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Factors influencing unsafe behaviors: A supervised learning approach

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ABSTRACT

Despite its potential, the use of machine learning in safety studies had been limited. Considering machine learning's advantage in predictive accuracy, this study used a supervised learning approach to evaluate the relative importance of different cognitive factors within the Theory of Reasoned Action (TRA) in influencing safety behavior. Data were collected from 80 workers in a tunnel construction project using a TRA-based questionnaire. At the same time, behavior-based safety (BBS) observation data, % unsafe behavior, was collected. Subsequently, with the TRA cognitive factors as the input attributes, six widely-used machine learning algorithms and logistic regression were used to develop models to predict % unsafe behavior. The receiver operating characteristic (ROC) curves show that decision tree provides the best prediction. It was found that intention and social norms have the biggest influence on whether a worker was observed to work safely or not. Thus, managers aiming to improve safety behaviors need to pay specific attention to social norms in the worksite. The study also showed that a TRA survey can be used to extend a BBS to facilitate more effective interventions. Lastly, the study showed that machine learning algorithms provide an alternative approach for analyzing the relationship between the cognitive factors and behavioral data.

1. Introduction

Understanding and managing unsafe behavior had always been an important aspect of construction safety management. In the seminal Domino Theory (Heinrich, 1931), unsafe behavior was identified as a key cause of accidents. According to Heinrich, among the direct causes of accidents, 88% are unsafe behavior, 10% are unsafe conditions, and 2% are unpreventable. However, unlike Heinrich (1931), who was focused on the individual's contribution to the unsafe behavior, current views are better reflected in systemic incident causation models (Chua and Goh, 2004) such as the Swiss cheese model (Reason, 1997) and Loss Causation Model (Bird et al., 2003). In these systemic models, unsafe behaviors are active failures influenced by underlying organizational and cultural issues. It is now common knowledge that frontline workers are not solely responsible for unsafe behaviors and managers are expected to implement measures to promote safe behaviors.

A number of safety behavior models were developed and tested over the past decades (Cui et al., 2013; Fang et al., 2015; Griffin and Neal, 2000; Guo et al., 2016; Seo, 2005). These studies provided important insights into safety behavior shaping mechanisms and behavior change interventions. In addition, existing models of behavior and/or motivation in the area of psychology, particularly theory of planned behavior (TPB) (Ajzen, 1991) and theory of reasoned action (TRA) (Fishbein and Ajzen, 2010)), have often been adopted to explain and predict safety behavior (Bakar et al., 2017; Fang et al., 2016; Goh and Binte Sa'adon, 2015; Johnson and Hall, 2005; Quick et al., 2008). The usual analysis approach to test behavioral models is through traditional statistical modelling techniques, such as linear regression, logistic regression, or structural equation modelling and model validation evaluated using goodness-of-fit tests and residual examination (Breiman, 2001).

In recent years there had been a growing interest in applying machine learning techniques in construction safety research (Ciarapica and Giacchetta, 2009; e.g. Goh and Binte Sa'adon, 2015; Goh and Chua, 2013; Patel and Jha, 2014a,b; Tixier et al., 2016). As a subset of artificial intelligence, machine learning can be defined as an algorithmic approach that learn from data without relying on rule-based programing (Alpaydin, 2010). In fact, machine learning and traditional statistical modelling are concerned with the same question, that is, what can be learned from data? Even though Breiman (2001) suggested that machine learning can be used as a more accurate and informative

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alternative to data modelling on smaller data sets, a vast majority of safety behavior studies adopted traditional statistical modelling approaches to test the relationships between variables (Fogarty and Shaw, 2010; Guo et al., 2016; Johnson and Hall, 2005; Poulter et al., 2008; Quick et al., 2008). The lack of adoption can be attributed to the fact that machine learning is relative new.

Considering the context, this paper applies machine learning to analyze data collected based on the theory of reasoned action (TRA) and observed safety behavior. In specific, the objectives of this paper are to (1) evaluate the relative importance of different TRA cognitive factors in influencing observed safety behavior, and (2) evaluate the effectiveness of six different machine learning algorithms in analyzing the cognitive and behavioral data. The first objective is concerned with developing a better understanding of predictive power of different cognitive factors, while the second is linked to the purpose of identifying better-performing algorithms so as to reduce future effort spent on selecting suitable algorithms for analysis of cognitive and behavioral data.

2. Literature review

2.1. TRA and its applications to safety behavior

In the 1970s, Fishbein and Ajzen developed the theory of reasoned action (TRA), with an attempt to “identify a relatively small set of variables that can account for a substantial proportion of the variance in any given behavior” (Fishbein 2008) (p.834). The early version of TRA posited that behavior is a function of behavioral intentions that are determined by attitudes and subjective norms. Subsequently, the theory included perceived behavioral control as an additional factor. In recent years, TRA had been updated as shown in Fig. 1 (Fishbein, 2008). It suggests that social human behavior can be predicted from an individual’s intention and that effects of intention are moderated by actual control (e.g., skills, abilities, and environmental factors). The intention is determined by attitude towards the behavior, perceived norm, and perceived behavioral control.

