Construction Project Risk Assessment Using Existing Database and Project-Specific Information

Hyun-Ho Choi[1] and Sankaran Mahadevan[2]

Abstract: This paper develops a risk assessment methodology for construction projects by combining existing large quantities of data and project-specific information through updating approaches. Earlier studies have indicated that risk assessment is still difficult for practicing engineers to use due to the requirement of data on too many input variables. However, the availability of existing large quantities of data and project-specific information makes it possible to simplify the risk assessment procedure. Two main ideas are pursued in this paper to facilitate practical implementation: identify and evaluate the critical risk events, and develop a systematic updating methodology. Both epistemic and aleatory types of uncertainties in the data are considered, and corresponding updating procedures are developed. The proposed methodology is illustrated for the construction risk assessment of a cable-stayed bridge.

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CE Database subject headings: Construction management; Databases; Information management; Fuzzy sets; Risk management.

Introduction

A number of accidents including the collapse of large infrastructure systems such as subways, bridges, and buildings have occurred during construction (Park 1995). The large scale of the facilities and the complexity of construction processes, equipment, and operations are important considerations. In the construction of large civil structures, it has been recognized that failures or collapse accidents are more likely to happen because of adverse or hazardous environments during construction. For example, the National Safety Council reported that despite employing only 5% of the industrial workforce, construction accounted for 14% of all workplace deaths and 9% of disabling injuries (Everett and Frank 1996). Thus, systematic procedures for risk assessment and management of construction projects are increasingly critical to minimize the disproportionate rate of accidents in construction projects.

Risk analysis methods currently used in actual engineering practice usually employ a qualitative approach for handling various risks in construction projects and do not explicitly analyze risk in quantitative terms that can provide helpful information for managing the risk. Also, risk assessment of construction projects is usually performed during the precontract phase or preconstruction phase for use in cost estimation or risk reduction strategies. Quantitative risk analysis during the precontract phase has to contend with many uncertainties due to lack of data. In many practical situations, it is difficult to obtain precise data. Thus, uncertainties in risk analysis may be attributed both to the inherent randomness in some variables and to inadequate as well as imprecise data. Imprecise information makes subjective judgment based on expert opinion important, and in such situations fuzzy-sets-based approaches for risk assessment may be useful.

A procedure for risk assessment of construction projects using fuzzy sets concepts has been developed earlier by Cho et al. (2002) and Choi et al. (2004). However, the earlier studies have identified two major problems. First, it may be possible for the risk assessment to lead to unreasonable results because the most common mistake made by novice and experienced investigators alike is that they fail to consider all possible risk scenarios. Omission of critical risks might lead to significant error in the total risk estimate. Second, the earlier method is difficult for practicing engineers to use due to the requirement of data on too many input variables.

The objective of this study is to propose a risk assessment methodology for construction projects by combining existing large quantities of data and project-specific information through updating approaches. That is, based on risk assessment and management activities, inspection, maintenance, etc., on similar previous projects, large quantities of data are stored; then, for a new project, the risk estimate is updated based on information specific to the new project. In this methodology, it is important to keep the procedure efficient by concentrating only on a few critical risks that are the dominant cost items.

Handling Qualitative Information

Information Uncertainty Modeling

Uncertainties in information may arise due to live ambiguity components—the experience of experts and statistical uncertainties. Therefore, the fuzzy membership curve is designed to consider the uncertainty range that combines the uncertainty in subjective judgment and probabilistic analysis methods.

- **Subjective judgments:** The fuzzy membership curves repre-

[1]Senior Researcher, Highway Design Evaluation Office, Korea Expressway Corp., 430, Daewang Pangyoro, Sujeong-gu, Seongnam, Kyungki, Korea. E-mail: padre@ex.co.kr, padre@hanyang.ac.kr

[2]Professor, Dept. of Civil and Environmental Engineering and Mechanical Engineering, Vanderbilt Univ., VU Station B #351831, 2301 Vanderbilt Place, Nashville, TN 37235-1831. E-mail: sankaran.mahadevan@vanderbilt.edu

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Table 1. Uncertainty Characterization from Subjective Judgments/Probabilistic Parameter Estimates

Subjective judgments		Probabilistic parameter estimates		
Complexity of work/judgmental condition	Uncertainty degree from education, confidence, and experience	Unreliable/ insufficient data	Approximation in statistical analysis methods	Determined uncertainty range
Very small	Very small	Very small	Very small	Very very close
Very small	Small	Very Small	Small	
Small	Very small	Small	Very small	
Very small	Normal	Very small	Normal	Very close
Normal	Very small	Normal	Very small	
Small	Small	Small	Small	
Small	Normal	Small	Normal	Close
Normal	Small	Normal	Small	
Very small	Large	Very small	Large	
Large	Very small	Large	Very small	
Normal	Normal	Normal	Normal	Fairly close
Small	Large	Small	Large	
Large	Small	Large	Small	
Normal	Large	Normal	Large	Somewhat close
Large	Large	Large	Large	

sented in the next section can be used to include the uncertainties in subjective judgments. The factors that influence the uncertainties in subjective judgments are divided into two main classes: (1) the complexity of work/judgmental condition and (2) the level of education, confidence, and experience. In general, there are four possible grades of uncertainties in these two mean classes, which are usually described as "Very Small," "Small," "Normal," and "Large." Table 1 shows the classification of linguistic variables that represents the degree of uncertainties according to different combinations of the two main factors.

