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USING BAYESIAN NETWORKS MODELS TO IMPROVE BEHAVIOR TOWARDS WASTE MANAGEMENT IN CONSTRUCTION PROJECTS

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The effective implementation of waste management strategies in construction projects requires the identification of critical factors that affect the behavior regarding waste management as well as quantifying the relationships between causal factors. In this context, the Bayesian Networks (BN) analysis technique is an effective means that not only identifies the influencing factors but also establishes a probabilistic relational network among causal factors, thereby providing a methodology to identify potential strategies for improving behavior towards construction waste management. The comprehensive literature review, presented in this paper, is a vital source of information required to build a research model that includes key factors influencing behavior towards waste and to construct a structured questionnaire. As such, the research model, along with the data collected, is necessary to demonstrate the application of the proposed BN model in the real world.

Keywords: Construction waste management, Causal factors, Strategies.

1 INTRODUCTION

The construction industry has witnessed a significant growth over the past decade, leading to an excessive amount of construction waste (CW) generated worldwide. The huge amount of waste generated by construction activities ties down landfill space, leading to considerable loss in land resources for the expansion of existing landfills or the creation of new ones (Esin and Cosgun 2007, Yuan 2013). CW generation not only consumes land resources, but also has several harmful environmental impacts including air pollution, water pollution, depletion of natural resources, and risks to human health (Poon *et al.* 2003).

In addition to the importance of raising the awareness towards CWM, a study conducted by Srour *et al.* (2013) affirmed that the effective implementation of CWM also necessitates defining roles and responsibilities of the construction and governmental authorities. One of these fundamental responsibilities is to propose practical strategies that aim at improving the behavior of construction workers towards waste management (Merino *et al.* 2010). As such, the improvement of behavior towards waste management in construction projects not only requires the identification of factors that influence the behavior towards waste but also entails the quantification of the relationships between causal factors in order to propose effective strategies at the site level. For this reason, a comprehensive literature review is carried out in this paper

to 1) shed light on the limitations of existing studies related to behavior towards waste management, 2) identify possible factors that might have influence on behavior towards waste minimization and/or recycling, and 3) suggest a new methodology that can be adopted to overcome the drawbacks of existing studies.

2 BEHAVIOR TOWARDS WASTE MANAGEMENT

Previous studies have used statistical analysis methodologies, particularly factor analysis, ranking analysis, regression analysis and structural equation modeling (SEM), to examine the possible factors that influence waste minimization and recycling for the purpose of improving the behavior regarding waste management. Factor analysis is a data reduction method that generates a set of factors (i.e., unobserved variables) that represent a set of correlated observed variables (Torres-reyna 2007a). For example, Wang and Yuan (2011) and Udawatta *et al.* (2015) explore the critical factors that have an influence on the behavior towards waste management by grouping the correlated observed variables. The ranking analysis, on the other hand, orders the variables under investigation based on their ranking values. The data are collected by asking respondents to rank alternatives based on their preferences (Coe 2002). Several studies (e.g., Kulatunga *et al.* 2006, Tam 2008) rank the factors based on their influence on the implementation of waste management strategies, where rank 1 indicates the most influential factor. The linear regression analysis method, applied by Begum *et al.* (2009) and Sidique *et al.* (2010), investigates the relationships between a dependent variable and its causal independent variables by testing the statistical significance of these linear relationships (Torres-reyna 2007b). At a more complex level, Ramayah *et al.* (2012) uses SEM to build a model that represents the relationships between the recycling behavior and its causal factors in addition to the relationships between the respective factors. SEM is an advanced prescriptive data-analytic technique that has become such an increasingly popular statistical analysis option due to various strengths.

In spite of its strengths, SEM, and generally regression analysis, has some limitations. One of these potential problems is multicollinearity that refers to high correlations between latent (i.e., unobserved) independent variables. When multicollinearity occurs, the variance of the coefficient estimates may be increased, making the estimates unstable and sensitive to minor changes in the model which consequently induce statistical non-significance of the estimates (Grewal *et al.* 2004). This situation, in turn, undermines the statistical power of the analysis making it more difficult to determine the correct model and to quantify the influencing factors affecting behavior towards waste management.

3 FACTORS AFFECTING BEHAVIOR

Factors influencing behavior towards waste minimization and/or recycling fall under two main categories, personal factors and corporate factors. Personal factors, also called individual factors, represent the psychological and cognitive factors that are involved in shaping the individual's decision-making. Corporate factors, also called organizational factors, act as part of the organizational context, which may either facilitate or constrain the success of individuals' initiatives to any behavioral change (Young *et al.* 2013).

3.1 Personal Factors

The *attitude* towards the behavior, as described by the theory of planned behavior (Ajzen 1993), refers to an individual's positive or negative evaluation of the behavior in question and is shaped based on personal beliefs and knowledge. Attitude is usually measured by asking individuals' to specify their feelings about performing the behavior, e.g., whether the behavior in question is good, useful, rewarding, etc. Begum *et al.* (2009) studies the relationship between attitude and behavior and concludes that contractor attitude towards waste management significantly affect the behavior regarding waste management. Contractors having positive attitude toward waste management also undergo satisfactory behaviors. In an effort to investigate the factors that positively affect attitude, Ramayah *et al.* (2012) found that employees' knowledge and awareness of environmental benefits are positively related to attitude, which in turn contributes to improving waste management behavior.

