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Assessing risk and uncertainty inherent in Chinese highway projects using AHP

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Abstract

The high-risk exposure associated with highway construction projects needs special attention from contractors to analyze and manage their risks. They cannot be eliminated but can be minimized or transferred from one project stakeholder to another. Highway projects carry out higher risk than traditional because they entail high capital outlays and intricate site conditions. Therefore, current research aims at identifying two main risk areas that affect highway projects: company (macro) and project (micro) levels; assessing their effect on risk; and introducing a risk model (*R*) that facilitate this assessment procedure and prioritize these projects. Four Chinese case studies (projects A, B, C, and D) were selected to implement the designed model (*R*) and test its results. The *R* index model is developed using the analytic hierarchy process (AHP). Results show that political risk has the highest average weight of 0.5196; however, financial risk has the second highest average weight of 0.2336 in the macro level (company) areas. On the other hand, in the micro level (project), emerging technology and resource risks have the highest average weight of 0.2492 and 0.2098, respectively. The developed *R* model is tested, which prove its robustness in risk assessment (93%). It can also be used to sort highway construction projects based upon risk. It is an essential tool to assess the level of risk associated with the highway project under study in the bidding phase in order to take preventive actions.

Keywords: Risk; Highway projects; Model; Analytic hierarchy process (AHP)

1. Introduction

The Chinese government is putting major investment into infrastructure projects throughout China with particular emphasis upon development of the Western area of the country Strain [9] and The InfoShop [10]. Since the early 1990s, the Chinese government has implemented a major program to extend and upgrade the country's highway network because the average passenger vehicle growth is 22% per annum whilst the road network has only expanded at 5% Commercial Section of the British Embassy [2]. In the 9th 5-year Plan (1996–2000) 240,000 km of highway were built taking the total mileage of highway in China to over 1.4 million km Strain [9] and The InfoShop [10]. The new 10th 5-year Plan lays out intended investment of RMB 1000 billion (approximately US $120 billion) on highway construction [9]. To date, around 10,000 km of trunk highways have been completed, at an estimated cost of US $150 billion. However, the government plans to complete 35,000 km by 2015 Commercial Section of the British Embassy [2] and The InfoShop [10]. Over the next decade, the Chinese government plans to build around 42,000 km of new roads in South Western China. This figure will include around 3400 km of new expressways and 1600 km of "grade one" (similar to UK "A" roads) highways Commercial Section of the British Embassy [2].

Based on the previous facts, the Chinese government is planning to make a revolution in its infrastructure systems, particularly highway construction. In conjunction with this revolution, there are many types of potential sources of risk

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and uncertainty that affect highway construction. These sources of risk and uncertainty include political, economical, cultural, market, and technical risks that might reduce the contractor(s) and/or subcontractor(s) profit. It is essential that contractors and subcontractors conquer these sources of risk and uncertainty in order to (1) assess the effect of these sources in order to decide which projects are more risky; (2) plan for the potential sources of risk in each project; and (3) manage each source during construction. There is a necessity to help contractor(s) and subcontractor(s) perform the aforementioned steps by building several models. Current research aims at designing a model that identifies the sources of risk and uncertainty and assesses their effect on highway construction projects based upon Chinese case studies.

2. Research objectives

The objectives of current research are:

(1) Identify sources (areas) of risk and uncertainty and their sub-areas for highway projects.
(2) Design an assessment model for the effect of these sources of risk and uncertainty using analytic hierarchy process (AHP).
(3) Test the designated model.

3. Background

Sources of risk and uncertainty always exist in construction projects and often cause schedule delay or cost overrun [1,12,14]. Project management considers risk management as one of the key knowledge areas for managers [12,7]. Project risk is defined by PMBOK as: an uncertain event or condition that, if it occurs, has a positive or a negative effect on at least one project objective, such as time, cost, span, or quality, which implies an uncertainty about identified events and conditions [1]. This definition of risk and uncertainty is the considered definition through the entire paper. Risk and uncertainty management used the following three-step approach [11,5,12,6]:

1. *Risk identification:* the first step of risk management process is risk identification. It includes the recognition of potential sources of risk and uncertainty event conditions in the project and the clarification of risk and uncertainty responsibilities. It is accomplished by a structured search for a response to the question – what events may reasonably occur that will impede the achievement of key elements of the highway construction?
2. *Risk assessment:* risk and uncertainty rating identifies the importance of the sources of risk and uncertainty to the goals of the project. It comes as a response to the questions – what is the probability that this risk will occur? and what is the severity of the impact on the project if a risk is allowed to take place? Risk assessment is accomplished by estimating the probability of occurrence and severity of risk impact.
3. *Risk mitigation:* mitigation establishes a plan, which reduces or eliminates sources of risk and uncertainty impact to the project's deployment. The question is – what should be done, and whose responsibility it is to eliminate or minimize the effect of risk and uncertainty? Options available for mitigation are: control, avoidance, or transfer.

Risk and uncertainty of highway construction projects did not receive sufficient attention from researchers. Therefore, current research is trying to open this area by studying several case studies in China. It only considers the first two steps of risk management: identification and assessment for highway construction in China. The third step, risk mitigation, might be covered in a future study. The following sections will explain risk identification and assessment model building for highway construction in China.

4. Identification of highway project sources (areas) of risk and uncertainty

Dias and Ioannou [3,4] emphasized that project financing requires identification and analysis of sources (areas) of risk and uncertainty during different phases of the project. Several authors have proposed classification and definition of risk in project financing concluding that the allocation of risks is the key ingredient for successful project financing undertakings. The identification of possible sources of risks is an essential area in the risk management process because it allows project parties to recognize the existence of uncertainty in the project and hence, to analyze its potential impact and to consider an appropriate strategy to mitigate its effect in the project. Dias and Ioannou [4] classified sources of risk in the following 10 categories: country (political and regulatory), force majeure, physical, financial, revenue, promoting, procurement, developmental, construction, and operating risks.

