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Prospective safety performance evaluation on construction sites

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ABSTRACT

This paper presents a systematic Structural Equation Modeling (SEM) based approach for Prospective Safety Performance Evaluation (PSPE) on construction sites, with causal relationships and interactions between enablers and the goals of PSPE taken into account. According to a sample of 450 valid questionnaire surveys from 30 Chinese construction enterprises, a SEM model with 26 items included for PSPE in the context of Chinese construction industry is established and then verified through the goodness-of-fit test. Three typical types of construction enterprises, namely the state-owned enterprise, private enterprise and Sino-foreign joint venture, are selected as samples to measure the level of safety performance given the enterprise scale, ownership and business strategy are different. Results provide a full understanding of safety performance practice in the construction industry, and indicate that the level of overall safety performance situation on working sites is rated at least a level of III (*Fair*) or above. This phenomenon can be explained that the construction industry has gradually matured with the norms, and construction enterprises should improve the level of safety performance as not to be eliminated from the government-led construction industry. The differences existing in the safety performance practice regarding different construction enterprise categories are compared and analyzed according to evaluation results. This research provides insights into cause–effect relationships among safety performance factors and goals, which, in turn, can facilitate the improvement of high safety performance in the construction industry.

1. Introduction

Construction is one of the most dangerous industries in the world (Waehrer et al., 2007; Sacks et al., 2009). In recent years, statistics from the United States, the United Kingdom and Hong Kong reveal no significant reduction in the number of fatalities in the construction industry (Zhang and Fang, 2013). The ramifications of construction accidents are growing with a trend toward larger scale and more complex projects (Lee et al., 2011), especially in developing countries, like China. With the construction industry booms and its gross product constantly increases, the number of construction accidents and the deaths have remained stubbornly high. Absolute mortality in the Chinese construction industry remains unacceptably high, and those accidents can cause huge losses of life and property, which support the importance of construction safety management (Ding et al., 2014). The measurement and assessment of safety performance are therefore urgent and important in order to improve safety management and prevent accidents in China.

Safety performance evaluation is an essential part of safety management systems, since it basically provides information on the system's quality in terms of development, implementation and results (Sgourou et al., 2010). The traditional approach to evaluate safety performance is through measurement and statistical analysis of incident-related data (such as number of injuries and ill-health, accident frequency and severity rates and accident costs), which are often referred to as retrospective or lagging indicators (Sgourou et al., 2010). These indicators are more easily understood by both managers and employees. However, they have often been criticized as measuring system failures without revealing cause–effect relationships that would drive system improvement, therefore they appear to have little predictive value (Carder and Ragan, 2003; Cooper and Phillips, 2004). Choudhry (2014) indicated traditional indexes system focused on the afterwards analysis, but paid less attention to the internal factors such as safety attitude, safety climate, safety culture and safety behaviors. Also, when injury and ill-health rates became a performance-based measure or related to a reward system, some

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construction companies would not report minor events as to 'maintain' performance. The criticism of incident-based indicators coincided with increased attention to the implementation of Occupational Health and Safety Management Systems (OHSMS). The development of OHSMSs and their integration to Total Quality Management (TQM) concepts drives the focus of safety management towards people, and made room for new human-oriented theories, such as human factors (Reason, 1990), behavior-based safety, safety perceptions and attitudes (Martínez et al., 2010). In recent years, the emphasis on safety performance has been shifted into a social system approach. Thus, in order to optimize the human/machine/environment system, a positive corporate safety culture with a participatory, team-based approach must be maintained (Flin et al., 2000; Guldenmund, 2000).

Prospective safety performance evaluation (PSPE) provides information lacking from incident-based measurement and keeps up-to-date with current organizational and safety management trends. Prospective methods reveal how well the company is performing with respect to those activities that prevent injuries and ill-health. These activities include safety management system activities (*i.e.*, audits, hazard identification, training, etc.), employee activities (*i.e.*, observable safe behaviors), supervisor activities (*i.e.*, communicating safety, conducting inspections, etc.), management activities (*i.e.*, management commitment, involvement in safety, etc.). PSPE aims to encourage the good performance of safety and health through reward and not to punish failure, which is oriented to finding and solving the problems in order to uphold the spirit of achieving performance targets and to continue improvement (Hsu et al., 2012). In a recent debate on process safety indicators (Dyreborg, 2009; Hopkins, 2009), it became apparent that prospective safety performance evaluation is still under investigation in regards to concepts, terminology, scientific theories and practice. However, two basic characteristics of this type of evaluation were emphasized in this debate: (a) the causal relationship which must be established between leading indicators and the unwanted outcomes (Grote and Kunzler, 2000; Dyreborg, 2009; Hale, 2009); and (b) the main purpose of PSPE which was to drive performance (Hale, 2009; Hopkins, 2009; Hudson, 2009).

