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Research article

Risk analysis of emergent water pollution accidents based on a Bayesian Network

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A B S T R A C T

To guarantee the security of water quality in water transfer channels, especially in open channels, analysis of potential emergent pollution sources in the water transfer process is critical. It is also indispensable for forewarnings and protection from emergent pollution accidents. Bridges above open channels with large amounts of truck traffic are the main locations where emergent accidents could occur. A Bayesian Network model, which consists of six root nodes and three middle layer nodes, was developed in this paper, and was employed to identify the possibility of potential pollution risk. Dianbei Bridge is reviewed as a typical bridge on an open channel of the Middle Route of the South to North Water Transfer Project where emergent traffic accidents could occur. Risk of water pollutions caused by leakage of pollutants into water is focused in this study. The risk for potential traffic accidents at the Dianbei Bridge implies a risk for water pollution in the canal. Based on survey data, statistical analysis, and domain specialist knowledge, a Bayesian Network model was established. The human factor of emergent accidents has been considered in this model. Additionally, this model has been employed to describe the probability of accidents and the risk level. The sensitive reasons for pollution accidents have been deduced. The case has also been simulated that sensitive factors are in a state of most likely to lead to accidents.

1. Introduction

Emergent water pollution accidents have large differences in terms of pollution sources, pollution levels, the pollution time and place; the pollution sources and levels are all very uncertain (Zhang et al., 2010; Ding et al., 2003). Due to environmental climates, human factors and technological faults, improper use of chemicals, spills and explosions of the chemical industry and oil tankers have resulted in large amounts of economic losses, environmental destruction, and casualties (Duan et al., 2011; Posthuma et al., 2014). Risk assessment of emergent pollution accidents has to take several factors into account, such as environment, regional economy, traffic, and information. Environmental risk assessment mostly concentrates on the risk assessment of poisonous chemicals. The main process is identifying the sources of risk for potential pollution accidents, analyzing accident types and reasons, and calculating the probabilities of accidents. At present, environmental risk assessment for water pollution is mainly divided into human health risk assessment of heavy metals in water and in fish aquatic organisms (Yi et al., 2011; Yi and Zhang, 2012); ecological risk assessment (Yang et al., 2013); and hydropower construction risk assessment (Chen et al., 2010). The Index of Risk is employed to evaluate the risk of water pollution in harbors (Grifoll et al., 2010). The Analytic Hierarchy Process (AHP) method is applied for uncertain, multiple criteria and multiple-objective problems (Chen et al., 2008) as well as in nature, society, and eco-environment problems (Aragones-Beltran et al., 2010; Ying et al., 2007). Fault Tree Analysis is a famous method of uncertain risk analysis and is extensively used for predicting the probabilities of emergencies and preparing for decision management (Liu et al., 2014; Rebelo et al., 2014). However, the AHP has a strong human subjective judgment function and often reaches imprecise results. Fuzzy Comprehensive Evaluation is a comprehensive evaluation method based on fuzzy mathematics (Shen et al., 2005; Hsiao and Ko, 2013).

Compared to the above risk analysis methods, Bayesian Network

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(BN) is popular for qualitative and quantitative descriptions and has the functions of causal inference and result inspection. It can describe events in different states, effectively use given information to deduce unknown information, and has very strong computational reasoning ability (Pearl, 1986). BN model is widely used in emergency risk analysis of maritime collisions (Trucco et al., 2008); genetic resources, water regulation, recreation, freshwater provision, and climate regulation in ecosystem services (Landuyt et al., 2013); estimating the risk of soil compaction (Troldborg et al., 2013); evaluating the influential factors in traffic accidents; and predicting probability of accident (Zhang, 2013). The characteristics of drivers, highways, trucks, accidents, and atmospheric factors are contributing factors in traffic accidents on rural highways in Spain (de Oña et al., 2013). Age, seatbelt use, driving experience, alcohol, weather, sex, and states of road are the main factors for the BN and these factors are demonstrated to contribute to accidents in Slovenia (Simoncic, 2004). Road environment and truck types are the main factor in traffic accident severity (Zong et al., 2013).

In existing research, driver's gender and age were considered as individual factors that have a direct effect on accident. While in this paper, driver's gender and age are divided into human factor. Human factor includes right and wrong judgments of human on accidents. The human judgment results are control of driver's gender and age. According to identifying the potential risk sources of polluting water based on the layout of buildings, a BN has been established for the risk of water pollution by emergent traffic accidents at the Dianbei Bridge. Based on the functions of reason diagnosis and result inference, the traffic accident probabilities and risk levels have been determined. The main causes have been analyzed depending on the risk assessment levels. This work provides the basis for reducing risk of accident along the main canal.