Current study focuses on the fundamental questions of whether a potential infrastructure project has the necessary characteristics for successful promotion by a company based on risk and uncertainty point of view, and whether the company has the capability of successfully negotiating these kinds of risk and uncertainty. Based upon literature and Chinese experts, who are specialists in highway construction, several risk areas and sub-areas are defined in two major hierarchies: Macro (company management level) and Micro (project management level) as discussed in the following sub-sections.

4.1. Macro (company) level risk areas and sub-areas

In the macro hierarchy (company management level), there are four risk areas as shown in Fig. 1: financial, political, cultural, and market risks. The financial risk includes

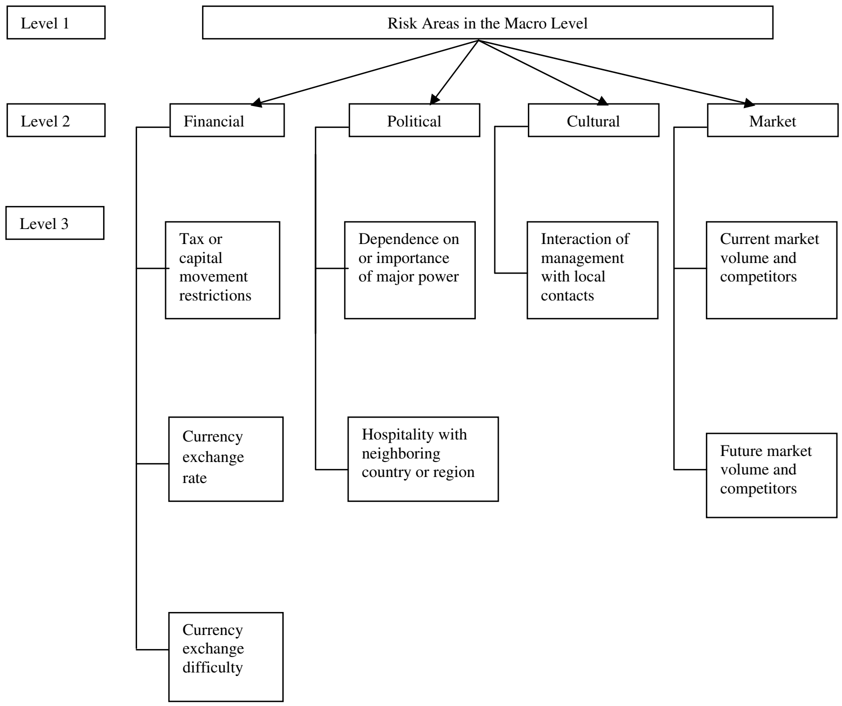

Fig. 1. Hierarchy of risk areas in the macro level.

tax or capital movement restriction, currency exchange rate, and difficulty of exchange. Currency exchange rate and its availability are essential to highway construction projects because of materials and equipment that are imported from foreign countries. Therefore, currency exchange rate and its availability increase greatly the financial risk of highway projects. In addition, capital movement restrictions and taxes amplify financial risk. Political risk includes political power effect and its hospitality with neighboring countries or regions. This type of risk affects greatly highway projects because it controls materials, equipment, and labor prices and availability. Most likely, if the political power is not well established, there will be fluctuation in the economy, and as a result fluctuation in materials, equipment, and labor prices and availability. Market risk area includes current and future market volume and competitors. Market work volume affects greatly the highway construction risk because if the amount of work volume available is little, then, the competition will be tough and risk of losing projects will be high and vice versa. Large number of competitors increases the likelihood of losing the project bid; therefore, risk is directly related to number of competitors. Culture adds one more dimension to highway construction projects risk because if the company does not communicate well with the community around the project, it will lose many privileges that might enlarge their expenses and as a result amplify risk.

4.2. Micro (project) level risk areas and sub-areas

In the micro hierarchy (project management level), there are many areas of risk that can be considered as shown in Fig. 2: emerging technology usage, contracts and legal issues, resources, design stage, construction stage, quality, and other areas, such as weather, natural causes of delay in addition to physical damages. Fig. 2 further describes the risk sub-areas for each micro hierarchy risk area. As well known, emerging technology is prevailing highway construction market in the last decade. A highway construction company that will not cope with this new technology will lose a lot of opportunities and as a result raise its project's risk likelihood. In addition, there are lots of risks arise from the highway projects' contracts and legal issues because of the large number of variables and clauses in contracts which make them risky and tough to manage. Potential of contractual disputes and claims in addition to problems in dispute settlement due to federal law complicate contract management and append more risk on these contracts. Resources (materials, labor, and equipment) are key players in highway construction projects' risk. Shortage of skilled workers, availability of specialty equipment, and delays of materials supply have to be managed carefully so that contractors can mitigate resource risks.

During design stage, the highway construction project faces many risks, such as design delay, errors that need rework, change orders, and unforeseen adverse ground conditions. These risks enlarge the project risk if design quality is not adequate. In the construction stage, highway projects suffer from many risks: project manager's skills, project's safety, and delays due to owner, subcontractor, or consultant. Quality of materials and workmanship are two major factors that affect risk during highway project's construction. Finally, weather conditions and physical damages enlarge project's risk because they affect produc-