There are three beliefs underlying the three determinants of intention, including behavioral beliefs (BB), normative beliefs (NB), and control beliefs (CB). According to the TRA, belief is defined as the subjective probability that an object has a certain attribute (Fishbein and Ajzen, 2010). A behavioral belief is the subjective probability that the behavior will produce a given outcome. Attitude, as a result of BB, is “*a latent disposition or tendency to respond with some degree of favorableness or unfavorableness to a psychological object*” (Fishbein and Ajzen, 2010) (p. 76). In the model, perceived norm (PN) is defined as perceived social pressure to conduct a given behavior. PN consists of injective (known as subjective in the TPB) and descriptive norms which capture the desires and the actions of important referent persons, respectively. PN is determined by normative beliefs (NB) which are beliefs that a particular person or group thinks *I should or should not perform a given behavior*. Perceived behavioral control (PBC), as a result of control beliefs, is another significant predictor of intention. PBC is defined as “*the extent to which people believe that they are capable of performing a given behavior, that they have control over its performance*” (Fishbein and Ajzen, 2010) (p. 154). Given positive attitude and PN to perform a given behavior, the greater the PBC, the stronger should be the intention to perform the behavior.

The TRA has been consistently shown to accurately predict behavioral intention and behavior in a wide range of domains, such as health-related behavior (Blank and Hennessy, 2012; Chassin et al., 1981; Finlay et al., 1999; Jemmott, 2012), environment protection behavior (Jones, 1989), and voting (Singh et al., 1995). The TRA has also been used as a useful framework to design behavior change interventions (Abraham and Michie, 2008; Ajzen and Albarracín, 2007; Gielen and Sleet, 2003; Jemmott, 2012). In addition, both TRA and TPB have been applied to safety behavior research. For example, Johnson and Hall (2005) applied TPB to safe-lifting among 136 materials management employees at a heavy manufacturing company. Using structural equation modelling and factor analysis, the study found that perceived behavioral control and intention were the strongest predictors of safe-lifting behavior. Similarly, Poulter et al. (2008) applied and tested the usefulness of TPB in predicting truck driving behavior by conducting path analysis. More recently, Fogarty and Shaw (2010) demonstrated the usefulness of TPB to understand violation behaviors in aircraft maintenance. One common characteristic of these studies is that traditional statistical modelling approaches were used to test the usefulness of TPB or TRA in predicting different behaviors.

In the construction industry, however, the application of TRA and TPB to safety behavior has been limited. In order to explore ways to reduce unsafe behaviors during work-at-heights, Goh and Binte Sa’adon (2015) investigated the cognitive factors influencing scaffolders’ decision to anchor safety harnesses. The authors adopted TPB (Ajzen, 1991) in their study and they realized that among the constructs highlighted in TPB, namely, attitude, subjective norms, perceived behavioral control, and intention, subjective norm had the greatest influence on a worker’s decision to anchor his or her harness. The study also highlighted the problems in using linear regression to analyze the relationship between cognitive factors and safety behaviors. It was discovered that machine learning techniques, more specifically artificial neural network and decision tree, were shown to produce more accurate predictions. Nevertheless, the study by Goh and Binte Sa’adon (2015) was exploratory in nature and several recommendations for further studies were provided. In addition, Fang et al. (2016) developed a cognitive model of construction workers’ unsafe behaviors in part based on TPB. The model can help better understand the causal mechanisms of unsafe behaviors on site and therefore develop targeted

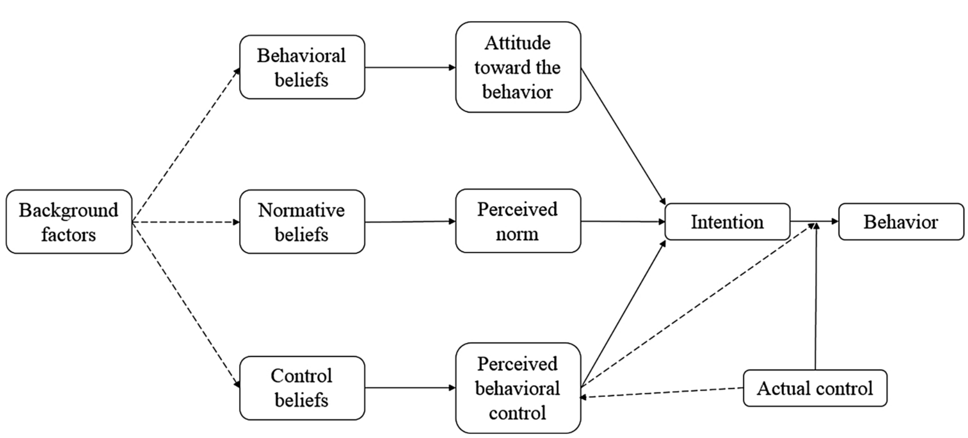

Fig. 1. Schematic presentation of the reasoned action model.