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Reliabilty assessment of conceptual cost estimates for building construction projects

Sung-Hoon An[1], Hunhee Cho[2], Ung-Kyun Lee[3,*]

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Abstract

In the early stages of a construction project, the reliability and accuracy of conceptual cost estimates are major concerns for clients and cost engineers. Previous studies applied scoring methods and established common rules or mathematical methods to assess the quality of cost estimates. However, those approaches have some limitations in adapting to real-world projects or require understanding of sophisticated statistical techniques. We propose a Conceptual Cost Estimate Reliability Index (CCERI), a simple, easy-to-use, and easy-to-understand tool that incorporates weights for 20 factors influencing the quality of conceptual cost estimates. The weights were obtained by eliciting experts' experience and knowledge. Cost data from 71 building projects were used in the analysis and validation of the CCERI. The analysis reveals that a conceptual cost estimate with a CCERI score of less than 3000 has a high probability of exceeding 10% error, and such conceptual cost estimates are unlikely to be reliable. With the CCERI score, a decision maker or a client can recognize the reliability of the conceptual cost estimates and the score can thus support decision making using conceptual cost estimates. In addition, with the CCERI and the relative importance weights of factors affecting the conceptual cost estimates, the estimator can find ways to modify a conceptual cost estimate and reestimate it. These alternatives can decrease the risk in the conceptual estimated cost and assist in the successful management of a construction project.

Keywords: Cost estimation, Reliability assessment, Reliability index, Decision making.

1. Introduction

Conceptual cost estimation is one of the most critical tasks in the early stages of a building project life cycle [1]. Because they must deal with numerous uncertainties in the project, cost estimators are required to have sufficient expertise and knowledge to reduce the risks caused by the uncertainties to an acceptable level in conceptual cost estimates [2]. Clients of construction projects, therefore, have wanted to know not only the conceptual cost estimates but also whether or not these estimates are reliable. In this context, the results of conceptual cost estimates are reliable if the quality of the conceptual cost estimates is high. Quality refers to the estimated cost having the expected accuracy range [2], and assessing the quality of conceptual cost estimates is considered a way of measuring the reliability of the conceptual cost estimates for a project. Previous research has developed various methods for assessing the quality of conceptual cost estimates. In general, related studies that have assessed the quality of conceptual cost estimates are divided into two categories according to their applied methods. Studies in the first category tried to analyze the gap between actual cost and estimated cost with deterministic figures or expected accuracy ranges using mathematical methods such as regression analysis [3], factor analysis [1], and support vector machines (SVMs) [4]. Those in the second category indicate the acceptable level of quality of conceptual cost estimates by using scoring methods [5][6] or established common rules [7].

Most of the methods developed have limitations that have made them difficult to utilize in real-world projects. First, the simplicity of the tool or assessment method has been an issue with most conceptual cost estimate evaluation models. Sophisticated statistical techniques employed in the studies including regression analysis, factor analysis, and/or SVMs are commonly responsible for this problem. The previous research activities that used scoring methods or rule-based decision making methods have partially solved the simplicity problem by making their methods a little easier to use.

** Corresponding Author. Email: uk.lee@okstate.edu*
1 Senior Lecturer, Ph. D. Department. of Architectural Engineering, Daegu University, Jillyang, Gyeongsan-Si, Gyeongsangbuk-Do 712-714, Republic of Korea
2 Associate Professor, Ph. D. School of Civil, Environmental and Architectural Engineering, Korea University, 5Ga, Anam-Dong, Sungbuk-Gu, Seoul 136-701, Korea
3 Post-doc fellow, Ph. D. School of Civil & Environmental Engineering, Oklahoma State University, Stillwater, OK 74078, USA

However, they still have limitations. Oberlender and Trost's [5] research is hard to understand because of the complicated data analysis techniques required to calculate the scores properly; they are not applicable to building projects because they focus mainly on industrial projects. In addition, Boeschoten's [6] approach and Serpell's [7] approach have
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The purpose of this study is to propose a simple, easy-to-use, and easy-to-understand tool for assessing the reliability of conceptual cost estimates in building construction projects. The proposed assessment model has also been structured by eliciting experts' experience and knowledge and validated with real-world building construction data.