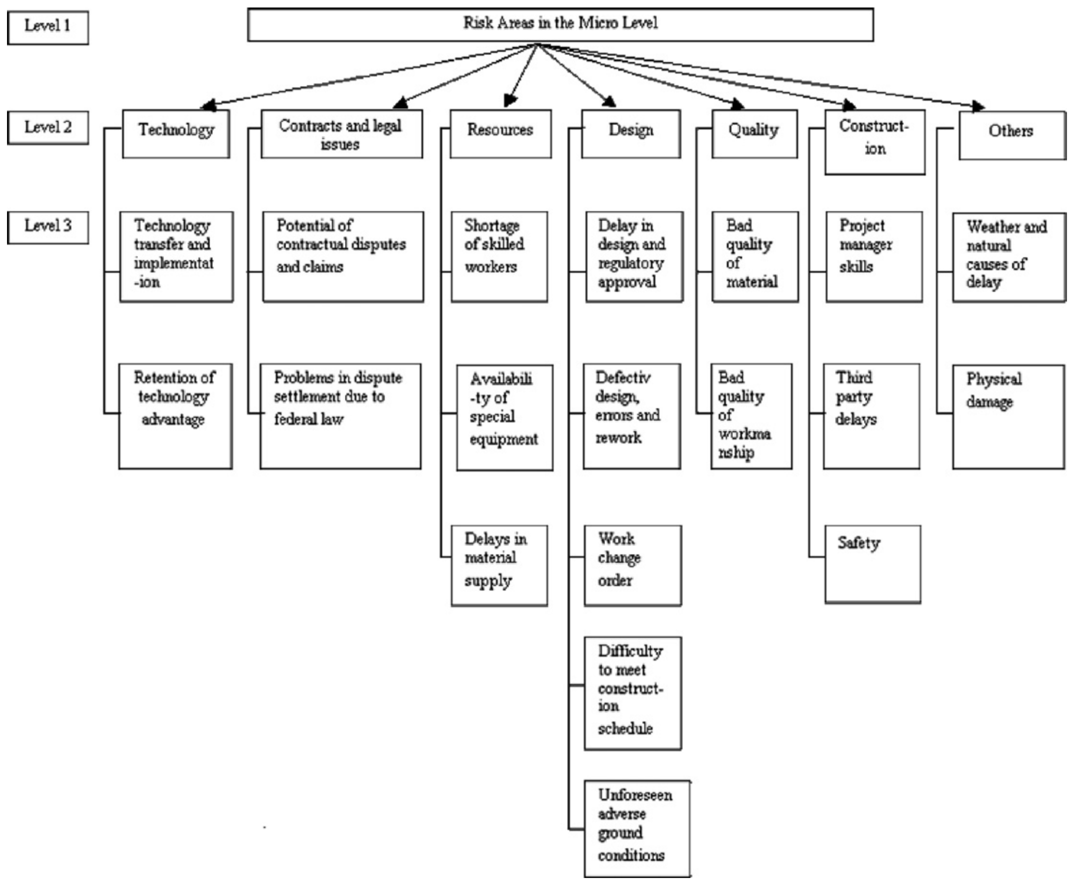

Fig. 2. Hierarchy of risk factors in the micro level.

tivity of labor and equipment in which they extend project duration and expenses.

5. Risk assessment model development and study methodology

According to the aforementioned factors, a risk index (R) model is designed to assess the effect of sources of risk and uncertainty on a construction project from contractor (company) prospective. It provides a logical, reliable, and consistent method of evaluating potential projects, prioritizing them, and facilitating company's decision in the promotion of highway project based upon potential sources of risk and uncertainty. The risk index (R) model characterizes the various sources of risk and uncertainty in a project and assesses their effect on such project in order to be able to take the remedial proactive management procedures that defeat these sources. The function of R-index is to only assess the effect of these sources; however, managing them is outside the scope of this paper.

The R-index consists of two parts: weights of risk areas and sub-areas and their effect score. Weights of risk areas will be determined using AHP developed by Saaty [8]; however, the effect score will be assessed using utility function or fuzzy logic approaches. Validation process will be performed to check the R index by comparing their results with the holistic evaluation of highway construction experts in China. Based on the R index value, highway construction projects can be evaluated and prioritized. The R-index is a developed evaluation tool composed of three-level hierarchical structures (Macro and Micro). Both hierarchies consist of main risk areas and their sub-areas. The R-index can be represented using models (1) and (2) as follows [14,13]:

$$R_k = \sum_{i=1}^{n} W_i * E_i(x_i) \tag{1}$$

where

R_k Risk index for a highway construction project using k levels (Probability of failure).
W_i Weight for each risk area i using Eigen value method.
$E_i(x_i)$ Effect score for each risk area (x_i).
x_i Different risk areas i.
i $1, 2, 3, \ldots, n$.
n Number of risk areas.
k $\begin{cases} 1 & \text{for macro level risk} \\ 2 & \text{for micro level risk} \end{cases}$

$$R(\text{Risk index}) = R_1 * R_2 \tag{2}$$

The procedures of model construction were selected on the basis of Zayed and Chang [13] and Zayed and Halpin [14]. Based on the risk areas shown in Figs. 1 and 2, the

R-index uses n = risk areas x_i. The overall contribution of each risk area is given by its effect score $E_i(x_i)$ multiplied by its composite weight W_i. The term x_i is added to the model to allow using the risk of sub-areas. The effect score of a risk area $E_i(x_i)$ reflects the one-dimensional value of the performance level of the risk area as it exists for a specific highway project. The decomposed weight of a risk area W_i reflects its importance relative to the other areas, irrespective of any particular highway project.

To determine the one-dimensional risk area effect score $E_i(x_i)$, it is necessary to evaluate the performance (quality) level x_i of the ith risk area for a given project and then to use a value function $E_i(x_i)$ to transform it into an equivalent effect score. The transformation from the performance (quality) level x_i of the ith risk area into an equivalent effect score requires two steps. Since the available macro and micro risk areas are qualitative in nature, the first step is to assess how well a given project performs with respect to a given risk area i using a meaningful qualitative scale as shown in Fig. 3. This is essentially a ''risk area measurement'' step in which the outcome is project-specific. The second step is to transform this qualitative performance into a one-dimensional effect (or value) score (from 0 to 100). This is a ''preference measurement'' procedure where the outcome depends on the preference and judgment of the person doing the analysis.

The weights of risk area and its sub-areas were obtained by performing the following procedure [14,13]:

1. A pair-wise comparison was performed between the risk areas of a highway project. The experts evaluated all the Macro and Micro risk areas and their sub-areas, then, they estimated a relative importance weight for each risk area against the other in addition to sub-areas against the others within the same risk area (pair-wise comparison).
2. The eigen vector or weighting W_i vector for each matrix was developed using eigenvalue method (developed by [8]).
3. Finally, the weight W_i for each risk area was calculated for usage in the R_k model.

