Quantifying Risk Factors on Cost Performance By Characterizing Capital Facility Projects

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Abstract

Risk-based estimation has been successfully introduced into the construction industry. By incorporating historical data associated with probability analysis, risk-based estimate is an effective decision support aid in considering whether to launch a particular project. The industry challenges, however, especially related with management issues, such as labor shortage, wage growth, and supply chain complexity, have often resulted in poor cost performance. The insufficient assessing the project characteristics (i.e., resource availability, project complexity, and project delivery method) can be the main reasons in the poor cost performance. Because the accuracy level of cost performance prediction can be enhanced by extensive evaluation of the subject project characteristics, a new approach for predicting cost performance in an earlier stage of a project can improve the industry substantiality, in other words, value maximization. The purpose of this paper is to develop a new methodology in developing a risk-based estimate tool by incorporating extensive project characteristics. To do this, an extensive industry survey was conducted from both private and public sectors in building industry in Korea. In addition, significant project characteristics were identified in terms of cost performance indicator. Although the data collection is limited to Korean industry, the suggested approach provides the industry with a straightforward methodology in risk management. As many researchers maintained that front-end planning efforts are crucial in achieving the successful outcome in building projects, the new method for risk-based estimation can improve the cost performance as well as enhance the fulfillment in terms of business sustainability.

Key Words : Cost Performance, Risk-based analysis, Building projects, Project Characteristics

1. Introduction

In earlier stage of a project, it is troublesome for many project managers and practitioners to evaluate the overall project risk in deciding on how much the project is open to uncertain circumstances, i.e., project risks. Because every project has different characteristics, it is very useful to provide any guidance in evaluating the overall project risk. Increase in the precision level of cost estimation is one of the key elements in construction industry.

Many estimators have tried to maximize the precision level in their estimation because a precise estimation is a starting point in achieving the success of cost performance in the construction industry. Since a project scope is discretionary in the earlier phase of a project, it is non-trivial to get a precise cost estimation in pre-project planning phase (Gibson and Dumont 1996).

As such, many researchers have tried to determine the relationship between the project success and the project definition level. Gibson and Dumont (1996) developed a Project Definition Rate Index (PDRI) tool to effectively quantify the risk level of a project for the purpose of predicting the current project status in terms of how the project objectives are met. They also maintained when the precision level of project risk analysis is improved, the more successfully the project objectives could be achieved. Furthermore, the PDRI can be used as a risk assessment tool by addressing all significant risk issues in developing project definition. In more recent years, excluding the PDRI, many risk assessment tools have been developed in the construction industry (Fang et al. 2004, Jannadi and Almishari 2003, Choi et. al. 2004) Nonetheless, not only the owners but also the contractors still suffer from economic difficulties in executing their projects. As the business environment become competitive, many construction companies have a great concern in enhancing the cost efficiency in delivering their own projects in hand. Therefore, it has

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1. Introduction

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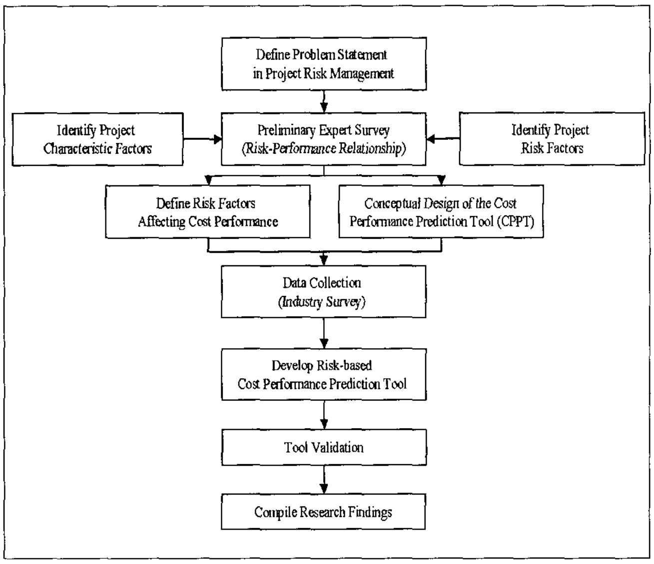

Figure 1. Research Methodology

The main objective of this paper is to develop a project diagnosis tool which provides the amount of the potential risk of a project, especially cost performance. To achieve the objective, this paper identified significant influential factors which affect the project risk and quantified their risk factors. The whole research methodology is depicted in Figure 1.