2. Bayesian Network method

The Bayesian formula is the basis of the BN method. It reflects the interrelation between the prior probability and posterior probability and can use existing prior probability to derive the specific probability of accident. This approach is widely used in uncertainty analysis. The probability of event A at the condition of event B can be expressed as:

$$P(A|B) = \frac{P(B|A) \times P(A)}{P(B)} \tag{1}$$

in which $P(A)$ is called the prior probability or marginal probability of A and is not relative with B. $P(A \mid B)$ is the probability of A under the condition of a known event B and is also known as the posteriori probability of A. $P(B \mid A)$ is the conditional probability of B at the occurrence of A, also known as the posteriori probability of B. $P(B)$ is prior probability or marginal probability of B, and has nothing to do with the event A.

If the corpora of accident B is $B = \{B_1, B_2, \ldots, B_n\}$, the Bayesian formula can also be expressed as:

$$P(A|B_1, B_2, \ldots, B_n) = \frac{P(B_1, B_2, \ldots, B_n|A) \times P(A)}{P(B_1, B_2, \ldots, B_n)} \tag{2}$$

A graphical method is employed by BN to expresses the probability model of uncertainty. A BN is a directed acyclic graph (DAG) which can directly reflect relationships between variables. Directed graphs denote the causal connection between stochastic variables that are expressed by notes; the conditional probability table (CPT) denotes the strengths of the connections. The DAG from the parent node to child node represents causal effects between these two nodes. The probability of the parent node is usually obtained through past experience. CPT is achieved by the score evaluation of experts and stakeholder knowledge according to related knowledge and experience if the CPT is a low dimension (Nadkarni and Shenoy, 2004).

A BN is composed of the topological structure (including network nodes and directed links) and the CPT of each node. The BN model of random variable $X = \{x_1, x_2, \ldots, x_n\}$ is expressed as $B = (Bs, Bp)$. $Bs = (X, E)$ is a directed acyclic graph, and $X = \{x_1, x_2, \ldots, x_n\}$ is the node set. Nodes are discrete or continuous variables. E, a set of directed edges, shows the relationship between the two nodes and depends on the CPT. The case that node X_i $(i = 1, 2, \ldots, n)$ is a discrete value and Bp is the set of $P = \{Y \mid X_i, i = 1, 2, \ldots, n\}$, is shown in Fig. 1.

The qualitative identification is a relatively simple, convenient and visual identification method of risk analysis. By describing some inaccurate and incomplete information, whether accidents occur and the causes of events happened are judged. The effects of risk on projects will be gradually analyzed. Methods of qualitative identification mainly include the risk source inspection table method, expert investigation method, brainstorming subjective scoring method, extrapolation method, and so on. Therefore, qualitative description can only help build a BN structure, while the CPT of nodes requires quantitative expression.

Risk factors should be identified according to the research questions before constructing a BN. The main risk factors are chosen as nodes of a BN based on the prior probability and the contribution degree of the result in an event. The CPT in the established BN structure results from the discussions of experts in the related field. Finally, historical data and practical experience are jointly used to solve for the prior probability of the root nodes. According to the above steps, a full BN model is constructed.

3. Risk analysis

3.1. Study area

The Middle Route of the South to North Water Transfer Project has a long water conveyance distance of 1275 km, and many types of buildings, including diversions, culverts, sluices, tunnels, inverted siphons, bridges, culverts and aqueducts. The Beijing-Shijiazhuang section contains 131 bridges across the canal. Channels are mainly composed of open channels. Ten meters in width protective barriers are set on both sides of the channel to prevent pollutants getting close to water (CISPDR, 2005; HRIWCH, 2003). So bridges are the main locations where personnel and trucks are closed. Bridges pose a potential threat to the water quality in an emergent pollution accident (Kalantarnia et al., 2010).

The Dianbei Bridge, 192 km distance from Shijiazhuang, is a Class II bridge of provincial road S232 across the Shijiazhuang-Beijing canal (Fig. 2). It is a typical bridge across the channel. The

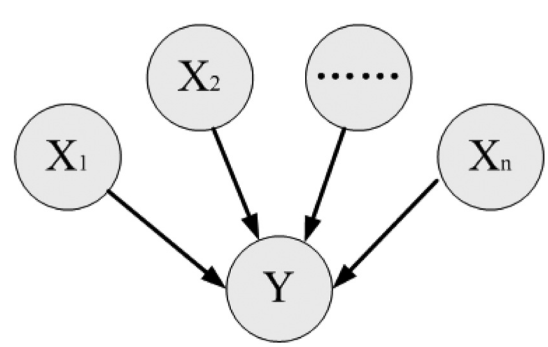

Fig. 1. Topological structure of the Bayesian Network.