- **Parameter statistics:** The parameter statistics estimates based on historical accident data are required to predict the occurrence probability of the associated risk events. Such estimates have uncertainties due to (1) unreliable/insufficient data or (2) approximation in statistical analysis methods. The combination of uncertainties in both subjective judgment and statistical parameter estimates may be represented through linguistic variables such as "Small/Very Small," etc., as shown in Table 1.

Fuzzy Membership Curves

In the following, membership curves using the fuzzy numbers concept, as modified forms of general ramp type, and uncertainty modelings are briefly discussed. These curves have been developed earlier (Cho et al. 2002; Choi et al. 2004) to consider uncertainties of risk events on the basis of existing studies (Blockley 1999; Fujino 1994; Hadipriono 1985; Baldwin and Pilsworth 1979) and are verified through a survey conducted among construction industry professionals in Korea. The fuzzy number concept can be used to handle ambiguity in modeling subjective probability judgment (Dubois and Prade 1982). The membership functions for the linguistic statements "Close to," "Lower than," and "Higher than" are defined as shown in Eqs. (1)–(3), respectively. Details regarding the derivation and justification of the formulas are discussed in Cho et al. (2002). Here, we simply summarize them to facilitate the development of the proposed information combination approach

$$f_A(x') = \begin{cases} \{[(2x'^{1/y})]^y\}^n, & 0.0^y \leqslant x' \leqslant 0.5^y \\ \{[(2-2x'^{1/y})]^y\}^n, & 0.5^y \leqslant x' \leqslant 1.0^y \end{cases} \quad (1)$$

$$f_A(x') = \begin{cases} \{[(1-2x'^{1/y})]^{1/y}\}^n, & 0.0^y \leqslant x' \leqslant 0.5^y \\ 0, & 0.5^y \leqslant x' \leqslant 1.0^y \end{cases} \quad (2)$$

$$f_A(x') = \begin{cases} 0, & 0.0^y \leqslant x' \leqslant 0.5^y \\ \{[(2x'^{1/y}-1)]^{1/y}\}^n, & 0.5^y \leqslant x' \leqslant 1.0^y \end{cases} \quad (3)$$

where x'=transformed axis such that the estimated or assumed fuzzy number is located at the midpoint (0.5) of the axis; thus $x^y = x'$, and for $x=0.5$, x' is at the midpoint of the fuzzy membership curve; n=parameter related to the linguistic variables; and y=midpoint transfer factor.

Fig. 1 shows an example of the fuzzy membership curves corresponding to linguistic statements of the form for "Close to" (Cho et al. 2002).

Identification of Critical Risks

Some practical risk assessments using the fuzzy membership functions discussed in the previous section have been performed by Choi et al. (2004) and Choi (2005). Risk assessment in the preconstruction phase or construction phase follows four major steps in accordance with a general procedure: risk-related information survey, risk identification, risk analysis/evaluation, and risk management. The developed tools and techniques include survey sheets, detailed check sheets, and the fuzzy uncertainty model, as documented in Choi et al. (2004).

However, as previously described, risk assessment is still difficult for practicing engineers to use due to the requirement of data on too many input variables. Therefore, if we have existing large quantities of data and new project-specific information, it is possible to identify and focus on the critical risks, thus simplifying the analysis and facilitating practical implementation. That is, we do not need to perform the risk assessment using all the col-

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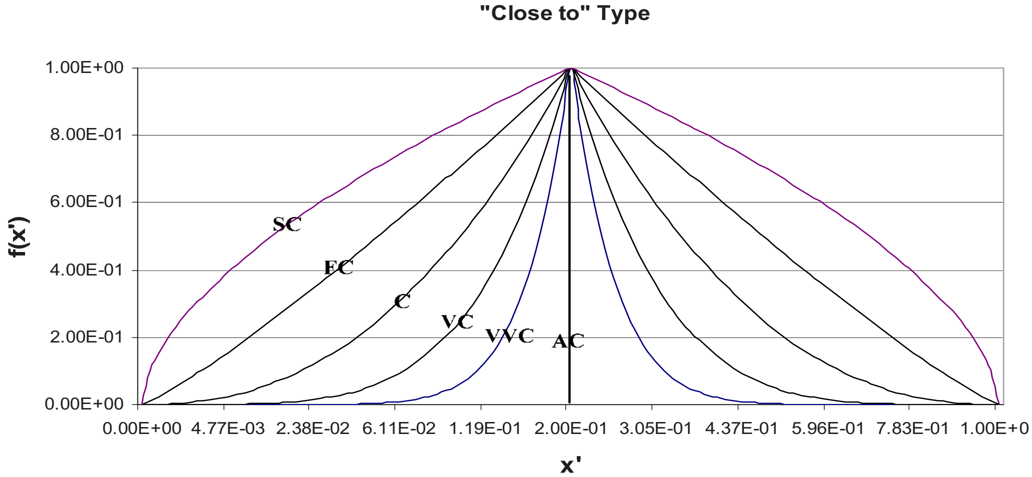

Fig. 1. Fuzzy membership curve for "Close to"

lected risk events again because only a few critical risks are important cost items, affecting a large proportion of the total risk.

