature is reviewed to provide existing applications of computer vision techniques in the construction industry and the technologies available for safety management. To establish the resilience system, a computer vision technique using video cameras is applied to monitor and analyze workers’ behavior automatically in terms of construction safety. Because this allows workers’ behavior to be monitored constantly without their participation and the measurements to be analyzed without a safety expert on site, it is expected to contribute to the improvement of site safety management. By applying the analytical results to a system dynamics model, which was established to simulate changes and interactions in a safety culture, an organization’s level of safety can be predicted and managed to maintain an acceptable level of safety.

The methodologies proposed in this paper provide site managers with a method to monitor workers’ behavior, which previously has not been efficiently managed at a site. Moreover, by applying the results to a simulation model, an organization’s safety level can be simulated and estimated to decrease the potential risk of accidents in advance. Thus, the framework established here helps illustrate the applicability of computer vision techniques for safety climate management and demonstrates the usability of a system dynamics model for a resilience system.

2 Literature review

Computer vision techniques have the advantage of automation in monitoring, tracking, and data acquisition. Hence, recent research has attempted to apply these techniques in the construction industry. For example, Gong and Caldas (2009) applied a video computing method to obtain productivity information automatically from images extracted from videos of crane operations; Peddi et al. (2009) analyzed human poses to measure construction productivity automatically in real time; Weerasinghe and Rewanpura (2009) applied techniques using video images with thermal images and audio to detect workers’ status and productivity; Cordova et al. (2009) tracked 3-dimensional positions of objects, such as an excavator bucket and worker, using the images extracted from two video cameras; and Teizer and Vela (2009) applied and compared existing computer vision techniques for tracking a worker to investigate the feasibility of techniques using video cameras. These techniques also have the potential to be applied for safety management; thus, the focus of this study is on workers’ behavior in safety management to understand the safety culture at a site.

Studies on computer vision have been actively ongoing in the computer science domain, and various techniques available for construction safety have been studied. Lao et al. (2008) conducted research on motion detection to identify human poses automatically from images, such as walking, pointing, kicking, leaping, and falling. Akbarzadeh et al. (2006) studied a three-dimensional model reconstruction to establish a virtual three-dimensional model from images taken from various angle points, and Golparvar-Fard et al. (2009) applied the technique to research in the construction industry to monitor the progress of a project. Studies on motion and time sequence analysis are applicable for tracking and route monitoring, and these have been applied in the construction industry as mentioned.

3 Framework for a resilience system

With the development of information technologies, surveillance cameras have increasingly been installed at construction sites to monitor workers and the sites. However, the application of video cameras has been limited to monitoring functionality in the construction industry even though it has
the potential to provide more useful information for project management, such as productivity, quality, and safety; thus, the focus of this paper is on an application for safety management. To improve safety management, a computer vision technique was technically applied for behavioral sampling observations, and resilience engineering was explored from a managerial perspective.

Field observation is among the methods used to measure workers’ behavior, and it has been applied in behavior-related research. For example, in a field experiment, Lingard and Rowlinson (1997) applied it in the construction industry to assess behavior-based safety management, and Cooper and Phillips (2004) found that with sufficient data, the relationship between a safety climate and safety behavior could be evaluated. Thus, in this paper a behavioral sampling observation is applied as a method to monitor construction workers and measure their behavior. Here, the concept of resilience engineering is adopted to predict the organization’s safety level in terms of the safety climate, based on the workers’ behavior measured, because the approach facilitates an organization’s ability to identify changes and restore the safety level (Schafer et al., 2009). Based on a resilience engineering approach, the safety culture was studied using a system dynamics model (Han et al., 2009), and the model was adopted in this paper to evaluate an organization’s safety level using the behavioral data measured with computer vision techniques. The framework for a resilience system that applies a computer vision technique and a simulation model is shown in Figure 1, and the two approaches are explained in more detail in the next section.

3.1 Behavioral sampling observation with a computer vision approach

A motion detection technique is available to conduct automated behavioral sampling observations of construction workers. Images taken from video cameras installed on a site are used to monitor and analyze workers, and workers’ motions are detected with a computer vision technique. To be detected, unsafe actions need to be defined in advance. Workers’ unsafe actions, the pace of work, and work procedures are monitored to measure workers’ perceptions of progress pressure, and unsafe poses used by workers that could cause back injury are also detected to evaluate workers’ attitudes toward

![Figure 1. IDEF0 diagram for a resilience system using a computer vision technique and a simulation model.](image-url)
safety. Through a motion and time sequence analysis, the previously defined motions are recognized and used as inputs for evaluating workers’ behavior.

In this paper, it is assumed that the procedures and pace of activities change under progress pressure, so any change in them may represent the extent to which workers perceive progress pressure that may lead them to engage in unsafe acts. For example, workers might tend to find shortcuts and skip a safety-related procedure under progress pressure. Hinze and Parker (1978) studied the relationship between progress pressure and safety and found them to be correlated; therefore, this study uses constant monitoring, which will contribute to a realistic understanding of the extent to which workers act in unsafe ways under progress pressure. To identify the changes in workers’ behavior, work procedures and the pace of work are monitored to examine the extent to which they sufficiently represent the activity as a prototype. Based on the data accumulated, work procedures and the pace of work are monitored in real time and compared with the prototype representing the regular status of the project. In cases in which the work procedures and pace of work are different from the statistical data, the possibility exists that workers may feel progress pressure and may act in unsafe ways. Thus, a manager or supervisor needs to supervise them more closely in advance to prevent an accident.