6. Data collection

Data were collected through a questionnaire that had been sent to 17 highway construction experts in China. However, only 4 questionnaires were received with 23.53% reply percent. These questionnaires represent 4 highway projects in China. Each questionnaire consisted of three parts: (1) information related to the expert's affiliation, address, and contacts; (2) effect score information using the scale shown in Fig. 3; and (3) pair-wise comparison matrices information. In part 2, the factors that affect highway construction risk were assessed using Fig. 3 on a scale from 1 to 9. In part 3, the reviewer was required to compare each risk factor (area) against the others to constitute pair-wise comparison matrices for risk areas and their sub-areas. This information was collected for the four projects through the four Chinese experts who were working in the top management levels of these projects.

7. Risk model application to chinese highway projects

Data were collected from highway experts in China throughout a questionnaire. Each individual expert evaluated the risk areas against each other in addition to evaluating the sub-areas within a risk area against each other (pair-wise comparison). They also evaluated the risk of each highway project as a whole with a number out of 1.0 (holistic evaluation) depending on personal judgment considering the project features. This holistic evaluation is used to test the developed risk model (R). Each risk area and its sub-areas were evaluated in every project on a scale from 1 to 9 points (performance scale in Fig. 3). This evaluation is embedded into this study to represent the highway project specific features and its effect on risk. Four projects were included in this study through the opinions of four-highway project's experts. The R-index in model (1) was implemented through the determination of two terms (W_i and $Ei(x_i)$) as described in the following sections.

7.1. $E_i(x_i)$ determination

The collected data were analyzed to determine the risk effect score of highway projects. Tables 1a and 1b show the average subjective evaluation of the four highway projects and their average effect score. These subjective evaluations were estimated according to a performance scale of (1–9) points as shown in Fig. 3. For example, Table 1a shows that the interaction of foreign management with local contractors (IMWLC) has the highest values of 0.3, 0.45, 0.48, and 0.38 in projects A, B, C, and D, respectively. Moreover, this risk area has the highest average

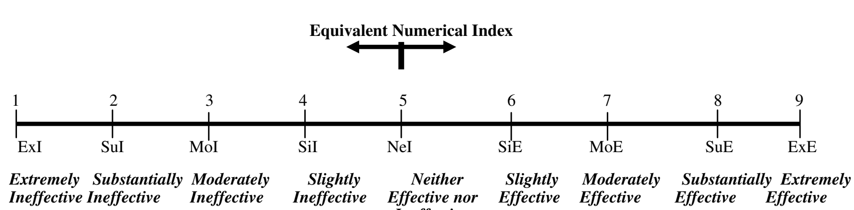

Fig. 3. Qualitative highway projects risk areas performance scale.

Table 1a
Effect score for company (macro) hierarchy risk sub-areas

Macro hierarchy risk sub-areas	Abbreviations	Effect score for different projects				Average effect
		A	B	C	D	$E_i(x_i)$
Financing difficulties because of tax or capital movement restrictions	CMR	0.15	0.23	0.28	0.15	0.2
Financial difficulties because of currency exchange rate	CER	0.23	0.35	0.38	0.25	0.3
Difficulty in converting local to foreign currency	CED	0.30	0.20	0.30	0.40	0.3
Dependence on or importance of major power	IMP	0.08	0.10	0.15	0.08	0.1
Hostilities with neighboring country or region	HNC	0.15	0.23	0.28	0.15	0.2
Interaction of foreign management with local contractors	IMWLC	0.30	0.45	0.48	0.38	0.4
Current market volume in competency	CMV	0.28	0.25	0.28	0.40	0.3
Future market volume in competency	FMV	0.20	0.25	0.40	0.35	0.3

Table 1b
Effect score for project (micro) hierarchy risk sub-areas

Micro hierarchy risk sub-areas	Abbreviations	Effect score for different projects				Average effect
		A	B	C	D	$E_i(x_i)$
Problems in technology transfer and implementation	TTI	0.15	0.23	0.28	0.15	0.2
Retention of technology advantage	RTA	0.05	0.15	0.15	0.05	0.1
Possibility if contractual disputes	PCDC	0.30	0.45	0.48	0.38	0.4
Problems in dispute settlement due to country's laws	DSFL	0.15	0.23	0.28	0.15	0.2
Shortage of skilled workers	SSW	0.25	0.30	0.30	0.35	0.3
Availability of special equipment	ASE	0.15	0.20	0.25	0.20	0.2
Delays in material supply	DMS	0.38	0.45	0.38	0.40	0.4
Delay in design and regulatory approval	DDRA	0.20	0.25	0.40	0.35	0.3
Defective design, error, and rework	DDER	0.35	0.43	0.48	0.35	0.4
Work change order	WCO	0.40	0.43	0.38	0.40	0.4
Difficulties to meet construction programs supply	DMCS	0.30	0.20	0.30	0.40	0.3
Unforeseen adverse ground conditions	UAGC	0.25	0.30	0.33	0.33	0.3
Bad quality of materials	BQM	0.15	0.23	0.28	0.15	0.2
Bad quality of workmanship	BQW	0.20	0.35	0.38	0.28	0.3
Construction manager	PM	0.28	0.25	0.28	0.40	0.3
Third party delays	TPD	0.20	0.25	0.40	0.35	0.3
Safety	SAF	0.05	0.13	0.10	0.13	0.1
Weather and natural causes of delay	WNCD	0.13	0.10	0.08	0.10	0.1
Physical damage	PD	0.10	0.08	0.13	0.10	0.1

effect score (0.4) in the macro hierarchy risk areas. On the other hand, there are several risk sub-areas that have high effect score value in the micro hierarchy level as shown in Table 1b. It shows that contractual disputes (PCDC), delays in material supply (DMS), design errors and rework (DDER), and change orders (WCO) have an average effect score of 0.4. However, weather conditions, safety, and technology advantages have minimal effect on risk of highway construction projects (average effect score equals 0.1).