Here is the key idea of this study for practical usage. First, it should be recommended that risk assessors carefully identify the critical risk events and also circumspectly construct the risk scenarios according to the characteristics of the specific project. Second, we need to simplify the use of risk assessment based on previous data of the same type projects combined with updating approaches, only updating critical risks for engineers so that it can find practical implementation. For example, data on two types of infrastructure systems such as underground structures (subway) and cable-stayed bridges are collected for specific construction projects in Korea (Choi et al. 2004; Choi 2005). A few pages of input sheets including the main characteristics of selected structures and critical risk scenarios are used. The reason it is possible to use these few pages of input sheet is as follows. For example, in the case of cable-stayed bridge in Choi (2005), data on risk events and scenarios are collected. Then, as illustrated in Fig. 2, it is found that only about more than half of the 60 risk scenarios based on 24 check sheets may have a significant effect on the total risk. Moreover, based on the observation, only 10 or 15 risk scenarios which are estimated in the occurrence probability range of 5–10% are important cost items, affecting more than 80% of total risk. Therefore, if the data of existing similar structures were well established and we have risk calculated in advance, then, a few pages of input sheets including the main characteristics of the selected structure and critical risk scenarios from previous risk assessment may be combined to perform the risk assessment of the new construction project.

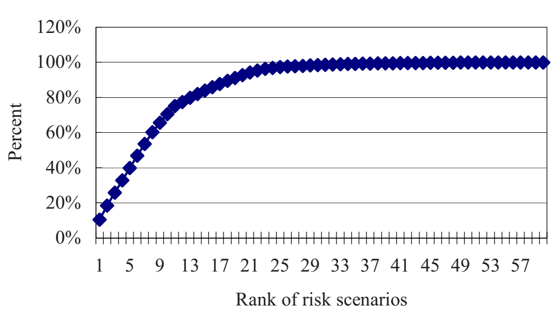

Fig. 2. Cumulative percentage of risk scenarios

Updating with Epistemic and Aleatory-Type Data

In practice, we might identify two broad types of uncertainty: namely, (1) uncertainty associated with the randomness of the phenomenon that is exhibited as variability in the observed information, and (2) uncertainty associated with imperfect models of the real world because of insufficient or imperfect knowledge of reality. These two types of uncertainty may be called, respectively, aleatory uncertainty and epistemic uncertainty (Ang and Tang 2006). An updating procedure may be useful for expressing uncertainty related to quantitative observations, but its applicability in many cases is rather limited. In many practical situations we would not be able to perform a formal Bayesian updating to incorporate new observations (Everett and Frank 1996).

Three types of combinations of prior information and new information are considered in this section.

- Case 1: Prior data are aleatory-type data that have a probability distribution and new data are also aleatory type. Then, a formal probabilistic Bayesian updating technique can be used simply for updating.
- Case 2: Prior data are aleatory-type data that have a probability distribution and new data are epistemic-type data such as fuzzy data. Also, prior data are epistemic-type data such as fuzzy data and new data have a probability distribution. Then, a fuzzy Bayesian updating procedure is used.
- Case 3: Prior data are epistemic-type data such as fuzzy data and new data are also epistemic-type fuzzy data. Then, the proposed fuzzy updating procedure is used.

Details of the updating procedures for these three cases are presented in the following.

Fuzzy Bayesian Updating

The formal probabilistic Bayesian updating in Case 1 is well represented in Ang and Tang (1975) and Haldar and Mahadevan (2000). In Case 2, prior aleatory-type data that have an appropriate distribution are combined with new epistemic data assumed as a uniform distribution (Apeland et al. 2002). Or, prior epistemic data are combined with new probability data (likelihood) that have an appropriate distribution.

Given a fuzzy set a defined on x and a number $\alpha \in [0,1]$, the α cut of a, denoted by a_α, is the crisp set that consists of all elements whose membership degrees in a are greater than or

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Table 2. Area Factors

Variables	Close to	Variables	Lower/higher than
VVC	2.00E−01	VV L/H T	8.00E−01
VC	3.33E−01	V L/H T	6.67E−01
C	5.00E−01	L/H T	5.00E−01
FC	6.67E−01	S L/H T	3.33E−01
FFC	8.00E−01	VS L/H T	2.00E−01

equal to α (Klir 2004). Thus, the new data are transformed to crisp probability format. Then, it is easily subjected to a Bayesian updating technique.

Bayesian updating is formulated as

$$f''(x) = \frac{L(x)f'(x)}{\int L(x)f'(x)dx} \tag{4}$$

where $f'(x)$=prior density function; $f''(x)$=posterior density function; and $L(x)$=likelihood function.

It is assumed that x is a continuous random variable. If there is no information on x except epistemic-type data such as an expert's opinion, a uniform distribution may be assumed from the α-cut method. Thus

$$f'(x) = \frac{1}{\tilde{a}_\alpha^U - \tilde{a}_\alpha^L} \tag{5a}$$

where the fuzzy number $\tilde{a}$ corresponding to a (constant) can be interpreted as "around a;" $\tilde{a}_\alpha^U$, $\tilde{a}_\alpha^L$=upper and lower limits of a with respect to α level.

Similarly, if uniform distribution $L(x)$ is assumed for the likelihood distribution, then

$$L(x) = \frac{1}{\tilde{a}_\alpha^U - \tilde{a}_\alpha^L} \tag{5b}$$

Fuzzy Updating

In Case 3, the proposed fuzzy updating procedure is presented.

- Step 1: As prior data are fuzzy and new information (i.e., data) is also fuzzy, fuzzy membership curves are used to represent expert opinion, as discussed earlier. Then, we choose the appropriate linguistic variable that represents the degree of uncertainty in subjective judgments in the uncertainty modeling. Depending on the linguistic variables, it can be indicated whether the expert opinion is valuable or not.
- Step 2: Generally, the strength or weight of the probability statement is governed by the state of information. In this paper, a weighting factor is proposed. The smaller the area under the membership curve for the corresponding linguistic variable, the larger is the weight. For example, "VVC" has more weight than "FFC" because the amount of uncertainty due to the complexity of the work and the assessor's health conditions, education, confidence, and experience is very small or small (Cho et al. 2002).