By detecting workers’ motions related to the potential for back injury, workers’ attitudes toward safety are also measured, based on the assumption that their attitudes are considered unsafe when they repeatedly use unsafe poses after receiving education on back injuries. The objective of safety education is to instruct workers to decrease the number of unsafe acts. However, repeating unsafe acts after receiving safety education shows that the safety education failed to educate the workers, and it may be related to workers’ attitudes toward safety. To measure workers’ attitudes, motions that may cause a back injury are detected and monitored since in construction, back injuries accounted for about 20% of nonfatal occupational injuries and illnesses requiring days away from work in 2005 (CPWR, 2008). For example, hurried movements can have an impact on the muscles in the back, twisting can cause a back injury when workers are lifting a heavy object, and bending at the back, not at the knees, contributes to back injury. These unsafe poses causing a back injury are defined and detected using a computer vision technique. Thus, the approach can monitor not only the risk of workers’ having a back injury but also workers’ attitudes.

3.2 Resilience engineering using a simulation approach

Resilience engineering aims at proactive management by identifying a safety level and a change in the organization and restoring the organization’s safety level within an acceptable state to prevent future risk. To establish a resilience system for construction safety management, a system dynamics model was proposed that focuses on the safety culture; in the model, leading indicators, such as workers’ behavior and employees’ perceptions, as measured by observations and surveys, were input to predict the future safety level of an organization (Han et al., 2009). In this paper, the safety level based on workers’ behavior and attitudes is automatically evaluated in comparison with the information extracted from video cameras, and the result is analyzed to anticipate an organization’s safety level.

Broadly, the system dynamics model consists of leading indicator variables and variables related to the safety culture. A leading indicator is a measurable and observable characteristic that has a strong relation to safety (Herrera and Hovden, 2008), so by monitoring the leading indicators, an organization’s safety level can be understood and estimated. Additionally, by using information gained from a review of the literature on safety cultures and safety climates (Cooper 2000; Choudhry et al. 2007; Goldberg et al. 1991; Mohamed 2002), variables related to a safety culture are implemented, and a safety climate, safety behavior, and a safety management system are modeled, with the focus on their interactions. The system dynamics model simulates an organization’s safety level using the behavioral data measured at a site, and as a result, potential risk is identified through the simulation.
In cases in which the simulated results reveal that the organization’s safety level is or would be in an unacceptable state, corrective management action needs to be taken to prevent an accident. For example, safety education and training can be applied if workers’ unsafe acts are derived from their lack of safety knowledge, and enforcement, incentives, or penalties can be applied to improve workers’ attitudes if their unsafe acts are caused by inattention or a neglect of safety. The simulated results would facilitate discovery of the potential causes of future risk, and managers could decide on corrective actions that need to be executed based on safety standards, regulations, and their experience.

4 Conclusion

A conceptual framework for a resilience system for safety management using a simulation and visualization approach was presented. A computer vision technique available for motion detection was introduced as a means to constantly monitor workers’ behavior with video cameras and to automatically analyze their level of unsafe acts. It is assumed that procedures and the pace of activities change under progress pressure, so any change in them may represent the extent to which workers perceive progress pressure. By detecting workers’ motions related to back injury, their attitudes toward safety can also be measured, based on the assumption that their attitudes should be managed if they repeatedly use unsafe poses after receiving education on preventing back injuries. The system dynamics model was established from the perspective of resilience engineering to represent the safety culture at a site, and as the results of the analysis are input, the organization’s level of safety is simulated to examine potential threats and restore safety to an acceptable level. The framework presented in this paper would contribute to illustrating the applicability of a computer vision technique for safety measurement and would demonstrate the usability of the system dynamics model for a resilience system.

As future work, the assumptions established to measure workers’ behavior and attitudes require investigation. By comparing the behavior level measured by the computer vision technique with the results of a survey, the assumption that it can be used as a method to measure behavior could be proved. Moreover, the accuracy of motion detection could be examined through field observations. If a comparison were done between the results of manual observations and automated observations, the accuracy of the technique could be revealed. Because monitored activities would already be recorded with a video camera, manual observations could easily be conducted, and these would provide accurate results. Furthermore, because the system dynamics model of a safety culture was constructed mainly based on a review of the literature, the model needs to be tested with actual data. Research on the safety culture model to examine use of the system dynamics and leading indicators is currently ongoing. By conducting further research to supplement the results presented in this paper, a reliable and practical safety management system can be studied that would be beneficial to manage workers’ behavior and attitudes at a site. Moreover, it is expected that more attention would be paid to the use of information technology in the field of behavioral studies because it allows a sample to be monitored automatically without the involvement of an observer.

References