2. Weights of factors for assessing conceptual cost estimates reliability

Assessing conceptual cost estimate reliability

Assessment of the reliability of the results of conceptual cost estimates usually means measurement of the quality of the conceptual cost estimates. As defined in previous studies, quality refers to the estimated cost of having the expected accuracy range in the cost estimate area [2] and reliability is measured by the range of accuracy [7]. Consequently, the reliability of a conceptual cost estimate is determined by whether the expected accuracy range matches the required accuracy range. Figure 1 [4] explains the reliability and quality of conceptual cost estimates.

The accuracy of a conceptual cost estimate can be defined as the difference between the actual and estimated costs [7][8] and can be measured by the error rate calculated from Equation (1):

$$\text{Error rate (\%)} = (|\text{Actual Cost} - \text{Estimated Cost}| / \text{Actual Cost})\ 100. \quad \text{Eq. (1)}$$

Determining factors affecting conceptual cost estimates

Because conceptual cost estimates are affected by various factors such as level of data and time to estimate, the identification of influencing factors as well as their degree of impact is a critical element in assessing the conceptual cost estimate's reliability. To identify the factors affecting the conceptual cost estimates, an intensive literature review was conducted. Related studies [5] and [7 ~ 12] revealed 25 influencing factors, which were reviewed in interviews with cost experts with 7~10 years of cost estimating experience. The 25 factors were further refined using Delphi analysis by cost experts and the final 20 factors were categorized into five different areas as shown in Table 1.

Table 1. Factors affecting the conceptual cost estimates

Category	Factor
Information (Data)	Availability of data on underground factors
	Level of site survey
	Experience with similar projects
	Level of available data
Definition of project	Level of planning definition
	Level of quality definition
	Level of quality of drawings
	Level of construction start date definition
	Capacity of architectural team
Cost estimator (Team)	Estimator’s career experience
	Estimator’s field work experience
	Estimator’s experience with similar projects
	Estimator’s experience with field work in similar projects
	Level of estimator’s commitment
Procedure	Time to estimate
	Standard procedure for estimating
Uncertainty	Capacity of client
	Level of construction difficulty
	Level of competition
	Contingency

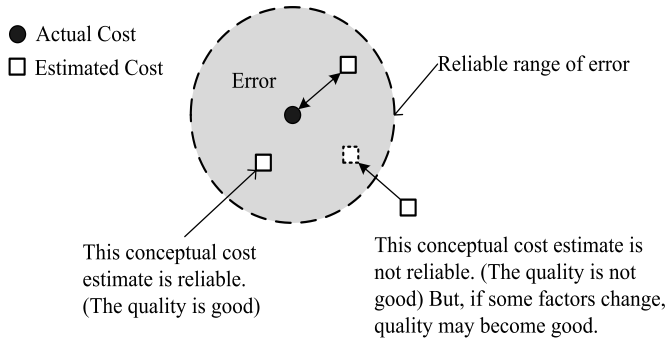

Fig. 1. Reliability and quality in conceptual cost estimates

Effectiveness of data collection and measurability of data were the most critical considerations in finalizing the factors affecting conceptual cost estimates. Therefore, some theoretically important factors were excluded, such as level of communication with original architect/designer and probability of changes in market conditions, because these factors are hard to measure quantitatively. Factors that could be derived from other factors were also excluded from this research.

Weighting the factors using AHP

The analytic hierarchy process (AHP), which was developed by Saaty [13] in the early 1970s, is a structured tool to help people deal with complicated decision-making problems by stratifying the problem into smaller issues and ranking the issues based on expert knowledge [14]. AHP has been applied in various areas of construction [15 ~ 21] as a systematic approach for solving decision-making problems. AHP determines the relative importance weights of factors for goals using pair-wise comparisons. Furthermore, consistency of judgments can be assessed from the comparison matrix for the evaluations within acceptable levels [22].