7.2. W_i determination

Pair-wise comparison matrices, that compare each risk area or sub-area to the other areas or sub-areas, were collected from reviewers. The eigenvalue method of AHP [8] was used to analyze the pair-wise comparison matrices in order to conclude relative weight vector from each matrix. The total collected number of pair-wise matrices in current study was 24 (six matrices are collected from each project with different dimensions) as shown in Table 2. It shows

Table 2
Pair-wise comparison matrices consistency index (CI) calculation

Matrix ($N*N$)	Matrix Dim. (m)	λ_{Max} for projects				CI for projects			
		A	B	C	D	A	B	C	D
$(4*4)$	4	4.22	4.05	4.08	4.22	0.07	0.02	0.03	0.07
$(3*3)$	3	3.01	3.07	3.02	3.00	0.00	0.04	0.01	0.00
$(7*7)$	7	7.46	7.49	7.44	7.38	0.08	0.08	0.07	0.06
$(3*3)$	3	3.05	3.00	3.04	3.02	0.03	0.00	0.02	0.01
$(5*5)$	5	5.29	5.43	5.36	5.05	0.07	0.11	0.09	0.01
$(3*3)$	3	3.00	3.02	3.02	3.02	0.00	0.01	0.01	0.01

the different matrix dimensions and their consistency index for different projects. The consistency index (CI) is calculated based upon the maximum eigenvalue [13]. The eigen value of each matrix is calculated using MATLAB® mathematics software. Table 3 shows the determination of consistency ratio (CR) by dividing the CI (from Table 2) by the ratio index (RI), which is adapted from Saaty [8]. The CR has to be lower than 0.1 otherwise the matrix will be considered inconsistent. If the matrix is inconsistent, the generated eigen vector from this matrix will be rejected. Table 3 shows that all matrices have a CR value lower than 0.1 (Fig. 4 supports this conclusion). It shows that several matrices are very consistent because they have a CR value of zero. Other matrices have values close to 0.1 (i.e., matrix number 1, 4, 18, and 19); however, they are accepted and their resulted eigen vectors will be considered. Normalization process is applied to all matrices to generate the eigen vectors (weight vector) that represent relative weights of each risk area or sub-area to the others. In other words, the summation of these weights in each vector is 1.0. The average weight of each risk area represents W_i in the *R*-index model.

Table 3
Pair-wise comparison matrices consistency ratio (CR) calculation

Matrix ($N*N$)	RI	CR for projects			
		A	B	C	D
(4 * 4)	0.9	0.081	0.017	0.030	0.080
(3 * 3)	0.58	0.008	0.063	0.016	0.000
(7 * 7)	1.32	0.058	0.062	0.055	0.048
(3 * 3)	0.58	0.046	0.000	0.033	0.016
(5 * 5)	1.12	0.065	0.096	0.080	0.011
(3 * 3)	0.58	0.000	0.016	0.021	0.016

The average weight for each main risk area and its sub-areas is shown in Table 4a and 4b. Table 4a shows the weight of each main risk area and its sub-areas in the macro level; however, Table 4b represent similar information in the micro level analyses. Based on the average of four projects, the average decomposed weight for each sub-area of risk is determined. Results show that political risk has the highest average weight of 0.5196; however,

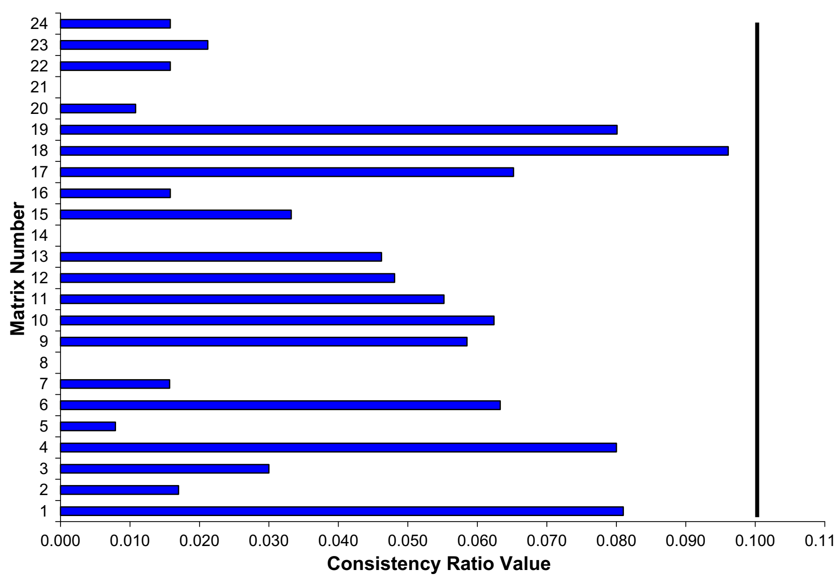

Fig. 4. Eigen value consistency ratio (RI) for the pair-wise comparison matrices.

Table 4a
Weight of macro level risk areas and sub-areas

Areas	Risk areas weight					Sub-areas	Risk sub-areas weight					Average decomposed weight
	Project A	Project B	Project C	Project D	Average		Project A	Project B	Project C	Project D	Average	
Financial	0.1727	0.2338	0.2607	0.2675	0.2337	CMR	0.5396	0.6144	0.6250	0.5714	0.5876	0.1373
						CER	0.2970	0.2684	0.2385	0.2827	0.2717	0.0635
						CED	0.1643	0.1172	0.1365	0.1429	0.1402	0.0328
Political	0.6186	0.4890	0.5023	0.4685	0.5196	IMP	0.5000	0.6667	0.3333	0.7500	0.5625	0.2923
						HNC	0.5000	0.3333	0.6667	0.2500	0.4375	0.2273
Cultural	0.0482	0.0635	0.0780	0.0586	0.0621	IMWLC	1.0000	1.0000	1.0000	1.0000	1.0000	0.0621
Market	0.1605	0.2137	0.1590	0.2055	0.1847	CMV	0.7500	0.7500	0.8000	0.7500	0.7625	0.1408
						FMV	0.2500	0.2500	0.2000	0.2500	0.2375	0.0439