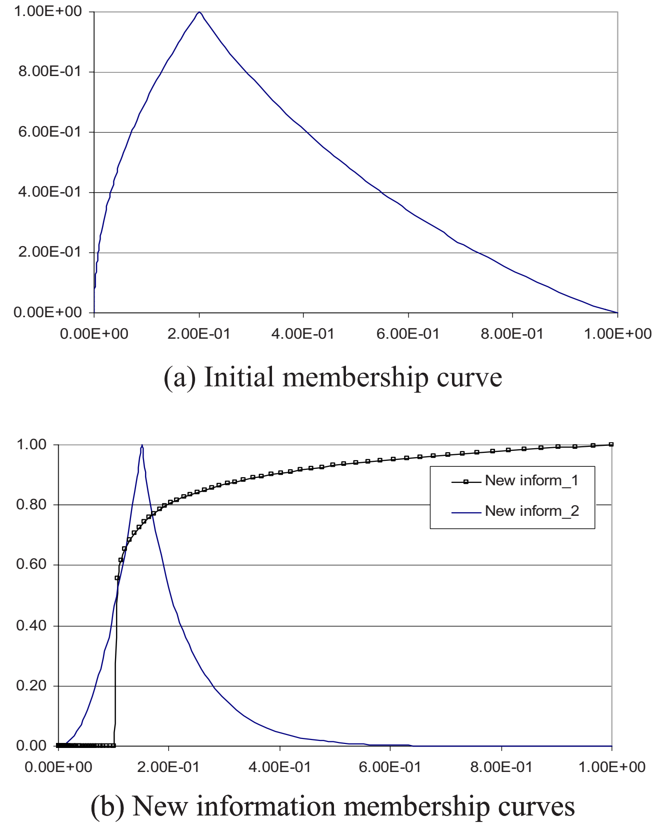

Fig. 3. Membership curves for initial and new multiple information

The weight factor is represented as

$$W_j = \frac{\sum_{i=1}^{5} \int_{0.0^y}^{1.0^y} f_{A\_i}(x')dx'}{\int_{0.0^y}^{1.0^y} f_{A\_j}(x')dx'} \tag{6}$$

where i=1 (VVC), 2(VC), 3(C), 4(FC), 5(FFC).

In case of combining, "Close to" type and "Lower/Higher than" type curves, the areas of curves according to selected linguistic variables are different for each type. In this study, it is assumed that same weight factors are used only according to selected linguistic variables such as "VVC," "FC," "SHT," "VLT," etc., regardless of the type of curves. In the case of "Lower/Higher than" type curves, the meaning of area of curves is different. The larger the area of a curve according to selected linguistic variable, the more weight for the expert's opinion; the corresponding defuzzied interval is smaller. For a similar example, "VSHT" or "VLST" has more weight than "VVHT" or "VVLT." Table 2 shows the area factors described.

Membership functions corresponding to "Close to," "Lower than," and "Higher than" statements, multiplied with the weight function, are defined as shown in Eqs. (7)–(9) respectively. Fig. 3 presents these functions in x scale not x' for easy understanding [see the definition of x' following Eq. (3)]

$$f(x') = W_i f_{A\_i}(x') = \begin{cases} W_i\{[(2x'^{1/y})]^y\}^n, & 0.0^y \leqslant x' \leqslant 0.5^y \\ W_i\{[(2-2x'^{1/y})]^y\}^n, & 0.5^y \leqslant x' \leqslant 1.0^y \end{cases} \tag{7}$$

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$$f(x') = W_i f_{A\_i}(x') = \begin{cases} W_i\{[(1-2x'^{1/y})]^{1/y}\}^n, & 0.0^y \leqslant x' \leqslant 0.5^y \\ 0, & 0.5^y \leqslant x' \leqslant 1.0^y \end{cases} \tag{8}$$

$$f(x') = W_i f_{A\_i}(x') = \begin{cases} 0, & 0.0^y \leqslant x' \leqslant 0.5^y \\ W_i\{[(2x'^{1/y}-1)]^{1/y}\}^n, & 0.5^y \leqslant x' \leqslant 1.0^y \end{cases} \tag{9}$$

where W_i is the weight factor.

- Step 3: Initial information and new information are combined. A simple approach is generally the most attractive one. Thus, we just add the new membership curve with weight factors to the initial membership curve and get the updated membership curves. If multiple pieces of new information are available, then more similar terms are added, as in

$$F(x') = \sum \int W_i f_{A\_i}(x')dx' = \begin{cases} \int W_1\{[(2x'^{1/y_1})]^{y_1}\}^{n_1}dx' + \int W_2\{[(2x'^{1/y_2})]^{y_2}\}^{n_2}dx' + \cdots, & 0.0^y \leqslant x' \leqslant 0.5^y \\ \int W_1\{[(2-2x'^{1/y_1})]^{y_1}\}^{n_1}dx' + \int W_2\{[(2-2x'^{1/y_2})]^{y_2}\}^{n_2}dx' + \cdots, & 0.5^y \leqslant x' \leqslant 1.0^y \end{cases} \tag{10}$$

In Eq. (10), the first term on the right-hand side indicates the original membership curve, and the subsequent term(s) come from new information.