Based on the industry problem statement, the author conducted preliminary survey to identify risk factors and project characteristic factors. The risk factors were also expanded from a rigorous literature review. While the risk factors were finalized, the Cost Performance Prediction Tool (CPPT) was conceptually designed. Through an extensive industry survey, the risk factors were quantified using a unique method, i.e., normalized weight-transition method.

Two real-case projects were used in validating the efficiency of the tool before the final research findings were compiled. The organization of this paper consists of six sections. After this introduction section, the background on the research topic is overviewed under the tile of literature review. The third section discusses data collection method and analyzed results with salient findings from industry survey. The next two sections address how the identified factors are quantified and the proposed Cost Performance Prediction Tool is developed. Finally, the summary and conclusions are provided.

2. Literature Review

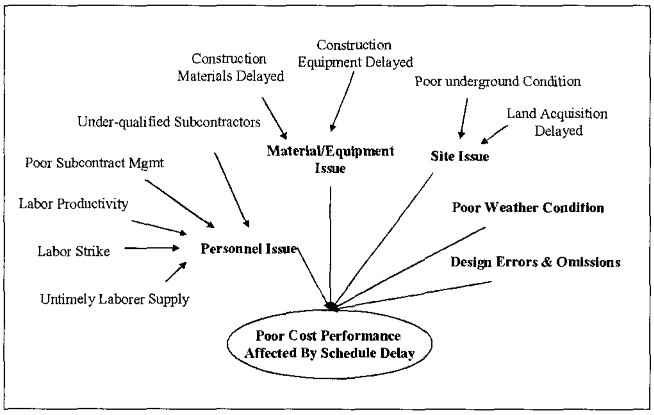

Figure 2. Cause-Effect Diagramming: An Example

Table 1. List of Project Risk Factors

A. Schedule Issue
A1. Insufficient amount of labor workforce (labor shortage)
A2. Below-averaged labor productivity
A3. Lack of subcontract management strategy
A4. Schedule delay in materials delivery
A5. Schedule delay in equipment delivery
A6. Poor underground condition
A7. Poor weather condition
A8. Authorities permission delay
A9. Frequent design changes
A10. Improper technology selection
B. Budget Issue
B1. Tightness of national tax regulations
B2. Budget loss by Inflation
B3. Interest rate increase
B4. Bulk material price uprise
B5. Exchange rate fluctuation
B6. Cost overrun affected by material damage
B7. Labor cost uprise
B8. Equipment rent fee uprise
B9. Land acquisition cost uprise
B10. Frequent civil appeals
B11. Construction claims and disputes
B12. Estimate errors and omission
B13. Delay and shortage of contract payment
C. Quality Issue
C1. Precise construction specifications
C2. Difference between drawings and specifications
C3. Incomplete drawings and related documents
C4. Quality problems by poor management discipline
C5. Non-conformance of quality by improper field inspections
C6. Non-conformance of quality by improper materials/equipment usage
C7. Quality problems by unskillful laborers
C8. Quality problems by construction errors
D. Safety Issue
D1. Shortage of labor skillfulness
D2. Lack of safety equipment and facilities
D3. Poor safety management system
E. Environment Issue
E1. Frequent change of regulations and legal aspects
E2. Environment problems by construction noise
E3. Environment problems by construction dusts
E4. Environment problems by construction waste
E5. Natural disaster and force majeur
F. Contract & Collaboration Issue
F1. Improper contractor selection method and criteria
F2. One-sided contract
F3. Vague contract clauses with unclear interpretations
F4. Inexperienced site supervisors
F5. Inexperienced construction managers
F6. Inexperienced site managers without strong leadership
G. Planning Issue
G1. No established risk management procedure in the planning phase
G2. Unclear work scope and/or project definition
G3. Insufficient site condition analysis
G4. Poor planning effort with tight schedule