Table 4b
Weight of micro level risk areas and sub-areas

Areas	Risk areas weight					Sub-areas	Sub-areas weight					Sub-areas decomposed weight
	Project A	Project B	Project C	Project D	Average		Project A	Project B	Project C	Project D	Average	
Technology	0.2428	0.2599	0.2516	0.2419	0.2491	TTI	0.6667	0.6667	0.7500	0.7500	0.7084	0.1765
						RTA	0.3333	0.3333	0.2500	0.2500	0.2917	0.0727
Contracts and legal issues	0.1403	0.1377	0.1507	0.1399	0.1422	PCDC	0.6667	0.6667	0.7500	0.7500	0.7084	0.1007
						DSFL	0.3333	0.3333	0.2500	0.2500	0.2917	0.0415
Resources	0.2056	0.2026	0.2106	0.2205	0.2098	SSW	0.4126	0.5714	0.6370	0.6250	0.5615	0.1178
						ASE	0.3275	0.2827	0.2583	0.2385	0.2768	0.0581
						DMS	0.2599	0.1439	0.1047	0.1365	0.1618	0.0339
Design	0.1231	0.1174	0.1207	0.1135	0.1187	DDRA	0.3578	0.3884	0.4049	0.3895	0.3851	0.0457
						DDER	0.2725	0.2638	0.2561	0.2797	0.2680	0.0318
						WCO	0.1312	0.1243	0.1356	0.1279	0.1298	0.0154
						DMCS	0.1194	0.1096	0.1004	0.0898	0.1048	0.0124
						UAGC	0.1181	0.1140	0.1030	0.1132	0.1121	0.0133
Quality	0.1337	0.1312	0.1248	0.1292	0.1297	BQM	0.5000	0.5000	0.6667	0.6667	0.5834	0.0757
						BQW	0.5000	0.5000	0.3333	0.3333	0.4167	0.0540
Construction and cultural	0.0457	0.0440	0.0426	0.0448	0.0443	PM	0.2000	0.1220	0.1168	0.1365	0.1438	0.0064
						TPD	0.4000	0.3196	0.1998	0.2385	0.2895	0.0128
						SAF	0.4000	0.5584	0.6833	0.6250	0.5667	0.0251
Others	0.1088	0.1073	0.0990	0.1103	0.1064	WNCD	0.6667	0.6667	0.7500	0.7500	0.7084	0.0754
						PD	0.3333	0.3333	0.2500	0.2500	0.2917	0.0310

financial risk has the second highest average weight of 0.2336 in the macro level (company) areas as shown in Table 4a. Cultural risk has the lowest average weight of 0.0621. These results show how much emphasis a company has to consider for political risk when bidding in Chinese market. On the other hand, emerging technology and resources risks have the highest average weight in the micro level (project) areas of 0.2492 and 0.2098, respectively. Contracts and legal issues risks rank third with an average weight of 0.1422. These results show that Chinese puts emphasis on emerging technology usage in performing their highway construction projects. In addition, resource is a critical risk area for any company that is pursuing highway projects in China. The aforementioned analysis is based upon the collected data sample; therefore, it is limited to projects under study.

7.3. R-index determination

Table 5a and 5b show the R-index of both macro and micro levels for project A. The value of W_i will be multiplied by the value of $E_i(x_i)$ to generate the R_1 index (0.1592) of macro level areas in project A as shown in Table 5a. The value of R_2 index for the same project in the micro level is 0.1930 as shown in Table 5b. The final R index value is the multiplication of R_1 by R_2 using model (2) as discussed earlier in this paper. Consequently, The R index value for project A is 0.0307 (3.07%). Similar procedure is applied to the other three projects B–D. Figs. 5a and 5b show the R_1 and R_2 values for risk sub-areas in all projects. Fig. 5a shows that current market volume in project D and hostility with neighboring regions in project C attain high risk in the macro level. On the other hand, in the micro level, the risk (R_2) of technology transfer, contractual disputes, and shortage of skilled workers represent the highest risk poles in all projects as shown in Fig. 5b. It further shows that bad quality of material and workmanship has high value of risk in projects B and C. By applying model (2) to all projects, Fig. 6 is generated. It shows that project C has the highest risk index ($R = 8.15\%$); however, project A has the lowest index ($R = 3.07\%$). The average R-index for all projects is 5.33%.

Table 5a
Risk index (R) for macro level risk areas and sub-areas

Risk areas	Risk sub-areas abbreviations	Risk area weight	Sub-area weight (Project A)	Decomposed weight (W_i) (Project A)	Risk index ($W_i^* E_i(x_i)$) (Project A)
Financial	CMR	0.1727	0.5396	0.0932	0.0140
	CER	0.1727	0.2970	0.0513	0.0115
	CED	0.1727	0.1643	0.0284	0.0085
Political	IMP	0.6186	0.5000	0.3093	0.0232
	HNC	0.6186	0.5000	0.3093	0.0464
Cultural	IMWLC	0.0482	1.0000	0.0482	0.0145
Market	CMV	0.1605	0.7500	0.1204	0.0331
	FMV	0.1605	0.2500	0.0401	0.0080
				Sum	0.1592