In this study, three levels of hierarchy were structured, as shown in Fig. 2, using 20 factors from Table 1. Level 1 included the goals, which were the effects on conceptual cost estimates. Level 2 contained the five categories. Level 3, the last level, contained the decision elements, which were the factors affecting the conceptual cost estimates.

To evaluate the weight of each factor, a questionnaire was developed. Pair-wise comparisons using a scale of 1-9 were used to evaluate the relative importance of factors [14]. Questionnaires were sent to experienced cost engineers in major Korean construction companies. Twelve cost engineers, who had an average working experience of 11 years (including five years in the cost estimating area), returned the completed questionnaires. The pair-wise comparisons were analyzed using Expert Choice, which is the software package for AHP. Consistency was also checked using Expert Choice.

The consistency ratios of the 12 questionnaires were 0.03, which is within the acceptable level (0.1) proposed by Saaty [22].

The AHP approach determined the relative importance weights of factors affecting the conceptual cost estimates. These relative importance weights of factors represented the domain knowledge of the experts. Table 2 shows the weights of the 20 factors used in the AHP analysis.

3. Development of conceptual cost estimates reliability index

Data Collection

To validate the CCERI assessment model proposed in this study, data from 71 completed building construction projects were collected from general contractors in Korea. The data included both the assessment of the conceptual cost estimates reliability and measurements of the factors.

As previously explained, conceptual cost estimates reliability could be assessed by its expected accuracy range. In this study, the conceptual cost estimate reliability was assessed using three classes based on the range of error rate (Class 1: ±0-5%, Class 2: ±5-10%, Class 3: over ±10%) between conceptual estimated cost and actual cost. Classification of the range of error rates was determined by using the study by Ahuja and Campbell [9]. According to their study, a 15% error rate is common in the concept stage of project while 10% in the detailed design phase and 5% in the tender preparation phase are acceptable. Of the selected data, 25 were in Class 1, 21 were in Class 2, and 25 were in Class 3.

Twenty factors were measured for assessing the conceptual cost estimate reliability. Among these, 17 are measured by numbers and were evaluated using a 1-5 ordinal scale. The other three factors (estimator's career experience, estimator's

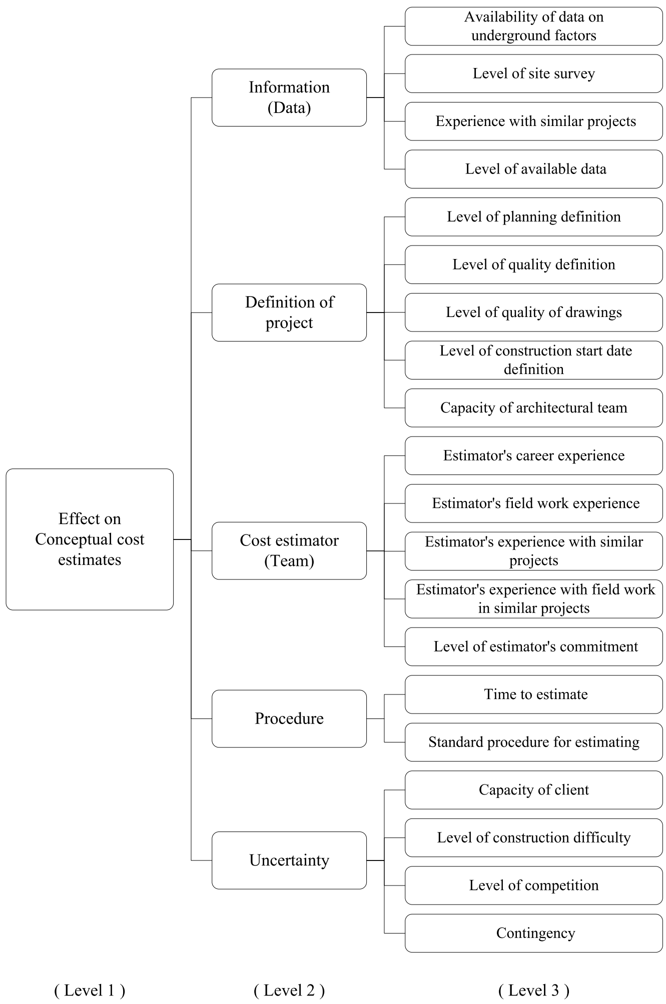

Fig. 2. Structure hierarchy

fieldwork experience, and time to estimate) are measured on a numerical basis. To transform these three numerical values to ordinal data, Table 3 was utilized.

