Abstract— Quantitative risk management is becoming more and more important, which however requires a large number of probabilities in numerical form resulting in a major obstacle of doing so. Following on the second author’s proposed Alien Eyes’ Risk Model, this paper proposes a risk management framework using a linguistic variable-based belief network, which just needs linguistic inputs. In the framework, identified risk factors are firstly categorized into key risk indicators (KRIs, Key Risk Indicators) and key risk drivers (KRDs, Key Risk Drivers), and a belief network is mapped with KRIs as leaf nodes and KRDs as parent nodes. A Monte Carlo simulation is then performed according to the acquired probabilities of KRIs so as to quantitatively evaluate project risks and to prioritize risk mitigation measures.

Index Terms— belief network, fuzzy number, linguistic variable, risk management.

1. INTRODUCTION

POOR performance of construction projects such as cost or time overruns are commonplace, because there are too many and complicated unforeseen or foreseen events to adequately allow for. Significant improvements in project management performance can result from greater attention to risk management[1].

Risk management generally involves risk identification, risk analysis, and risk response. In addition to the different definitions of risk, there are various ways for categorizing risk for different purposes too. In the second author’s previously proposed Alien Eyes’ Risk Model, the identified risks are sorted into three levels, i.e. country, market and project levels[2]. In the next place, it is drawn that there is relationship among risks at different levels[3, 4]. The country level risks are influencing both the market and project levels risks, while the market level risks are influencing the project level risks. The Alien Eyes’ Risk Model shows the hierarchical levels of the risks and the influence relationship among the risks in detail[2].

Most of the aforementioned researches are on qualitative risk management while quantitative risk management is becoming more and more important. The latter however requires a large number of probabilities in numerical form. This is often a major obstacle. One of the reasons is that there is usually insufficient objective data to calculate the probability of occurrence of specific outcomes of risk events due to the individual nature of construction projects[5]. A high degree of subjective judgment is therefore needed. In practice the parameters involved are best described subjectively in linguistic rather than mathematical terms[5-7].

Based on the above, the aim of this paper is to help construction firms evaluate risks of a potential construction project, especially in an unfamiliar market. The research objectives are:

- to fully utilize the historic project data, not only in mathematical but linguistic forms;
- to develop a model for representing the risks and calculate their influence relationship;
- to formulate a risk management framework that can be adopted by construction firms to evaluate risks associated
with a potential construction project.

2. Risk Management Framework Overview

The proposed risk management framework is a generic quantitative method to comprehensively assess the influence relationship among risks, from which construction firms can estimate risks to access an unfamiliar market by giving a linguistic judgment on country and market level risks.

The general structure of the risk management framework consists of two parts as shown in Fig. 1.

Knowledge management is a long-standing and update-keeping process. Projects data is firstly collected, including influence relationship among risks and the linguistic estimation of risk criticality. Then a belief network is constructed which consists of a qualitative and a quantitative part. The qualitative part is a graph in which nodes represent risks and arrows their influence relationship. The quantitative part encodes influence relationship over these risks, where fuzzy arithmetic operation and Bayesian equation might be referred to.

Correspondingly, risk management is a one-off process, which also involves three parts: risk identification, risk analysis, and risk response. In risk identification period, country and market level risks must be identified firstly and their linguistic critical judgments should be given. After that, the criticalities of project level risks can be calculated. A Monte Carlo simulation is then performed according to the acquired probabilities of project level risks, and a quantitative evaluation of project risks is provided. Based on the result, hierarchical level of mitigation measures could be proposed.

Knowledge management and risk management could interact with each other, resulting in their better performance. The belief network constructed in knowledge management is used to calculate project level risks in risk management, while the data in the risk management would update the belief network.

In the following sections, this paper will explain the linguistic variable and its arithmetic operations which are involved in knowledge management part as well as the mapping and calculation of a belief network. A case study is then used to demonstrate the application of the proposed risk management framework.

3. Linguistic Variable

The quantitative part of the belief network, with the influence relationship over risks, is rather problematic. On the input side, it involves the elicitation from domain experts of critical judgment for all risks. This may be a prohibitive quantity of risks, because of the individual nature of construction projects. What is more, experts are required to express all these criticalities numerically, something they are often reluctant to do. Ranasinghe et al. propose an elicitation approach to elicit expert knowledge as accurate, calibrated and coherent subjective probabilities, combining the theoretical requirements for valid subjective probabilities with a practical process[8]. More than that, Clemen et al. concerns the combination of experts’ probability distributions in risk analysis, discussing a variety of combination methods and attempting to highlight the important conceptual and practical issues to be considered in designing a combination process in practice[9].