°°The construction industry is characterized as a "risky" industry, which means the success is highly dependent on unknown conditions, for example, weather condition, labor productivity, site condition including various project characteristics. "Risk" is a word which originated from the French word °Ærisque' , and has become a widely-used term in insurance transactions in the early 1800s (Smith 1999). However, the definitions of risk are used in a variety of different areas. In Webster's dictionary, risk is defined as "the possibility of loss, injury, disadvantage, or destruction." Risk is often considered as being where the outcome of an event in a statistical approach. In analyzing risks, there are two different perspectives. One is focused on the significance of an event, while the other is related with the frequency of the event. By analyzing these two criteria, the set of potential risk factors are effectively prioritized and their results are regarded as valuable sources for decision makers (Jannadi and Almishari 2003). For the purpose of this study, risk is defined as "a possibilities of any event which affect the overall performance of a project." Because the performance of a project is hard to define, this study has only focused on cost performance. The cost performance, i.e., cost growth, is easily determined by comparing the predicted cost with the actual cost as the following equation (CII 2001). There were many different types of project risks identified in the previous research. Based on a rigorous literature review along with industry knowledge and experience, the set of 65 individual project risk factors was initially identified. The whole identified risk factors were classified into the following seven classes; schedule, budget, quality, safety, environment, contract and collaboration, and planning issues. Then, using a cause-effect diagramming method, research participants and industry practitioners brainstormed in order to effectively compile the detail-level risk factors (See Figure 2). Finally, forty-nine risk factors were elicited in this study as listed in Table 1.

Table 2. Survey Respondents By Company Size

Type of Company	Top Rank (in Korea)	Percentile
Contractors	1st -10th	39.4
	11th- 20th	13.4
	21st -50th	8.5
	51st -200th	4.9
	Others	17.6
Owners	N/A	16.2

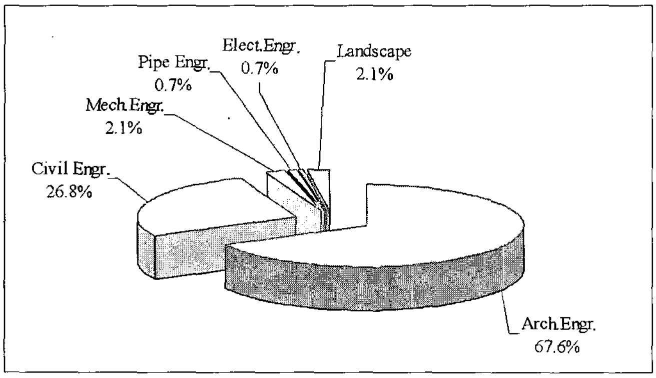

Figure 3. Survey Respondents By Expertise

3. Data Collection & Analysis

For the purpose of verifying that the finalized factors are significant and effectively quantifying the importance level of each factor, industry-wide data collection has been conducted. In Appendix I, a set of questionnaire survey sample is presented. In this survey tool, the whole list of 49 factors are included and the respondents are required to choose the options in terms of the impact level in affecting the cost performance of a project. Seven Likert-Scale (1: lowest impact, 2: low impact, 3: medium-low impact, 4: medium impact, 5: medium-high impact, 6: high impact, 7: highest impact) has been used in assessing the impact level of the factors. The total number of survey participants was 142 and their average work experience in the industry was 9 years. The respondents were chosen on the voluntary basis. Thirty nine percent of the respondents were from the top 10 general contractors in Korea. In table 2, the profile of the survey participants are briefly provided. The source of data collection consists of various disciplines including estimation, planning, architectural, civil, mechanical, electrical engineering, and landscaping. The respondent profiles regarding on the company size and expertise are summarized in Table 2 and Figure 3 respectively. Since most of the respondents (67.6%) are from architectural

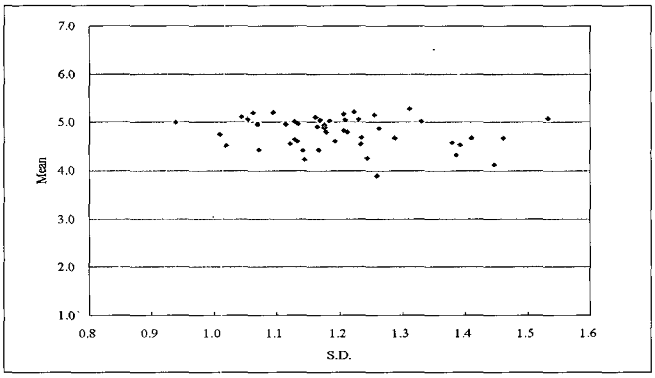

Figure 4. Survey Results: Mean vs. S.D.

