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Review

Fall risk assessment of cantilever bridge projects using Bayesian network

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ABSTRACT

Fall or tumble is one of the most common accidents in bridge construction. Failing to implement safety management and training effectively may result in serious occupational accidents. Current site safety management relies mostly on checklist evaluation; however, its effectiveness is limited by the experience and the abilities of the evaluators, which may not consistently achieve the goal of thorough assessment. Recently, several systematic safety risk assessment approaches, such as Fault Tree Analysis (FTA) and Failure Mode and Effect Criticality Analysis (FMECA), have been used to evaluate safety risks at bridge projects. However, these traditional methods ineffectively address dependencies among safety factors at various levels that fail to provide early warnings to prevent occupational accidents. In order to overcome the limitations of the traditional approach, in this paper a fall risk assessment model for bridge construction projects is developed by establishing a Bayesian network (BN) based on Fault Tree (FT) transformation. The model was found to provide much better site safety management ability by enabling better understanding of the probability of fall risks through the analysis of fall causes and their relationships in a BN. The system has been used to analyze and verify safety practices at five cantilever bridge construction projects currently under construction in Taiwan. It was found that BN analysis is consistent with the conventional safety performance assessment. In practice, based upon the BN analysis by inputting prior information about the site safety management, the probabilities of fall risks and their sensitive factors can be effectively assessed. Proper preventive safety management strategies could then be established to reduce the occurrences of fall accidents at the bridge construction projects.

Contents

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1. Introduction

A complete transportation network in high-speed railroad or highway systems must rely on the use of bridges. Unfortunately, the construction of bridges is often accompanied by occupational accidents, such as fall and object collapse. The construction companies are required to take every safety measure to prevent occupational accidents. The current method to implement safety management is to inspect regularly with checklists on unsafe equipments and worker behaviors. However, this current method is conducted under passive supervision, which fails to provide warning in advance about likely occupational accidents. Recently, several systematic safety risk-assessment approaches, such as FTA and FMECA, have been used to evaluate safety risks at bridge projects. However, these traditional methods ineffectively address dependencies among safety factors at various levels that fail to provide early warnings to prevent occupational accidents. Because of that, several new approaches have been developed to address the relationship among a variety of safety variables in order to devise a preventive model. Structural equation models (SEM) and BNs are some classical examples of the approaches (Paul and Maiti, 2007; Martin et al., 2008). Using BNs, the most important causes of site accidents can be identified and, most importantly, the relationships among these causes can also be determined, which may allow early and preventive safety measures to be implemented.

In general, there are three approaches to construct a BN: (1) learning from a large amount of training data; (2) basing analyses upon the experiences of domain experts; and (3) hybrid method. The second approach is usually used for practical BN construction because the training data are often limited in engineering fields. In addition, establishing a mutual relationship among nodes in the network by directly incorporating the views of experts is generally difficult and tedious. It could be more effective to build the BN by FT transformation (Boudali and Dugan, 2005; Franke et al., 2009; Marsh and Bearfield, 2007; Qian et al., 2005; Xiao et al., 2008).

The rest of this paper is organized as follows. Section 2 reviews the state of the art of safety risk assessment and BNs. Section 3 introduces basic statistics about occupational accidents at bridge construction projects in Taiwan. Section 4 describes the basic concepts of FT and BN. Section 5 discusses the BN development process proposed in this study. Mainly, FT provides the fundamental frameworks and BN is then developed by FT transformation. Section 6 discusses and verifies a fall risk assessment model by effectively transforming a FT into a BN framework, and Section 7 concludes the paper.

2. Literature survey

Common methods used to assess risks include in-depth interviews, Delphi, Factors Analysis, FTA, FMECA, etc. Moreover, quantitative risk-analysis methods, such as statistical inference, reliability analysis, decision trees, and simulation, have also been used for safety risk assessment in construction projects (Hartford and Baecher, 2004; Ebeling, 1997; Rao, 1992; O'connor, 2002; Kales, 2006). Nevertheless, limited data can generally be collected during the life cycle of the construction projects, which constrains the use of these quantitative methods in safety assessment because of data availability. Furthermore, the methods, such as FTA and FMECA, ineffectively address dependencies among safety factors at various levels that fail to provide an early warning in preventing occupational accidents. Thus in recent years, BN has become a popular tool used for the risk assessment on uncertain causal relationships among multi-dimensional factors. Bedford and Gelder (2003) assessed safety of third parties during construction in multiple places using BNs. Martin et al. (2008) used BN to analyze workplace accidents caused by falls from a height. In addition to safety assessment, BNs have been also applied in several knowledge areas, such as medicine (Antal et al., 2007), ecology (Adriaenssens et al., 2004), environmental assessment impact (Baran and Jantunen, 2004; Marcot et al., 2001; Matias et al., 2007), business risk (Marcot et al., 2001), and product life-cycle analysis (Zhu and Deshmukh, 2003).

Generally, the knowledge of professionals is used in developing BNs that illustrate problems with causal relationships between nodes and their conditional probabilities. However, the direct construction of BN is more applicable to simple problems, even though it is quite difficult to develop complicated BNs directly. At present, some scholars have proposed several systematic approaches to BN construction by FT transformation. The main techniques make use of「OR Gate」and「AND Gate」logic transforms into BNs to perform probabilistic analysis of event occurrences (Bobbio et al., 1999, 2001; Xiao et al., 2008; Boudali and Dugan, 2005; Marsh and Bearfield, 2007; Qian et al., 2005; Franke et al., 2009). Some past

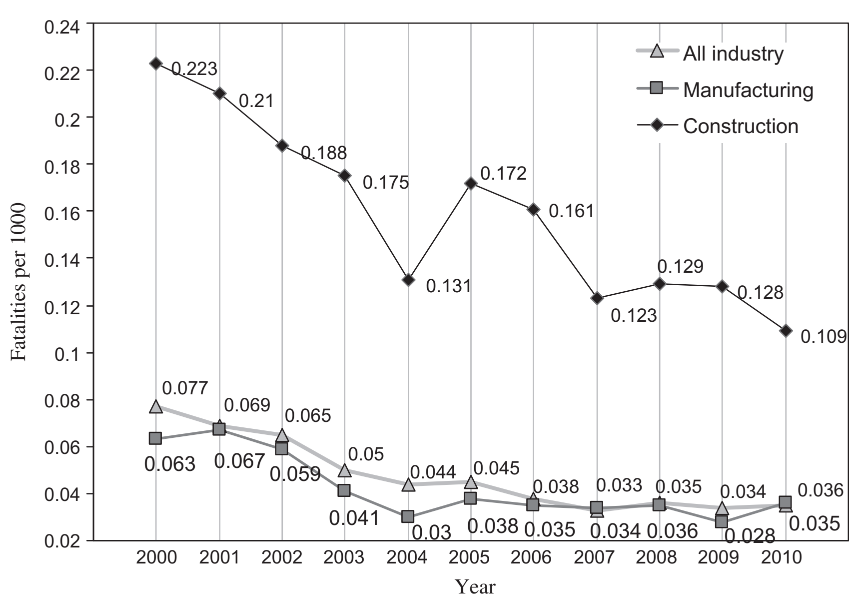

Fig. 1. Fatalities per 1000 persons in construction industry and all industries (excluding deaths from occupational disease and traffic accidents), 2000–2010.