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Application of Bayesian Network Model for Enterprise Risk Management of Expressway Management Corporation

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Abstract. The enterprise risk management can enhance enterprise value or performance level. During operation, Expressway Authority of Thailand has faced a large number of key risk factors that affect the enterprise performance, such as strategic risks, financial risks, and operation risks. The Bayesian network model is constructed for expressway enterprise risk management and applied to the enterprise risk assessment in this paper. The preliminary evaluation of the model was performed through examples.

Keywords: enterprise risk management, expressway enterprise value or performance, Bayesian Networks

1. Introduction

Expressway or toll way is one of important infrastructures of countries, including Thailand. The Royal Thai government has realized that expressway networks play an important role in the national economic development, especially in enhancing the logistics systems. However, the investment in expressway projects requires lump sum capital, and it is usually subsidized by the government. In general, the expressway management corporation is responsible for project planning, managing the construction, operating, and maintaining. While the investment amount is huge, the return on investment will be gained after the operation phase. Nevertheless, there are a large number of uncertainty factors or risks that could influence the performance of an expressway enterprise during the operation phase. In order to well manage the expressway operation and increase the enterprise value, it is essential to efficiently discover and manage the enterprise risks via the enterprise risk management (ERM) approach. ERM is the process by which organizations assess, control, exploit, finance and monitor risks from all sources for the purpose of increasing short-term and long-term values for stakeholders [1]. ERM is the proactive approach that involves predicting and managing business risks before the occurrences rather than responding and reacting to the threats after the fact, when the damage has already been imposed [2]. Therefore, an enterprise risk management system associated with a capable enterprise risk assessment model need be established. Due to the problems about the relationship of the risk factors and the subjectivity of risk management, this paper proposes an approach to applying Bayesian Network model for enterprise risk management of expressway management corporations. Bayesian probability theory is a branch of mathematical probability that allows one to model uncertainty and to predict their outcomes of interest by combining common-sense knowledge and observed evidence. After establishing all the variables in a model, one must deliberately associate the variables that cause changes in the system to those variables on which they influence [3]. In general, a Bayesian network describes the joint probability distribution for a set of variables. The network or graph visualization represents the cause-and-effect relations among variables, pointed out by arcs. The degree of relationship is interpreted in terms of conditional probabilities according to Bayes theorem. Bayesian

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Networks allow stating conditional independence assumptions that apply to subsets of the variables, providing more tractable and less constraining than the global assumption of conditional independence. In this paper, the Bayesian Network model is applied to the risk management process focused on the risk factor analysis that influences the enterprise value and performance. It is also applied for predicting the enterprise value and performance during operation.

2. Bayesian Networks

Bayesian Networks (also known as Belief Networks, Causal Probabilistic Networks, Probabilistic Cause-Effect Models, or Probabilistic Influence Diagrams) describe the probability distribution governing a set of variables by specifying a set of conditional independence assumptions along with a set of conditional probabilities. A Bayesian Network is represented by a directed acyclic graph (DAG), associated with sets of local conditional probabilities attached to each node, called Conditional Probability Table or CPT [4]. The network arcs represent the assertion that the variable labelled in each node is conditionally independent of its nondescendants in the network given its immediate predecessors in the network.

2.1. Calculation of Bayesian Networks

For variables X_i $(i = 1, \dots, n)$ given $\pi(X_i)$, X_i is conditionally independent on all non-parents nodes, a joint distribution probability of n variables can be decomposed according to a chain rule as shown in Equation 1.

$$P(X_1, \dots, X_i) = \prod_{i=1}^{n} P(X_i/X_1, \dots, X_{i-1}) = \prod_{i=1}^{n} P(X_i/\pi(X_i)) \quad (1)$$

where $\pi(X_i)$ = ØP(Xi /π (Xi) is marginal probability of Xi, P(Xi)

In order to do Bayesian inference, prior probabilities and posterior probabilities are required.