Table 3. Survey Results: Factor Importance

Rank	Factor ID	Mean	S.D.	Rank	Factor ID	Mean	S.D.
1	A08	5.28	1.31	26	D01	4.83	1.21
2	A06	5.24	2.93	27	B04	4.81	1.21
3	A09	5.23	1.22	28	E05	4.80	1.18
4	C08	5.21	1.06	29	D05	4.75	1.01
5	B07	5.20	1.09	30	B08	4.70	1.23
6	E02	5.17	1.21	31	D08	4.69	1.41
7	F04	5.16	1.26	31	E06	4.69	1.29
8	D03	5.12	1.16	33	B13	4.67	1.46
9	F03	5.11	1.04	34	C02	4.65	1.13
10	B09	5.09	1.53	35	B12	4.62	1.19
11	F01	5.07	1.05	36	C06	4.62	1.13
12	A10	5.07	1.23	37	A01	4.58	1.38
13	E03	5.06	1.17	38	A02	4.56	1.12
14	C03	5.05	1.21	39	D07	4.55	1.23
15	A03	5.04	1.18	40	B02	4.54	1.39
16	B10	5.01	1.33	41	D06	4.53	1.02
17	E01	5.01	1.13	42	C01	4.44	1.07
18	F02	5.01	0.94	43	E04	4.43	1.17
19	A04	4.98	1.13	44	C04	4.42	1.14
20	D02	4.96	1.11	45	B03	4.33	1.39
20	D04	4.96	1.07	46	B06	4.26	1.24
22	A05	4.95	1.17	47	C05	4.23	1.14
23	A07	4.92	1.16	48	B05	4.12	1.45
24	B11	4.89	1.18	49	B01	3.89	1.26
25	C07	4.88	1.26				

Table 4. T-test Results By Respondents' Company Type

Factor ID	Mean		P-Value
	Owner	Contractor	(α=0.05)
A09	4.78	5.31	0.029
B09	5.61	4.98	0.037
B11	5.3	4.81	0.033
D02	5.39	4.87	0.02
E02	5.09	4.67	0.041
F02	4.78	5.24	0.046
F03	4.52	5.16	0.008
G02	4.52	5.1	0.003

Table 5. T-test Results By Respondents' Company Size

Factor ID	Mean		P-Value
	Large-size Company	Small-size Company	(α=0.05)
A04	5.09	4.73	0.046
A07	4.64	5.30	0.001
B01	3.60	4.30	0.003
E01	4.80	5.18	0.030
E02	4.52	4.95	0.013
E03	4.37	4.70	0.044
F03	5.34	4.86	0.016

engineering, the survey results may be useful not in overall project performance but only limited to building projects. When analyzing the whole dataset, the identified risk factors were effectively found to be significant in affecting cost performance. Except for "B01," as seen in Figure 4 and Table 3, the average scores of each factor were all distributed above medium impact (4.0) although the standard deviations varied from 0.94 to 2.93.

Throughout this survey, "authorities permission delay (A08)" was regarded as the most important. Standard deviation of this factor was also small enough to conclude the respondents agreed on its significance. Including this factor, the top 5 risk factors in cost performance are listed as follows.

- Authorities permission delay (A08)
- Poor underground condition (A06)
- Frequent design change (A09)
- Quality problems by construction errors (C08)
- Labor cost uprise (B07)

When analyzing the results by respondent's company type and size, there were some factors found to be statistically different in terms of their mean value at the significance level of 5%. Table 4 and 5 show the factors which were determined to be significantly different between two groups (owner versus contractor and large-scale company versus small- or medium-scale company). These results can be interpreted that some risk factors are arguable in view of company type and scale when it comes to their level of importance. For example, "construction noise (E02)" is regarded as more important factor to owner group and "contract clause (F03)" are considered to be more important to larger-size companies (See Tables 4 and 5).

$$X\_n = \frac{X\_r - m(X)}{\sigma(X)} \quad (1)$$

4. Quantifying Project Risk Factors

The risk factors in this study are equivalent to influential factors on a project performance because successfulness of a particular project is dependent upon uncertain circumstances and conditions as the project proceeds. The survey results, therefore, provide the industry

$$X\_R = Integer\{\frac{X\_n - Min(X\_n)}{Max(X\_n) - Min(X\_n)}\} \quad (2)$$

with useful information in assessing project vulnerability, i.e., risk exposure. Under an assumption that the influential factors vary in terms of the magnitude of impact on a project, a unique methodology has to be developed to effectively utilize the survey results.