Similarly, a combination of "Close to" type and "Lower/Higher than" type statements is as follows:

$$F(x') = \sum \int W_i f_{A\_i}(x')dx' = \begin{cases} \int W_1\{[(2x'^{1/y_1})]^{y_1}\}^{n_1}dx' + \int W_2\{[(1-2x'^{1/y_2})]^{1/y_2}\}^{n_2}dx' + \cdots, & 0.0^y \leqslant x' \leqslant 0.5^y \\ \int W_1\{[(2-2x'^{1/y_1})]^{y_1}\}^{n_1}dx' + 0 + \cdots, & 0.5^y \leqslant x' \leqslant 1.0^y \end{cases} \tag{11}$$

$$F(x') = \sum \int W_i f_{A\_i}(x')dx' = \begin{cases} \int W_1\{[(2x'^{1/y_1})]^{y_1}\}^{n_1}dx' + 0 + \cdots, & 0.0^y \leqslant x' \leqslant 0.5^y \\ \int W_1\{[(2-2x'^{1/y_1})]^{y_1}\}^{n_1}dx' + \int W_2\{[(2x'^{1/y_2}-1)]^{1/y_2}\}^{n_2}dx' + \cdots, & 0.5^y \leqslant x' \leqslant 1.0^y \end{cases} \tag{12}$$

- Step 4: The normalization factor c is computed as

$$c = \frac{1}{\max\{F(x')\}} \tag{13}$$

- Step 5: The uncertainty range in the normalized combined membership curves is then defuzzified by using an appropriate defuzzification technique based on x' values. In this paper, the α-level cut method was selected, as it is relatively easy to apply.

For example, defuzzied intervals of membership functions corresponding to "Close to," "Lower than," and "Higher than" statements are defined as shown in Eqs. (14)–(16), respectively

$$\tilde{x}_\alpha^L = \left\{ \tfrac{1}{2}((\alpha^{1/n})^{1/y})\right]^y, \quad 0.0^y \leqslant \tilde{x}_\alpha^L \leqslant 0.5^y$$

$$\tilde{x}_\alpha^U = \tfrac{1}{2}\{ 2-((\alpha^{1/n})^{1/y})]^y, \quad 0.5^y \leqslant \tilde{x}_\alpha^U \leqslant 1.0^y \tag{14}$$

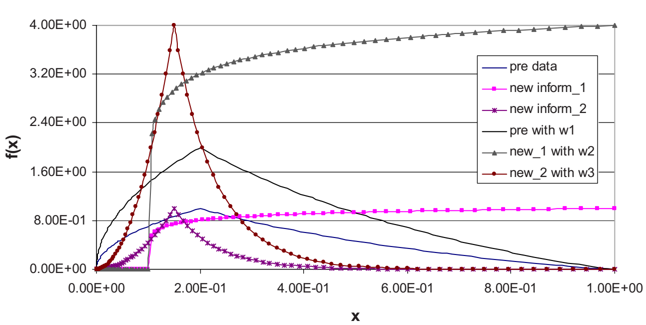

Fig. 4. Membership curves with weight factors

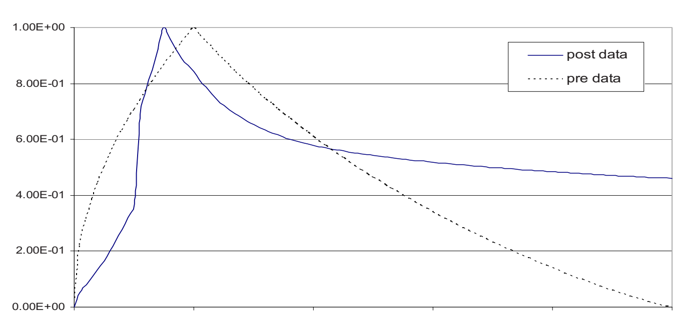

Fig. 5. Normalized combined membership curve compared with initial curve

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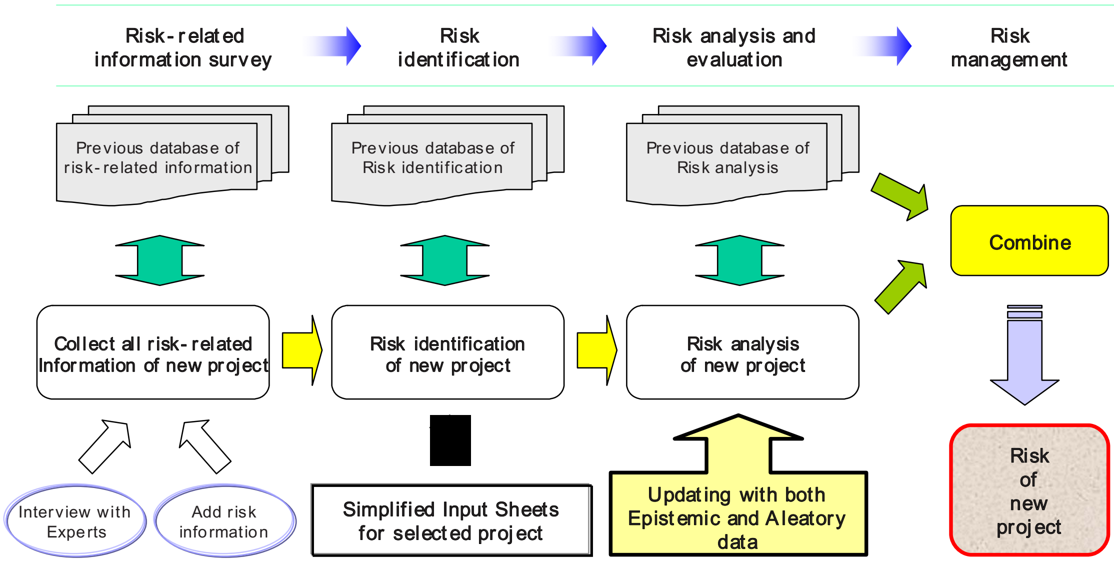