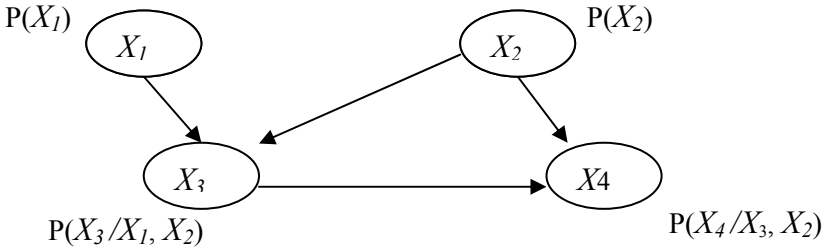

Figure.1 Example of Bayesian Network [5]

Let X, and Y be two stochastic variables, and suppose that X = x and Y=y is evidence. Before considering the evidence Y=y, the prior probability of the event X = x or P (X = x) should be estimated first. After taking into account of the evidence Y=y, according to Bayes theorem, the posterior probability P(X=x|Y=y) can be calculated as shown in Equation 2.

$$\mathrm{P}(X = x|Y = y) = \frac{\mathrm{P}(X=x,Y=y)}{\mathrm{P}(Y=y)} = \frac{\mathrm{P}(X=x)\mathrm{P}(Y=y/\mathrm{X=x})}{\mathrm{P}(Y=y)} \quad (2)$$

where $\mathrm{P}(X = x|Y = y)$ is the probability of the joint event $\mathrm{P}(X = x \wedge Y = y)$. If X, Y are independent, then P(X=x|Y=y) = P(X=x).

2.2. Inference of Bayesian Networks

The inference of Bayesian Networks can be categorized into three types: one is the inference of posterior probability, one is the maximum a posterior hypothesis (MAP), and the other is the most probable explanation (MPE). In this paper, the Bayesian Network model applied to the enterprise risk management employs the inference of posterior probability for analyzing the risk factors and predicting the enterprise value and performance. In particular, the known values or evidences are used to calculate other variables' posterior probability [5]. There are four types of posterior probability inference defined as following [5]:

- Diagnostic inference, which can infer the causes in the light of the results.
- Predictive inference, which can forecast the results according to the causes.

- Intercausal inference, which can reveal the relationship between different reasons with the same result.
- Mixed inference, which includes all the ways mentioned above.

3. Building Bayesian Network Model of Enterprise Risk Management

Prior to building the Bayesian Network Model of Enterprise Risk Management, the three pre-processing steps are performed: risk identification, risk analysis, and risk assessment.

3.1. Expressway Operational Enterprise Risk Identification

Identify sources of enterprise risks and set the key risk drivers (KRDs) or the key risk indicators (KRIs).

In the expressway operation, the factors influencing the management performance of the corporation mostly come from the internal and external environments of expressway projects. The external risk factors are uncontrollable and difficult to be prevented. The internal risk factors appear mostly in 3 ways: financial benefit, the ability/efficiency of management, and the services [6,7,8,9,10,11]. This paper focused on the internal key risk factors of an expressway operational enterprise from the perspective of the Thailand expressway corporation that include three aspects: strategic risks, financial risks, and operation risks as shown in Figure 2.

3.2. Expressway Operational Enterprise Risk Analysis

There are two steps when applying Bayesian Networks for risk analysis:

1) To determine the risk status of each node. The status of node can be classified based on historical experience. First, set the threshold for each node and determine the level, which can be divided into three states: 1, 2, and 3 corresponding to the three levels: low, Medium, and High.