Consequences awareness refers to individuals' awareness towards benefits of waste management, including the environmental, economic and social benefits. Yuan (2013) highlights the critical role of enhancing workers' awareness about saving economic resources and environmental protection in improving waste management performance. In this context, several studies identify factors that contribute to raising the awareness towards consequences of waste management. For example, Sidique *et al.* (2010) argue that communication efforts raise the awareness towards benefits of recycling behavior and positively affect attitude towards recycling and consequently behavior.

Wang and Yuan (2011) demonstrate that *work experience*, which represents the number of years of professional experience, is a critical factor affecting workers' attitudes in construction projects. Ajzen (1993) argues that *past experience in a behavior* contributes to the formation of attitude that in turn plays an important role in shaping the behavior, Macey and Brown (1983) report that past experience is the best direct predictor of conservation behavior. Terry *et al.* (1999) indicate that previous recycling experience should be included when considering the prediction of behavior towards recycling.

Studies show that behavior is highly influenced by *social pressure*, also called social norms, especially when the perception of the social group about the behavior is important to the individual performing the behavior (Chan 1998, Shaw 2008). For example, social pressure has the greatest impact on recycling behavior, where an individual has a great intention to perform a certain behavior positively when he/she perceives that it is important what others think he/she should be doing.

3.2 Corporate Factors

Attending *training courses* is one of the best sources of information for gaining knowledge about various waste management strategies, and thus is proved to be an effective way in improving waste minimization and recycling behavior (Udawatta *et al.* 2015). Kulatunga *et al.* (2006) report that training and education about waste minimization methods play an important role in 1) raising the awareness on the importance of waste management as a cost-effective and profitable technique, 2) forming positive attitudes regarding waste management at both corporate and individual levels, and 3) enhancing actual behavior towards waste management.

Adequate *supervision* of waste management activities with clear instructions from the top level to the bottom level of the organization is identified as an important solution for proper implementation of waste management strategies (Kulatunga *et al.* 2006).
Tam and Tam (2008) report on a *financial reward* scheme used to motivate construction workers to adopt a waste management strategy, resulting in waste reduction by up to 23%. Therefore, introducing financial incentives for better waste management practices would help to develop and implement waste management applications in the construction industry (Kulatunga *et al.* 2006).

Several statistical methods have been used to examine the effect of personal and corporate factors on behavior towards CWM practices. However, these methods cannot quantify the relationships between causal factors and do not offer practical strategies for improving behavior towards waste management. Hence, this paper advocates the use of Bayesian Networks (BN) to quantify the relationships between related factors. BN allow for the quantification of such relationships through probabilistic relations. What follows is a review of relevant literature on BN demonstrating the effectiveness of this method in constructing a behavioral model that relies on probabilistic analysis.

4 BAYESIAN NETWORKS (BN)

A BN is a mathematical model where each variable is represented by a node, with arrows representing the dependencies between related variables. It is a directed acyclic graph that cannot include a feedback, i.e., a path traced along its links cannot pass through a variable more than once. The first step in constructing a BN requires identifying the important nodes, the states of each node and the relationships between them, which can be done based on existing literature, experts' consultation and/or the analyst's experience and knowledge of the analyzed system (Dambacher *et al.* 2007).

The BN model shows the causal structure in a problem using conditional probability distributions to define relationships between variables, where a conditional probability table (CPT) is generated for each variable after compiling the model. If a variable has no incoming arcs and hence does not depend on any other variable in the model (i.e., conditionally independent), its CPT includes one probability distribution. However, the CPT of a variable that has parents consists of one probability distribution for every combination of possible values of the parents, leading to a large number of combinations in case of complex BNs. In this case, filling in the CPTs may require many conditional probability assignations and can thus be difficult to complete (Ames *et al.* 2005, Uusitalo 2007). For this reason, Cain (2001) recommends simplifying the BN by either combining nodes or reducing the number of states within each node (called "data pre-processing"), which in turn reduces the overall size of the CPTs. Netica, Hugin, GeNIe and B-course are examples of software packages, which have been ported to most commonly used operating systems (Uusitalo 2007).

The BN technique has no minimum sample size requirements. It has the ability to show accurate prediction of outcomes even with small sample sizes (Kontkanen *et al.* 1997). The technique works with variables of categorical data type, which allows capturing non-linear relationships between the variables (Myllymaki *et al.* 2002). Once the BN is compiled and the conditional probabilities are estimated, then the model is complete and the downward and upward propagation of information through the model can be used to view how observed conditions or evidences at certain nodes affect the

probable conditions at the other nodes (i.e., states are known with certainty) – the so-called "reasoning" (Zhou *et al.* 2008). The reasoning characteristic is one of the key points of BNs as it allows stakeholders and decision makers to visually interpret a given problem, thus serving as an effective tool in predicting the probable outcomes of management decisions on selected variables.

5 CONCLUSION

The effective implementation of CWM practices requires understanding the influencing factors of behavior towards waste and the quantification of the relationships between these factors as well. As such, this paper represents a comprehensive literature review covering possible influencing factors, limitations of existing studies related to behavior towards waste management, and applicability of BN as a methodology to generate BN model with quantified relationships between causal factors. Based on this literature review, a research model as well as a questionnaire required to collect data about factors affecting the behavior of construction workers are being built, thus serving as seeds for the ongoing project aiming at generating a CWM behavioral BN model. Construction field workers from various construction projects located in Beirut (Lebanon) are currently being interviewed. Data will be incorporated into the research model to generate the behavioral BN model and strategies for improving the behavior regarding waste management will be proposed accordingly.

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