Except in situations where the odds are objectively measurable, most people feel more at ease with verbal probability expressions than with numbers. Renooij et al. conduct some experiments concerning the development of a probability scale that contains words as well as numbers. The scale appears to be an aid for researchers and domain experts during the elicitation phase of building a belief network and might help users understand the output of the network. They also prove that the scale with seven categories of linguistic expressions is mostly closed to the probability points of 100%, 85%, 75%, 50%, 25%, 15%, and 0%[7]. Recently, Sachs et al. propose a knowledge based fuzzy expert system for quantifying qualitative information on risks, where linguistic variables represented by trapezoidal fuzzy numbers are used to represent expert opinion[10].

Based on the findings of these literature reviews, this paper used trapezoidal fuzzy numbers to represent linguistic expressions of risk criticalities and influence relationship. Table 1 shows the specific assignment of trapezoidal fuzzy numbers to linguistic expressions. The centers of gravity are mostly closed to the probability points of 100%, 85%, 75%, 50%, 25%, 15%, and 0%, referred to Renooij’s research. The scale for the quadruples a, b, c and d is chosen to make the distances ab, bc, and cd all equal to 10%.

<table>
<thead>
<tr>
<th>Linguistic Expressions</th>
<th>Trapezoidal Fuzzy Numbers</th>
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<tbody>
<tr>
<td>Not critical at all</td>
<td>0 0 0.05 0.15</td>
</tr>
<tr>
<td>Slightly critical</td>
<td>0 0.1 0.2 0.3</td>
</tr>
<tr>
<td>Somehow critical</td>
<td>0.1 0.2 0.3 0.4</td>
</tr>
<tr>
<td>Critical</td>
<td>0.35 0.45 0.55 0.65</td>
</tr>
<tr>
<td>Very critical</td>
<td>0.6 0.7 0.8 0.9</td>
</tr>
<tr>
<td>Very much critical</td>
<td>0.7 0.8 0.9 1.0</td>
</tr>
<tr>
<td>Exceptionally critical</td>
<td>0.85 0.95 1.0 1.0</td>
</tr>
</tbody>
</table>

Take the linguistic expression “somehow critical” presented in Fig. 2 for instance, the linguistic variable is “risk criticality”, the value of linguistic variable is “somehow critical”, and the membership function (which associates a grade of membership belonging to the interval of crisp numbers with each quantified linguistic value) is trapezoidal membership function with the quadruples a, b, c and d as 0.1, 0.2, 0.3, and 0.4.

![Fig. 2 Trapezoidal number of “somehow critical”](image)

In this paper, the trapezoidal fuzzy arithmetic operation will not be demonstrated in detail, but briefly listed in the following\[5, 6, 10, 11\]:

\[
A + B = (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2)
\]

(1)

\[
A - B = (a_1 - d_2, b_1 - c_2, c_1 - b_2, d_1 - a_2)
\]

(2)

\[
A \times B = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2, d_1 \times d_2)
\]

(3)

\[
A / B = (a_1 / d_2, b_1 / c_2, c_1 / b_2, d_1 / a_2)
\]

(4)

As shown in Fig. 1, the outcome of influence relationships is a fuzzy number, which should be converted into a probability distribution function for running the subsequent stochastic cash flow simulation. According to Chen\[12\] and Sheen\[13\], there are two methods to do that. The first is uniform conversion keeping the same shape of the fuzzy number, while the other is proportional conversion keeping the same intervals. Following Sachs’ idea\[10\], this paper will employ the second one as shown in Fig. 3.

![Fig. 3 Conversion with the same intervals](image)

4. **BELIEF NETWORK**

4.1 **Mapping**

Belief networks, also referred to as Bayesian networks, are a form of artificial intelligence that incorporates uncertainty through probability theory and conditional dependence. Variables are graphically represented by nodes, whereas conditional dependence relationships between the variables are represented by arrows. A belief network is developed by first defining the variables in the domain and the relationships between those variables. During evaluation of the network, evidence may be entered at any node without concerning about whether the variable is an input or output variable\[14\].

In the second author’s research on Alien Eyes’ Risk Model, a survey was conducted and twenty-eight critical risks were identified, categorized into three (country, market and project) hierarchical levels and their criticality evaluated and ranked. Moreover, the hierarchical levels of the risks and the influence relationship among the risks were also proposed. This paper firstly sorts the identified risks into key risk indicators (KRI s) and key risk drivers (KRDs). Key risk indicators are relevant to the risks which are the parameters of the finance report forms or the factors having direct influence to the parameters. They are almost the project level risks except some market level risks. Other risk factors influencing the KRI s in the survey are deemed as KRDs. Therefore, a belief network can be mapped with KRI s as leaf nodes and KRDs as parent nodes. Fig. 4 is an example.

![Fig. 4 An example of belief network](image)

4.2 **Calculation**

In Alien Eyes’ Risk Model, the criticalities of the identified risks are evaluated, which are also regarded as evidences at the relevant nodes in the belief network. Then the influence relationship represented by arrows can be calculated. Please note that the influence relationship is supposed to be a crisp number in order to minimize calculations.