Fig. 6. Risk assessment procedure combined with updating

$$\tilde{x}_\alpha^L=\tfrac{1}{2}\{\ (1-\alpha^{1/n})^y)^{\ y},\quad 0.0^y \leqslant \tilde{x}_\alpha^L \leqslant 0.5^y$$

$$\tilde{x}_\alpha^U = x',\quad 0.5^y \leqslant \tilde{x}_\alpha^U \leqslant 1.0^y \tag{15}$$

$$\begin{cases} \tilde{x}_\alpha^L = x', & 0.0^y \leqslant \tilde{x}_\alpha^L \leqslant 0.5^y \\ \tilde{x}_\alpha^U = \tfrac{1}{2}\{\ (1+\alpha^{1/n})^y)]^y, & 0.5^y \leqslant \tilde{x}_\alpha^U \leqslant 1.0^y \end{cases} \tag{16}$$

Illustrative Examples

As an example, consider updating with multiple sources of information. Suppose we have prior information as "Improper cable installing and stressing work occurs around two in ten cases," and the linguistic variable is determined as "FC" from the uncertainty modeling in Step 1. And, new information is available such as "The occurrence probability of improper cable installing and stressing work is higher than 0.1," and then the linguistic variable is determined as "SHT" from uncertainty modeling. Also, we have a second source of information as "Improper work has happened in about one or two in ten cases in my experience," and the linguistic variable is determined as "VC" from uncertainty modeling. Now we have the following membership curves as shown in Fig. 3.

Then, go to Step 2. In Step 2, the membership function with weight factor is constructed using Eqs. (7) and (9). Fig. 4 shows all the membership curves with weight factors for this example.

In Step 3, Eqs. (10) and (12) are used to combine prior and new membership functions, and the normalization is done in Step 4. Thus, the membership curves obtained with multiple pieces of information are shown in Fig. 5.

Finally, in Step 5, the defuzzified interval corresponding to membership level α is calculated by solving $F(x')=\alpha$

$$\alpha = \begin{cases} c*\langle W_1\{[(2x'^{1/y_1})]^{y_1}\}^{n_1} + 0 + W_3\{[(2x'^{1/y_3})]^{1/y_3}\}^{n_3}\rangle, & 0.0^y \leqslant x' \leqslant 0.5^y \\ c*\langle W_1\{[(2x'^{1/y_1})]^{1/y_1}\}^{n_1} + W_2\{[(2x'^{1/y_2}-1)]^{1/y_2}\}^{n_2} + W_3\{[(2x'^{1/y_3})]^{1/y_3}\}^{n_3}\rangle, & 0.5^y \leqslant x' \leqslant 1.0^y \end{cases} \tag{17}$$

where y_l=midpoint transfer factor of prior information; and y_2, y_3=midpoint transfer factor of new information 1 and 2.

The result in quantitative range of this event for $\alpha=0.8$ is as follows. Quantitative range of initial range with predata is calculated as 0.13–0.29. And normalized updated range is calculated as 0.13–0.22.

Practical Application

Risk Assessment Procedure Combined with Updating

The first step in the risk assessment process is a risk-related information survey. As described earlier, these data are collected based on previous experience. Then, risk assessors carefully add to or modify the risk events considering the characteristics of the new construction project.

Risk identification is done in two main stages—the classification of critical risk events/risk scenarios and simplified detailed check sheets. Critical risk events/risk scenarios are determined based on the risk-related information survey. Then input sheets developed in Choi (2004) only consist of critical risk events/risk scenarios for the particular project. Historical data, if available, and detailed check points are used to develop the database, which is updated for a particular project in the next step.

Risk analysis/evaluation is performed by using the proposed updating approach. Significant project risks are analyzed in terms of their probability and potential consequences to eventually

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Table 3. Critical Risk Events

Previous database	New construction project
Construction-related	Use previous database
• Careless barge driving	Update critical risk scenarios as follows:
• Poor working steel concentrations	Construction-related
• Improver design of temporary works	(1) Improper work of measurement → Incorrect placement of well foundation → Redesign
• Improper work on shoe leveling at the end and key segment	
• Improper cable installation and stressing work	• Improper design of temporary works
	(2) Improper design of temporary work → Collapse and damage of structure
• Use of overweight material or equipment, etc.	
	(3) Improper design of temporary work → Loss of material and equipment
	(4) Improper design of temporary work → Injury and fatality
• Design-related	
• Incomplete design, etc.	• Improper elevating work of tower crane → Structural deficiency → Delay
• Political and financial-related	(6) Improper elevating work of tower crane → Structural deficiency → Damage of structure
• Work stoppage by subcontractors	
• Bankruptcy of subcontractors	(7) Improper elevating work of tower crane → Structural deficiency → Injury and fatality
• Underbid, etc.	
	• Poor work in steel connection
Act of God	(8) Poor work in steel connection → Falling of steel material → Injury and fatality
• Typhoon	
• Earthquake	(9) Poor work in steel connections → Structural deficiency → Damage of structure
• Tsunami, etc.	
	• Improper work on shoe leveling at the end and key segment
	(10) Improper work on shoe leveling → Reconstruction
	(11) Improper work on shoe leveling → Reconstruction
	• Improper cable installation and stressing work
	(12) Improper cable installation work → Delay
	(13) Improper cable installation work → Injury and fatality
	Act of God
	• Typhoon
	(14) Typhoon → Loss of material and equipment
	(15) Typhoon → Injury and fatality
	(16) Typhoon → Delay
Total 75 check sheets and 175 risk scenarios	Total 7 check sheets and 16 risk scenarios

manage the risks and to devise response strategies. As described earlier, updating with epistemic and aleatory-type data is carried out based on the new information from the characteristics of the new construction project. Then, risks are calculated by multiplying probability and expected cost. After analyzing and evaluating risks, a response strategy may be developed to reduce or prevent the critical risks. Fig. 6 summarizes the above-mentioned risk assessment procedure for a construction project using existing large quantities of data and project-specific information.