Table 5b
Risk index (R) for micro level risk areas and sub-areas

Risk areas	Risk sub-areas abbreviations	Risk area weight	Sub-area weight (Project A)	Decomposed weight (W_i) (Project A)	Risk index ($W_i * E_i(x_i)$) (Project A)
Technology	TTI	0.2428	0.6667	0.1619	0.0243
	RTA	0.2428	0.3333	0.0809	0.0040
Contracts	PCDC	0.1403	0.6667	0.0935	0.0281
	DSFL	0.1403	0.3333	0.0468	0.0070
Resources	SSW	0.2056	0.4126	0.0848	0.0212
	ASE	0.2056	0.3275	0.0673	0.0101
	DMS	0.2056	0.2599	0.0534	0.0200
Design	DDRA	0.1231	0.3578	0.0440	0.0088
	DDER	0.1231	0.2725	0.0335	0.0117
	WCO	0.1231	0.1312	0.0162	0.0065
	DMCS	0.1231	0.1194	0.0147	0.0044
	UAGC	0.1231	0.1181	0.0145	0.0036
Quality	BQM	0.1337	0.5000	0.0669	0.0100
	BQW	0.1337	0.5000	0.0669	0.0134
Cultural	PM	0.0457	0.2000	0.0091	0.0025
	TPD	0.0457	0.4000	0.0183	0.0037
	SAF	0.0457	0.4000	0.0183	0.0009
Others	WNCD	0.1088	0.6667	0.0725	0.0091
	PD	0.1088	0.3333	0.0363	0.0036
Micro level sub-factors summation					0.1930
Macro level sub-factors summation					0.1592
Risk index = sum (Macro) * sum (Micro)=					0.0307

8. Model test process

Convergent validation was used to test the designated model and verify its robustness in predicting highway construction project's risk. The reviewers, on a scale from 0 to 1.0, holistically evaluate all case study projects. The model results are compared to this holistic evaluation using the test factor in model (3) as follows:

$$\text{Test factor(TF)} = \text{RMR}/\text{RHE} \tag{3}$$

where

TF Test factor
RMR Risk model result
RHE Risk holistic evaluation

The results of the holistic and model evaluations are shown in Table 6. It shows the test factor (TF) for the four projects. The TF value for project C is the highest (96.4%); however, it is 106.7 for project B. It has the lowest value in

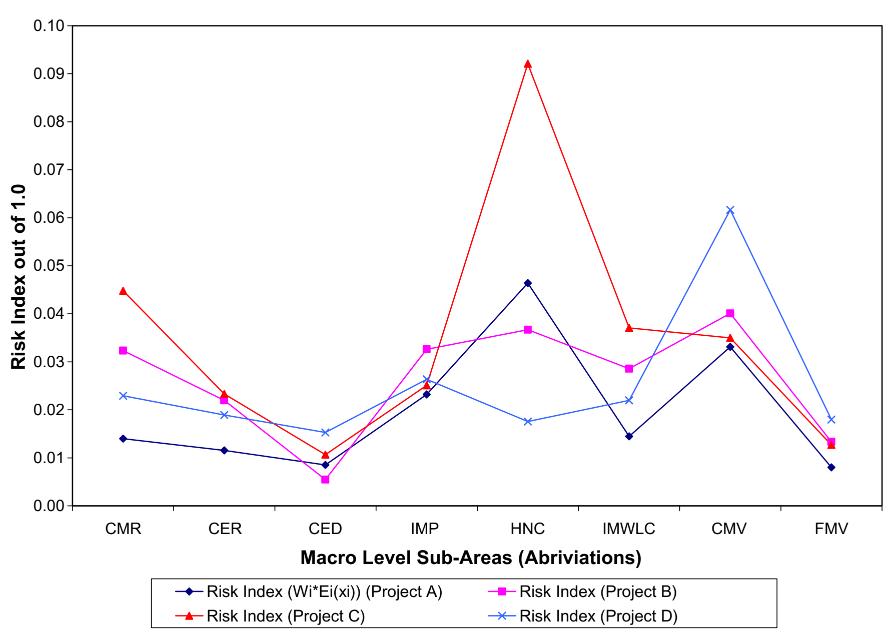

Fig. 5a. Risk index (R_1) for company (macro) level sub-areas.

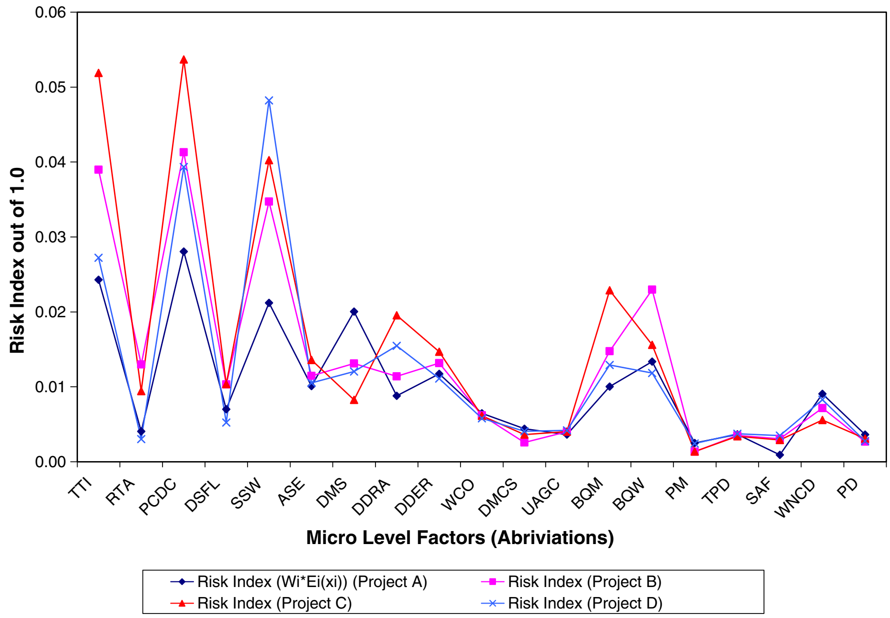

Fig. 5b. Risk index (R_2) for project (micro) level sub-areas.