Despite a large number of studies on occupational accidents, risk assessment or safety practices, few studies utilize a reliable methodology for the analysis and evaluation of prospective safety performance. Gurcanli and Mungen (2009) proposed a method for assessment of the risks that workers expose in construction sites using a fuzzy rule-based safety analysis to deal with uncertain and insufficient data. Taha and Nazaruddin (2005) proposed a model based on artificial neural networks to predict cumulative trauma disorders when workers were exposed to a dusty environment, particularly in construction works. Shen et al. (2009) analyzed road safety performance of various counties using data envelopment analysis and proposed a composite safety index. Teo and Ling (2006) developed a model called construction safety index (CSI) to measure the effectiveness of safety management systems of construction sites using the analytic hierarchy process (AHP). Vinodkumar and Bhasi (2009) studied the safety climate factors in the chemical industry in India using principal component factor analysis with varimax rotation. Hermans et al. (2008) studied the safety performance in the construction process using factor analysis, analytic hierarchy process, and data envelopment analysis. It is widely recognized that the empirical validation of how the key enablers are inter-related within a safety performance-based model is limited in previous literature (Feng et al., 2014). The interactions between what construction workers are doing and how safety climate and behaviors influence safety performance appear to be ignored (Chinda and Mohamed, 2008). In general, a commonly accepted safety index system or model regarding PSPE has not been reached in the construction industry. Moreover, causal links between those internal enablers and external goals have not been properly addressed (Chinda and Mohamed, 2007). This paper intends to present an innovative Structural Equation Modeling (SEM) based approach to address these deficiencies, aiming to verify the causal relationships and interactions between enablers and the goals of PSPE.

SEM is a statistical methodology that takes a confirmatory approach to the analysis of a structural theory bearing on some phenomenon. It represents causal processes that generate observations on multiple variables. The advantages of using SEM include: (i) it can handle complex relationships among variables, where some variables can be hypothetical or unobserved (latent variables); (ii) it estimates all coefficients in the model simultaneously and thus, one is able to assess the significance and strength of a particular relationship in the context of the complete model; and (iii) the hypothesized model can then be tested statistically in a simultaneous analysis of the entire system of variables to determine the extent to which it is consistent with the data (Dion, 2008; Martínez et al., 2010). Several construction research studies have reported successful use of SEM. For instance, Al-Refaie (2013) indicated that management commitment, interrelationships harmony and employee empowerment significantly affect safety performance in Jordanian companies using SEM. Hsu et al. (2012) conducted a study on the application of SEM in systematic safety performance model fitness verifications, and revealed that the safety performance can be composed of four dimensions: organization-oriented, management-oriented, control-oriented, and behavior-oriented, and they were closely related to each other. Chinda and Mohamed (2008) modeled the construction safety culture using SEM, aiming to provide insights into the interactions among safety culture enablers, and the relation between those enablers and safety culture goals in the context of the Thai construction industry. Generally, SEM has proven to be an effective tool in testing and investigating inter-relationships among the hypothesized models. There are more than 70,000 construction enterprises with great differences in scale, ownership and business strategy in China. Those differences, however, are usually ignored in most of empirical studies in previous research. In this research, a conceptual model for PESE in the construction industry in China is hypothesized and empirically tested using data gathered via a questionnaire survey. Three different types of enterprises, namely state-owned enterprises, private enterprises, and Sino-foreign joint ventures, are selected as samples to measure the level of safety performance given the enterprise scale, ownership and business strategy were different. Finally, a greater understanding of inter-dependence for PESE is provided, which, in turn, facilitates safety performance improvement in the construction industry.

The remainder of the paper is structured as follows: in Section 2, data regarding the safety performance on working sites are gathered via a questionnaire survey. In Section 3, SEM is used to investigate the inter-relationship among variables in the hypothesized safety performance model. In Section 4, the verified model is used to measure the safety performance level in three different types of construction enterprises in China, and the modeling results and analysis are performed. Finally, the conclusions are drawn in Section 5.

2. Data collection

Data collection aims to gather and measure information on variables of interest, and capture quality evidence that translates to rich data analysis. Basically, questionnaires, that enable one to answer the stated research questions, test hypotheses, and evaluate outcomes, are commonly used for data collection. This