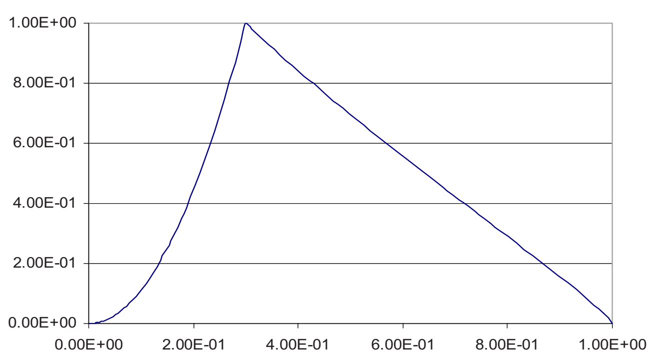

Fig. 7. Fuzzy membership curve of "Poor prestressing"

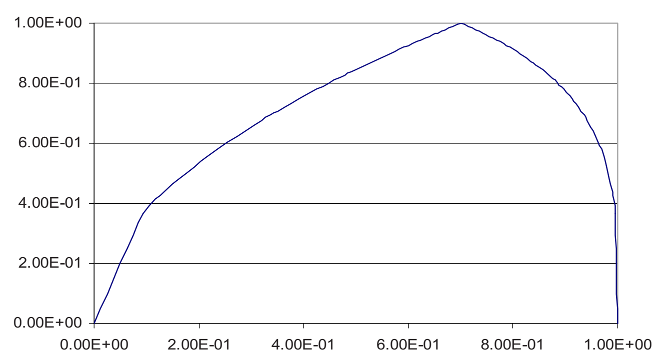

Fig. 8. Fuzzy membership curve of "Delay"

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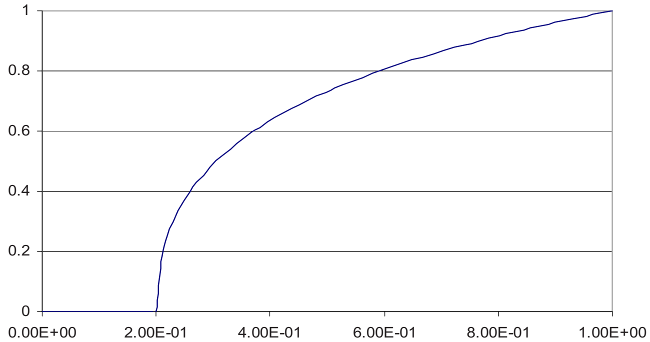

Fig. 9. Fuzzy membership curve of "Injury/fatality"

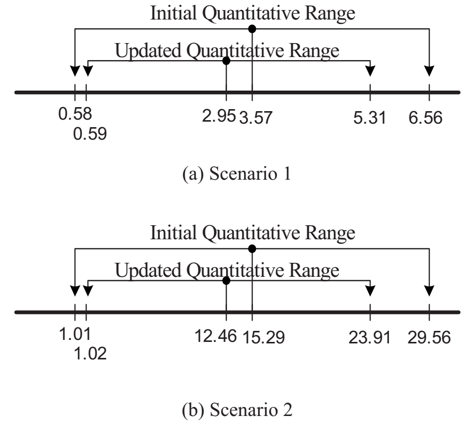

Fig. 10. Quantitative ranges of risk scenarios

Table 4. Uncertainty Range of Each Path

Probability type	Assumed or estimated probability	Linguistic variables	Quantitative range
(1) Initial	0.2	Fairly close	0.128–0.272
(1) Updated	0.1/0.15	Slightly higher than/ very close	0.100–0.197/ 0.134–0.165
(2) Conditional	0.3	Close to high side	0.268–0.408
(3) Conditional	0.7	Fairly close	0.448–0.952
(4) Conditional	0.2	Higher than	0.200–0.592

Table 5. Uncertainty Range of Expected Cost ($ Thousands)

Path	Description	Expected cost	Linguistic variable	Quantitative range (cost)
1	Delay: 3 days	50	Very close	37.87–62.13
2	Dead: two people Injury: three people	450	Lower than	147–450

Cable-Stayed Bridge Construction Project

In order to demonstrate the effectiveness and applicability of the proposed method for construction projects, it is applied to a cable-stayed bridge construction project. Although the model is applied to a cable-stayed bridge, the method and procedure can be applied to various other real structures, such as buildings, other types of bridges, etc., with minor modifications according to characteristics of projects.

From the risk-related information and risk identification step, critical risk events are shown in Table 3. It is acknowledged that the previous data can be biased depending on the source. In this case, the data are based on projects in Korea.