$$X\_Factor\ Weight = \frac{X\_Range\ Value}{\sum_{i=1}^{49} X_i\_Range\ Value} \quad (3)$$

Quantifying factor importance has been for a long time a great concern among many researchers. For the purpose of eliminating personal anchoring issue, new methods have been developed. The

Table 6. Project Risk Factor Weight

Factor ID	Normalized Mean	Range Value	Factor Weight
A01	−0.253	38	0.0157
A02	−0.258	38	0.0157
A03	0.159	58	0.0240
A04	0.158	59	0.0244
A05	0.164	65	0.0269
A06	0.286	60	0.0248

Factor ID	Normalized Mean	Range Value	Factor Weight
A07	0.119	72	0.0298
A08	0.423	68	0.0281
A09	0.353	11	0.0045
A10	0.259	42	0.0174
B01	-0.787	32	0.0132
B02	-0.175	53	0.0219
B03	-0.361	23	0.0095
B04	0.056	53	0.0219
B05	-0.556	23	0.0095
B06	-0.481	26	0.0108
B07	0.354	68	0.0281
B08	-0.045	48	0.0199
B09	0.303	66	0.0273
B10	0.209	61	0.0252
B11	0.058	53	0.0219
B12	-0.179	42	0.0174
B13	0.077	47	0.0194
C01	-0.387	31	0.0128
C02	-0.146	43	0.0178
C03	0.175	59	0.0244
C04	-0.37	32	0.0132
C05	-0.465	27	0.0112
C06	-0.142	43	0.0178
C07	0.091	55	0.0227
C08	0.391	70	0.0289
D01	0.049	53	0.0219
D02	0.145	58	0.0240
D03	0.226	62	0.0256
E01	0.112	57	0.0236
E02	-0.063	47	0.0194
E03	-0.248	38	0.0157
E04	-0.196	41	0.0170
E05	-0.06	48	0.0199
F01	0.15	43	0.0178
F02	0.273	64	0.0265
F03	0.158	58	0.0240
F04	-0.332	34	0.0141
F05	0.037	52	0.0215
F06	-0.075	47	0.0194
G01	0.208	61	0.0252
G02	0.156	58	0.0240
G03	0.261	64	0.0265
G04	0.325	67	0.0277
Sum			1

most common method is Analytical Hierarchy Process (AHP). Furthermore, in recent years, the weights are computed in association of Fuzzy theory (Cha 2006). AHP?based quantification approach is, however, useful when the survey respondents are experts and the number of factors is limited.

In differentiating the importance level of factors, the most common method is to put different weights on each factor using the mean score of the survey results. However, this weighting approach may be error-some in that each survey respondent has different perception level in assessing the importance of factors. In order to overcome this anchoring issue, each respondent's raw data on the factor list is normalized. By normalizing the raw data, the complete

$$\text{Project Risk Score} = \sum_{i=1}^{49} \{X_i\_\text{degree of agreement} \times X_i\_\text{factor weight}\} \quad (4)$$

$$\text{,where } X_i\_\text{degree of agreement} = 1, 2, \ldots 5$$

data set is transformed into a standard normal distribution. Detailed methodology for computing normalized factor weight is presented as follows.

1. Convert all of the raw data by normalizing the data set using the following equation

, where X_n=normalized factor score; X_r=raw factor score; M(X)=mean value of raw factor score; •Ú(X)=standard deviation of raw factor score

2. Calculate normalized mean score of each factor
3. Compute the range value using the following equation

, where X_R=range value of factor; Min(X_n)=minimum value of normalized factor scores; Max(X_n) = maximum value of normalized factor scores