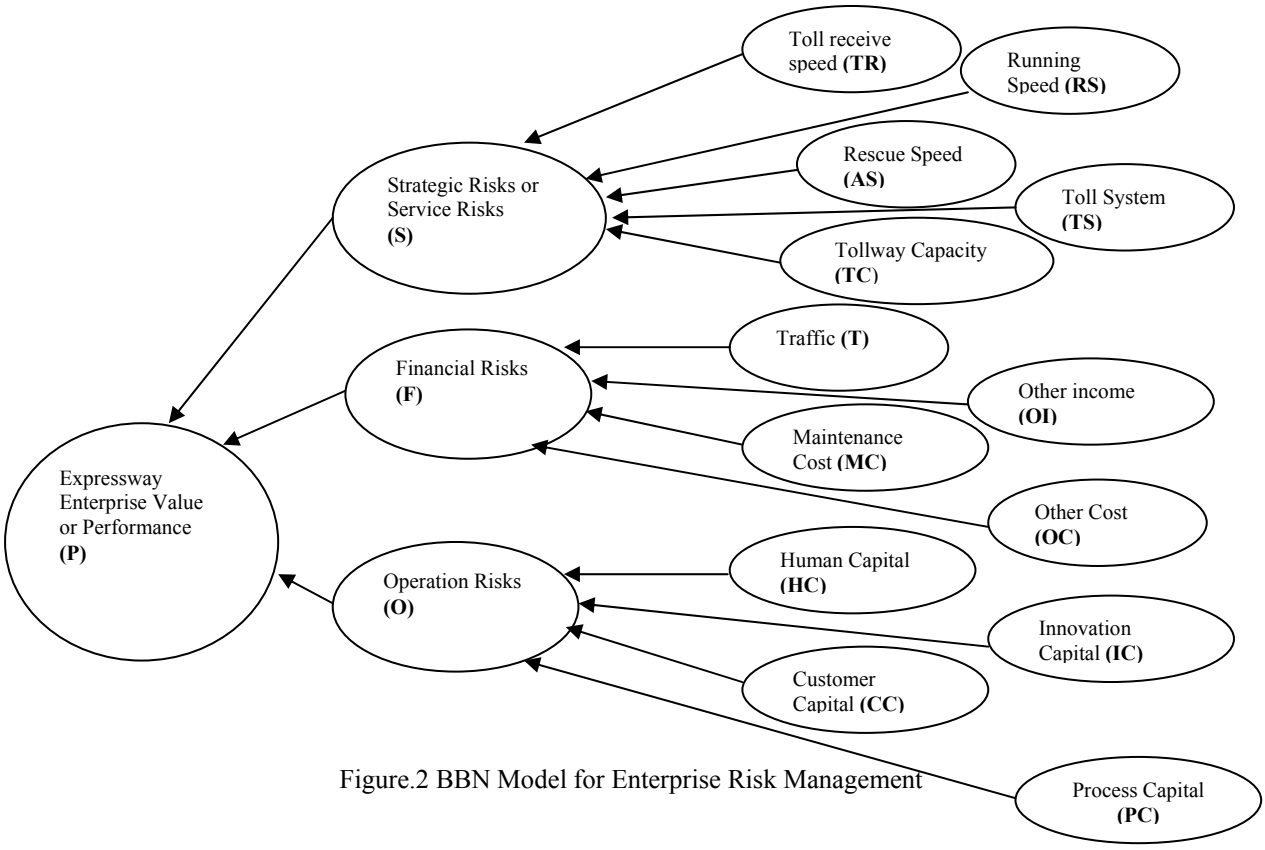

Figure.2 BBN Model for Enterprise Risk Management

2) Calculate the conditional probability of each node. According to the state of each node, determine the probability of occurrence in the current node state. For example, P (T=3) means that how much is the probability when traffic is high level, and if human capital level is low, the operation risk rated higher probability is expressed as P (O=3/ HC=1). The calculation of the probability calculation based on historical data, and one can be drawn from the experience of experts if there is no historical data.