Take Fig. 4 for example, the criticalities of the four country level risks in one respondent’s result are 3, 4, 1 and 7 (1 = Not critical at all, 2 = Slightly critical, 3 = Somehow critical, 4 = Critical, 5 = Very critical, 6 = Very much critical, 7 = Exceptionally critical); the criticality of the market level risk is
4. Convert all the points of criticalities to fuzzy numbers firstly as per Table 1, and then introduce them into the following equation:

\[ P_{B2} = P_{A9} \cdot P_{A2-B2} + P_{B2} \cdot P_{A2-B2} + P_{B1} \cdot P_{A2-B2} + P_{A2} \cdot P_{A2-B2} \]  (5)

Where \( P_{A9} \) is the criticality of B2 risk; \( P_{A2-B2} \) is the influence relationship from A9 risk to B2 risk. The result of \( P_{A9-B2}, P_{A2-B2}, P_{B1-B2}, P_{A2-B2} \) is 0.3776, 0.4337, 0.1888 and 0.1888.

The average of the influence relationship obtained according to the same operations above is represented in Table 2.

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<tr>
<th></th>
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<tbody>
<tr>
<td>Value</td>
<td>0.2689</td>
<td>0.2464</td>
<td>0.3430</td>
<td>0.1417</td>
</tr>
<tr>
<td></td>
<td>B1-D1</td>
<td>A2-D1</td>
<td>B2-D1</td>
<td></td>
</tr>
<tr>
<td>Value</td>
<td>0.2744</td>
<td>0.4428</td>
<td>0.2828</td>
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</tbody>
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5. CASE STUDY

To demonstrate the application of the proposed risk management framework, a hypothetical BOT power project is employed. Its concession period is 20 years excluding construction period. The base-case cash flows of the projects are employed. Its concession period is 20 years excluding construction period. The average of the influence relationship obtained according to the same operations above is represented in Table 2.

Table 2 Averge of the influence relationship

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As shown in Fig. 1, the first step in risk management using the proposed framework is country and market risks (key risk drivers, KRDs) identification and their linguistic criticality judgment. In this case, assume that the criticality points of government policies, public image, cultural differences and Change in Law risks are 6, 2, 3 and 6 respectively.

The second step is to calculate the criticality of KRIis in the belief network, then convert it into a probability distribution function, and conduct a Monte Carlo simulation at last. Introduce the criticalities of KRDs and the influence relationships which are known already into equation 5, so that the fuzzy number of human resource risk obtained is 0.3217, 0.4217, 0.5217 and 0.6217. Similarly, the fuzzy number of improper design risk is 0.4284, 0.5284, 0.6284 and 0.7284.

As demonstrated above, proportional conversion keeping the same intervals for converting the fuzzy number will be used. The outcome of probability distribution function is represented in Fig. 3. Moreover, a stochastic cash flow simulation is performed using @risk software. Table 3 provides the simulation results.

Table 3 Simulation results

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>ΔNPV</th>
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</thead>
<tbody>
<tr>
<td>NPV</td>
<td>18111.7</td>
<td>-38%</td>
</tr>
<tr>
<td>5%</td>
<td>16037.87</td>
<td>-45%</td>
</tr>
<tr>
<td>95%</td>
<td>20104.64</td>
<td>-31%</td>
</tr>
</tbody>
</table>

Risk response is the last step in risk management. In Alien Eyes’ Risk Model, a qualitative risk mitigation framework integrating the key findings of the research was proposed providing detailed risk management strategies and procedure. The proposed framework is practical and relatively easy to apply. More than that, the quantitative analysis in step 2 can provide a lot of other information. Users can compare the simulation results to their risk capability, so that they can make more rational decisions. The final NPV result can even provide the basis of the guarantee or insurance amount.

Please note that the case is used to explain the application of the proposed risk management framework. It would not be so appropriate since it has been simplified for minimizing calculations. Meanwhile, all risks’ criticalities and the influence relationships in the case are cited from the second author’s research. If not, the process of knowledge management in the framework is necessary.

6. CONCLUSIONS

A generic risk management framework has been proposed which can be applied to quantitatively and comprehensively assess the influence relationship among risks. It is of usefulness for construction firms to make more rational risk management decisions especially in an unfamiliar market. Decision-makers can make an approximate judgment of risks in the potential project by rating the criticality of country and market level risks which is more possible and precise than rating the criticality of project level risks.

A limitation of the current risk management framework is that the arithmetic operations are rather complicated, as a risk might be influenced by many other risks. It is therefore worth looking for a generic, simple and authentic connection among risks. Further study could also be carried out on the criterion for scaling risks, such as a planar criterion (probability, impact) or a three-dimensional criterion (probability, impact, nature).

REFERENCES