4. Compute the factor weight using the following equation

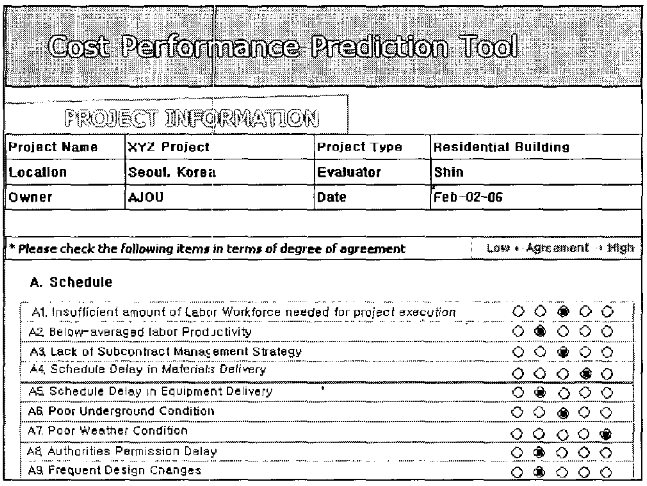

Figure 5. Cost Performance Prediction Tool: Project Information Screenshot

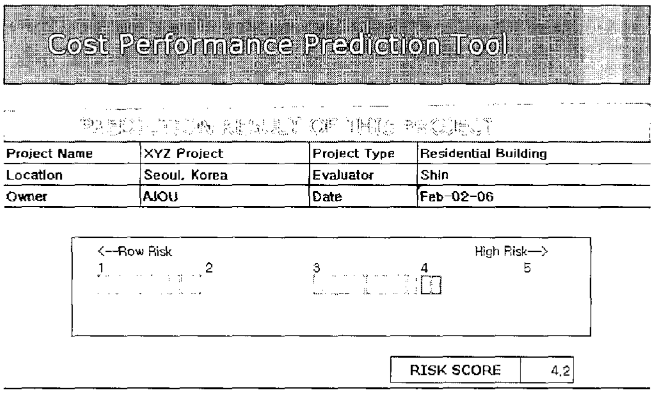

Figure 6. Cost Performance Prediction Tool: Prediction Result Screenshot

Following the above steps, all of the 49 risk factors have been effectively quantified in terms of level of importance in assessing project risks (See table 6).

5. Developing Cost Performance Prediction Tool (CPPT)

Just as a patient is fully diagnosed in advance of declaring the patient's health condition, it is important to check a project's condition before the project is launched. In addition, when the performance of a project is forecasted, the project manager and participants can implement a detailed-plan more effectively. In this paper, a project risk assessment methodology is provided. Using the factor weights computed by normalization approach, a project score is calculated using the following equation (4).

For the purpose of quantifying the project score, the degree of agreement is used as an indicator which shows how well a target project is matched with the 49 potential risks. For example, if a project is exactly characterized using "A1" risk factor, the degree of agreement of "A1" of the particular project is scored "5." The range of this value is between 1(lowest agreement) to 5(highest agreement). The project score is a useful measure which predicts the performance of a project. To expedite the assessment process, a computerized tool has been developed. The tool is user-friendly and designed to facilitate the manipulation via Microsoft ExcelTM Visual Basic Application software. Pilot test of the tool have proved the validity of the logic described in this study. Two real-case projects have been used in the validation process. The score of the successful project was 2.3 (maximum of 5.0) while the poor project was 4.2 (See Figures 5 & 6). By comparing the risk scores with the others, any projects can be evaluated in terms of the level of risk vulnerability.

APPENDIX I. Cost Performance Risk Factor Survey Instrument

The following questionnaire is intended to quantify the relative impact of risk factors on cost performance in building projects

1-1. The factors listed below are related with project schedule. Please mark "√" in the relative impact options for each factor based on your experience and knowledge.

Risk Factor	Relative Impact on Cost Overrun Low	←		Med.		→	High
A1. Insufficient amount of labor workforce (labor shortage)	①	②	③	④	⑤	⑥	⑦
A2. Below-averaged labor productivity	①	②	③	④	⑤	⑥	⑦
A3. Lack of subcontract management strategy	①	②	③	④	⑤	⑥	⑦
A4. Schedule delay in materials delivery	①	②	③	④	⑤	⑥	⑦
A5. Schedule delay in equipment delivery	①	②	③	④	⑤	⑥	⑦
A6. Poor underground condition	①	②	③	④	⑤	⑥	⑦
A7. Poor weather condition	①	②	③	④	⑤	⑥	⑦
A8. Authorities permission delay	①	②	③	④	⑤	⑥	⑦
A9. Frequent design changes	①	②	③	④	⑤	⑥	⑦
A10. Improper technology selection	①	②	③	④	⑤	⑥	⑦

1-2. The factors listed below are related with project budget. Please mark "√" in the relative impact options for each factor based on your experience and knowledge.