3.3. Expressway Operational Enterprise Risk Assessment

Risk assessment deals with the evaluation of the current risk factor status, that is, the probability and the consequence. The consequence can be used actually of the quantitative scoring method and the probability presented the thinking of Bayesian which is the key in this paper. Bayesian inference can be divided into positive causal reasoning that is a risk factor in a certain state of risk impact on the enterprise value (probability). For example, P (P=1/S=1, F=1, O=2) indicates that the probability of enterprise value when the levels of strategic risk, financial risk, and operation risk are low, low, and medium, respectively. Another is the reverse of the diagnostic reasoning that if we know the certain probability of the enterprise value, we can then infer the probability of a risk factor. For example, P (F=2/P=3) denotes that when the enterprise value level is high, the probability of financial risk is medium. The significance of diagnostic reasoning is that when the enterprise value level is high, we can infer the target level of factors which are mounting or the impact on the enterprise value greater, as to indicate the future direction of risk management. Compared to conventional risk assessment techniques such as Fault trees, Bayesian Networks provide a superior modelling method for dynamic risk analysis and assessment [12]. The virtue of Bayesian Network model is that its inference engine for updating the posterior probability of enterprise value given new information or new key risk factors. It implies that once the Bayesian Network model has been built, it enables the corporation for different judgments from the network structure by adding an auxiliary node to the parent set of the node of interest. This probability updating not only continuously reduces the data uncertainty, but it also provides the enterprise risk scenario with real-time and up-to-date analysis.

4. Example

The assessment of expressway enterprise risks using the Bayesian Network Model is presented as follow.

A. Causal reasoning

If the relationship of the enterprise value level and the risk factors are as follows:

$P(P= i/S=j, F=k, O=m)$; i, j, k, m= 1, 2, 3 and $P(X=i/X1=j,X2=k)$; i, j, k = 1, 2, 3

Such as financial risk, there is the probability distribution supposed as follows:

1) Conditional probability distribution:

TABLE 1. CONDITIONAL PROBABILITY

P(F=3/T=i,MC=j)	i=1	i=2	i=3
j=1	0.1	0.1	0.25
j=2	0.05	0.1	0.1
j=3	0.05	0.1	0.15

2) Probability distribution:

TABLE 2. PROBABILITY

P(T=i,MC=j)	i=1	i=2	i=3
j=1	0.1	0.3	0.05
j=2	0.2	0.1	0.1
j=3	0.05	0.05	0.05

Computing the probability of financial risk for the high level, the solution process is as follows:

$P(F=3) = \sum(P(F=3/T=i,MC=j) * P(T=i,MC=j))$; Finally, P(F=3) = 9.75%

B. Diagnostic reasoning

The probability of strategic risk is medium when the enterprise value level is high.

1) Conditional probability distribution:

TABLE 3. CONDITIONAL PROBABILITY

	i=1	i=2	i=3
P(P=3/S=2)	0.35	0.5	0.15

2) Probability distribution:

TABLE 4. PROBABILITY

	i=1	i=2	i=3
P(S=i)	0.5	0.2	0.3

So, $P(S=2/P=3) = P(S=2,P=3)/P(P=3) = P(P=3/S=2)P(S=2)/P(P=3)$

and $P(P=3)=P(P=3/S=1)P(S=1)+P(P=3/S=2)P(S=2)+P(P=3/S=3)P(S=3)$ Finally, P(S=2/P=3) =32%

C. Probability updating

Such as adding the Economic situation (ES) factor to be the parent node of the financial risk, there is

The probability distribution supposed as follows:

1) Conditional probability distribution:

TABLE 5. CONDITIONAL PROBABILITY

P(F=3/T=i,ES=j)	i=1	i=2	i=3
j=1	0.05	0.1	0.1
j=2	0.1	0.05	0.15
j=3	0.25	0.1	0.1

2) Probability distribution:

TABLE 6. PROBABILITY

P(T=i,ES=j)	i=1	i=2	i=3
j=1	0.05	0.2	0.05
j=2	0.1	0.05	0.1
j=3	0.1	0.05	0.3

Computing the probability of financial risk for the high level, the solution process is as follows:

$P(F=3) = \sum(P(F=3/T=i,ES=j) * P(T=i,ES=j))$; Finally, $P(F=3) = 11.5\%$

5. Summary

This study built the Bayesian model for Thailand expressway enterprise risk management, which can identify the risk source from three areas: strategic or service risk, financial risk, operation risk. To assess the enterprise value or performance level this study analyzed those factors. The Bayesian model can effectively address the problem of traditional risk management. This study proved the feasibility of the model through simulation experiments.

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