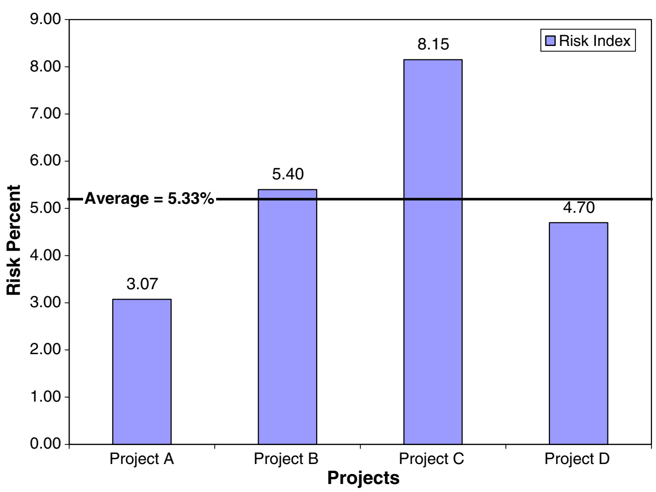

Fig. 6. Risk index (R) for different projects.

project A (79.2%). On average, the model TF equals to 93.3%, which is considered reasonable for such type of projects. Fig. 7 shows the developed model results in addition to the holistic evaluation (average, average plus standard deviation, and average minus standard deviation values).

Table 6
Test factor (TF) values

Projects	Test factor (%)
Project A	79.2
Project B	106.7
Project C	96.4
Project D	89.5
Average	93.0

It is noticed that results of the developed model are within the range or average ± standard deviation of the holistic evaluation. Furthermore, it shows that model results are close to the average holistic evaluation. For example, the model result for project C is 8.15%; however, the holistic evaluation is 8.45%. For project B, the model result is 5.4%; however, the holistic evaluation is 5.06%. Based on the previous discussion, results of the developed model are, to great extent, robust and capture the experience of practitioners quite well. Consequently, the developed model concepts are recommended for risk evaluation of future highway projects.

9. Risk index (*R*) as a project ranking method

The developed *R*-index can be used to prioritize highway construction projects from risk perspectives. For example, if the four case study projects are considered as projects that a company is supposed to promote, the *R*-index will provide a value to prioritize them. The lower the *R*-index value the higher the project rank because *R*-index represent risk associated with the project. Therefore, Project A has the first priority because it has the lowest *R*-index value (3.07%) as shown in Fig. 6. The four projects can be sorted based on risk as follows: A, D, B, and C because they have *R*-index value of 3.07%, 4.7%, 5.4%, and 8.15%, respectively. Consequently, the highway construction company has the flexibility to select the appropriate project based on its workload and need for projects. The developed *R*-index attracts the company attention to the project that has high potential risk to consider risk management procedures.

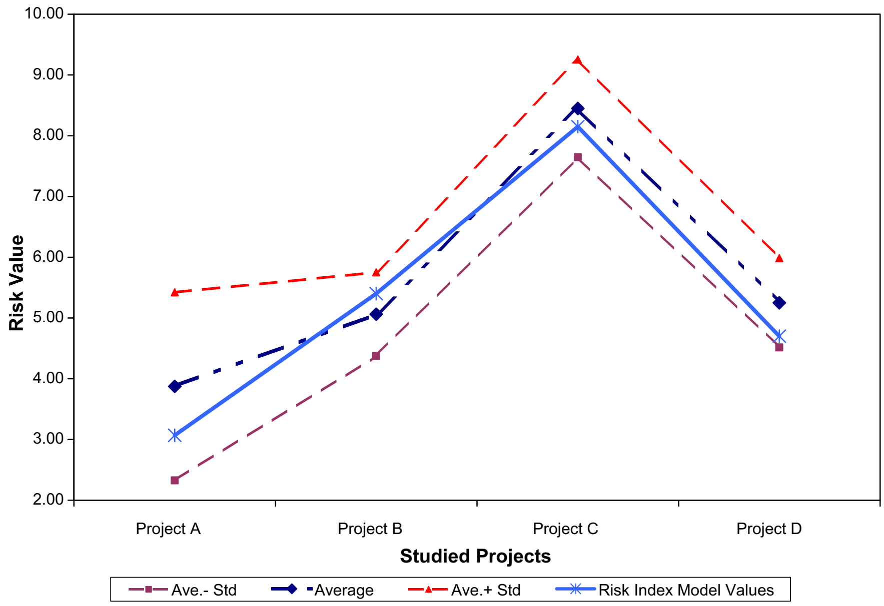

Fig. 7. Validation chart.

10. Conclusions

This study proposes a risk index (R) that performs two functions: evaluate sources of risk and uncertainty and accordingly prioritize highway construction projects. Main sources (areas) of risk and uncertainty and their sub-areas in highway projects were identified and analyzed for company (macro) and project (micro) levels. A model for calculating the R-index was designed and its components were explained and discussed in detail throughout this paper. The developed model was applied to four Chinese case studies (projects A–D). It shows that the interaction of foreign management with local contractors (IMWLC) has the highest average effect score (0.4) in the macro hierarchy risk areas. However, weather conditions, safety, and technology advantages have minimal effect on risk of highway construction projects (average effect score equals 0.1). Results also show that political risk has the highest average weight of 0.5196; however, financial risk has the second highest average weight of 0.2336 in the macro level (company) areas. For a company that pursues highway construction has to consider seriously political risk when bidding in Chinese market. On the other hand, emerging technology and resource risks have the highest average weight in the micro level (project) areas of 0.2492 and 0.2098, respectively. Accordingly, emerging technology usage in performing highway construction projects and resources are critical in Chinese market. These conclusions are limited to the collected data set; however, if the collected data set is extended to cover more projects, it might truly represent the Chinese market and general conclusions can be drawn.

The accuracy and robustness of this model have been tested using holistic evaluation, which proves its robustness in risk assessment (93%). Results show that project C conquer the highest risk (8.15%); however, project A attain the lowest risk (3.07%). Therefore, the developed model can be used to sort highway projects based upon risk, which facilitate company's decision of which project can be pursued.

Current research is relevant to both researchers and practitioners. It provides practitioners with a tool to evaluate and prioritize their highway construction projects based on risk. It provides researchers with risk areas and sub-areas, model to evaluate this risk, and methodology of quantifying the qualitative effect of subjective factors.

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