Risk Factor	Relative Impact on Cost Overrun Low	←		Med.	→		High
B1. Tightness of national tax regulations	①	②	③	④	⑤	⑥	⑦
B2. Budget loss by Inflation	①	②	③	④	⑤	⑥	⑦
B3. Interest rate increase	①	②	③	④	⑤	⑥	⑦
B4. Bulk material price uprise	①	②	③	④	⑤	⑥	⑦
B5. Exchange rate fluctuation	①	②	③	④	⑤	⑥	⑦
B6. Cost overrun affected by material damage	①	②	③	④	⑤	⑥	⑦
B7. Labor cost uprise	①	②	③	④	⑤	⑥	⑦
B8. Equipment rent fee uprise	①	②	③	④	⑤	⑥	⑦
B9. Land acquisition cost uprise	①	②	③	④	⑤	⑥	⑦
B10. Civil appeals arisen	①	②	③	④	⑤	⑥	⑦
B11. Construction claims and disputes	①	②	③	④	⑤	⑥	⑦
B12. Estimate errors and omission	①	②	③	④	⑤	⑥	⑦
B13. Delay and shortage of contract payment	①	②	③	④	⑤	⑥	⑦

1-3. The factors listed below are related with project quality. Please mark "√" in the relative impact options for each factor based on your experience and knowledge.

Risk Factor	Relative Impact on Cost Overrun Low		←	Med.	→		High
C1. Precise construction specifications	①	②	③	④	⑤	⑥	⑦
C2. Difference between drawings and specifications	①	②	③	④	⑤	⑥	⑦
C3. Incomplete drawings and related documents	①	②	③	④	⑤	⑥	⑦
C4. Quality problems by poor management discipline	①	②	③	④	⑤	⑥	⑦
C5. Non-conformance of quality by improper field inspections	①	②	③	④	⑤	⑥	⑦
C6. Non-conformance of quality by Improper materials /equipment usage	①	②	③	④	⑤	⑥	⑦
C7. Quality problems by unskillful laborers	①	②	③	④	⑤	⑥	⑦
C8. Quality problems by construction errors	①	②	③	④	⑤	⑥	⑦

1-4. The factors listed below are related with project safety. Please mark "√" in the relative impact options for each factor based on your experience and knowledge.

Risk Factor	Relative Impact on Cost Overrun						
	Low		←	Med.	→		High
D1. Shortage of labor skillfulness	①	②	③	④	⑤	⑥	⑦
D2. Lack of safety equipment and facilities	①	②	③	④	⑤	⑥	⑦
D3 Poor safety management system	①	②	③	④	⑤	⑥	⑦

1-5. The factors listed below are related with law and environment issues. Please mark "√" in the relative impact options for each factor based on your experience and knowledge?

Risk Factor	Relative Impact on Cost Overrun						
	Low		←	Med.	→		High
E1. frequent change of regulations and legal aspects	①	②	③	④	⑤	⑥	⑦
E2. environment problems by construction noise	①	②	③	④	⑤	⑥	⑦
E3. Environment problems by construction dusts	①	②	③	④	⑤	⑥	⑦
E4. Environment problems by construction waste	①	②	③	④	⑤	⑥	⑦
E5. natural disaster and force majeur	①	②	③	④	⑤	⑥	⑦

1-6. The factors listed below are related with contract and collaboration issues. Please mark "√" in the relative impact options for each factor based on your experience and knowledge.

Risk Factor	Relative Impact on Cost Overrun						
	Low		←	Med.	→		High
F1. Improper contractor selection method and criteria	①	②	③	④	⑤	⑥	⑦
F2. One-sided contract	①	②	③	④	⑤	⑥	⑦
F3. Vague contract clauses with unclear interpretations	①	②	③	④	⑤	⑥	⑦
F4. Inexperienced Site Supervisors	①	②	③	④	⑤	⑥	⑦
F5. Inexperienced Construction Managers	①	②	③	④	⑤	⑥	⑦
F6. Inexperienced Site Managers without strong leadership	①	②	③	④	⑤	⑥	⑦

1-7. The factors listed below are related with planning effort. Please mark "√" in the relative impact options for each factor based on your experience and knowledge.

Risk Factor	Relative Impact on Cost Overrun						
	Low		←	Med.	→		High
G1. No established risk management procedure in the planning phase	①	②	③	④	⑤	⑥	⑦
G2. Unclear work scope and/or project definition	①	②	③	④	⑤	⑥	⑦
G3. Insufficient site condition analysis	①	②	③	④	⑤	⑥	⑦
G4. Poor planning effort with tight schedule	①	②	③	④	⑤	⑥	⑦