Table 3 shows a partial list of critical risk events among a total of 75 check sheets and 175 risk scenarios based on the previous large quantities of data for a typical cable-stayed bridge. First, we use all these data for initial risk assessment. Then, the updating for critical risks according to characteristics and project-specific information of new construction project is performed. For example, the risk events represented in an illustrative example are integrated into the risk scenario including this event into an event

Table 6. Risk of Each Scenario ($ Thousands)

Scenario	Path	Probability range (min–max)	Cost range (min–max)	Mean risk (max) for one occurrence of the scenario
1 (Initial)	(1)(2)(3)	0.015368–0.105649	37.87–62.13	3.57 (6.56)
2 (Initial)	(1)(2)(4)	0.006861–0.065698	147–450	15.28 (29.56)
1 (Updated)	(1)(2)(3)	0.015608–0.085452	37.87–62.13	2.95 (5.31)
2 (Updated)	(1)(2)(4)	0.006968–0.053138	147–450	12.47 (23.91)

Table 7. Summarized Risk of Cable-Stayed Bridge (Unit: U.S. Dollar)

Classification	Total risk (mean) from previous database	Total risk (mean) from updating of new project	Note
Construction-related	5,988,322	5,563,557	7% reduce
Design-related	37,550	37,550	—
Political and financial-related	36,280	36,280	—
Act of God	1,434,453	1,256,300	12% reduce
Total	7,496,605	6,893,687	

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tree analysis model. Similar to reference [2], two simple risk scenarios (Paths 1 and 2) are described herein as an illustration example:

Path 1: (1) Improper work of cable installation and stressing $_{(\mathrm{Pr}=0.15)}$

→ (2) Poor prestressing $_{(\mathrm{Pr}=0.3)}$ → (3) Delay $_{(\mathrm{Pr}=0.7)}$

Path 2: (1) Improper work of cable installation and stressing $_{(\mathrm{Pr}=0.15)}$

→ (2) Poor prestressing $_{(\mathrm{Pr}=0.3)}$ → (4) Injury/Fatality $_{(\mathrm{Pr}>0.2)}$

The fuzzy membership curves of each event in these two paths are shown in Figs. 7–9, respectively. Event (1) is already described in Fig. 5. Fig. 7 shows that the occurrence probability of "Poor prestressing (2)" is about 0.3 obtained from expert opinion, assuming that improper cable installation and stressing work has occurred. The linguistic variable is determined as "Close to high side of the given value." Fig. 8 represents the fuzzy membership curve for the uncertainty of fuzzy number 0.7 obtained from frequency analysis. The fuzzy number 0.7 is the occurrence probability of "delay (3)," assuming that "Poor prestressing" has occurred. The linguistic variable is determined as "Fairly Close" based on "Large" for (1) unreliable/insufficient data and "Small" for (2) use of inadequate statistical analysis methods (see Table 1). The fuzzy number 0.2 in Path 2 was analyzed by frequency analysis technique with sufficient data. However, if some subcontractor has bad accident records with respect to "Injury/fatality (4)" and poor plan for preventing accidents during the cable installation, the linguistic variable for determining the uncertainty range is given as "Higher than 0.2" by the assessor, as shown in Fig. 9. It may be noted that 0.2 will be the lowest limit in this case. Table 4 shows the probability and linguistic variable for Paths 1 and 2. Table 5 shows the expected cost in Scenarios 1 and 2. For modeling of the costs, the uncertainty ranges of the expected costs are also calculated by similar methods (Cho et al. 2002). The data on costs are obtained from KOSHA (2000).

As a result, the analyzed risks of each scenario are shown in Table 6 in which risks and updated risks of each scenario are represented. The probability range for each scenario in Table 6 is obtained through the product of probabilities for the events in that scenario calculated in Table 5. Based on the results from the case study, it may be stated that the uncertainty is reduced with updating. That is, as the information increases the risk estimate become more precise. Therefore, the quantitative range is reduced as shown in Fig. 10.

This updating calculation is only one example of the risk events in the seven risk assessment sheets for the new construction project (see Table 3). The updating of all the risks in the seven sheets is performed similarly. Table 7 summarizes the total results for four categories of the cable-stayed bridge construction project. It is assumed in this example that no new information on design-related and political and financial-related risks is available, so there is no change in these risk estimates. It is observed that the total risk of the new construction project is estimated to be 6.8 million dollars, which is about 9.8% of the total project cost.

The results in Table 7 show the summarized risk of both previous large quantities of data and updating for the new project. This paper does not intend to focus on the specific quantitative risk values. The new construction structure considered in this application example is assumed very similar to the previous large quantities of data. That is, it is assumed that the total length and width, bridge type, and project cost about 70 million are similar, hence the risk estimation in Table 7 is similar. The risk estimates would be significantly affected by the general and peculiar features of the new project, especially the project construction cost.

Concluding Remarks

This paper develops a risk assessment methodology for construction projects by combining existing large quantities of data and project-specific information through updating approaches. Two main ideas are pursued in this paper to facilitate practical implementation: identify and evaluate the critical risk events, and develop a systematic updating methodology. Both epistemic and aleatory types of uncertainties in the data are considered, and corresponding updating procedures are developed. This paper also develops a general risk assessment procedure for construction projects along the following steps: risk-related information survey, risk identification, risk analysis/evaluation combined with updating approaches. The proposed procedure is expected to be very useful for the systematic and rational risk assessment of real structures.

The proposed risk assessment approach is quite general, and can be applied to many types of practical construction projects such as bridges, industrial plants, dams, etc. The method is able to effectively integrate past and new information to provide a quantitative basis for risk management decision-making. Effective data fusion and processing capabilities are needed to integrate various risk survey and inspection activities, to develop the required database, and to facilitate practical implementation.

Acknowledgments

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