Among the 17 factors measured by ordinal scale, three factors (level of construction difficulty, level of competition, and contingency), which originally had negative relationships with the conceptual cost estimates reliability, were converted to positive relationships to increase consistency with others. The CCERI described in the following section was developed through the data analysis and conversion process as explained.

Conceptual cost estimate reliability index

The CCERI is a score that incorporates the weights of 20 factors influencing the quality of conceptual cost estimate. The

Table 2. Weights of factors by AHP

Level 1		Level 2		Level 3	
Effect on conceptual cost estimates	1.000	Information (Data)	0.249	Availability of data on underground factors	0.075
				Level of site survey	0.039
				Experience with similar projects	0.061
				Level of available data	0.074
		Definition of project	0.228	Level of planning definition	0.092
				Level of quality definition	0.083
				Level of quality of drawings	0.024
				Level of construction start date definition	0.015
				Capacity of architectural team	0.014
		Cost estimator (Team)	0.221	Estimator’s career experience	0.048
				Estimator’s field work experience	0.035
				Estimator’s experience with similar projects	0.058
				Estimator’s experience with field work in similar projects	0.048
				Level of estimator’s commitment	0.032
		Procedure	0.155	Time to estimate	0.098
				Standard procedure for estimating	0.057
		Uncertainty	0.147	Capacity of client	0.034
				Level of construction difficulty	0.03
				Level of competition	0.047
				Contingency	0.036

Table 3. Rule for transforming numerical data to ordinal data

Value	Estimator’s career experience (years)	Estimator’s field work experience (years)	Time to estimate (days)
1	$x \leq 1$	$x \leq 1$	$x \leq 2$
2	$1 < x \leq 3$	$1 < x \leq 3$	$2 < x \leq 4$
3	$3 < x \leq 5$	$3 < x \leq 5$	$4 < x \leq 6$
4	$5 < x \leq 7$	$5 < x \leq 7$	$6 < x \leq 8$
5	$7 < x$	$7 < x$	$8 < x$
Reference	Min.: 1.3 Max.: 11 Ave.: 4.9	Min.: 0 Max.: 9 Ave.: 4.6	Min.: 1 Max.: 18 Ave.: 5.7

weights of each element in CCERI were assigned the range 0-1000 by multiplying the weights shown in Table 2 by 1000. Figure 3 shows the spreadsheet utilized in calculating the CCERI.

The process of calculating the CCERI score is as follows: each element in four different categories as shown in Fig. 3 is evaluated based on a 1-5 scale and multiplied by the weight of the element. The sum of the values calculated for each element represents the subsum of corresponding category. By adding up all the subsums, the total sum is derived and it is called a CCERI score. Therefore, the maximum CCERI score is 5000.

4. Analysis and validation

As previously mentioned, data from 71 real-world cost estimates for building projects were used in the analysis and validation of the CCERI. The CCERIs for the 71 projects are summarized in Table 4.

We tried to identify a meaningful guideline from CCERI scores that would allow us to assign projects to Class 1, Class 2, or Class 3, which have significant differences in their ranges of error rate in their conceptual cost estimates. This is a very critical step in this research effort because the cost estimator can take necessary actions to increase the reliability of the conceptual cost estimate when the results of calculating the CCERI score for a conceptual cost estimate for a building project are not acceptable compared with a meaningful guideline for the CCERI score. For example, cost estimators could be alerted when the CCERI score is less than 3000, meaning that the error may exceed 10%.

To identify the appropriate CCERI scores, analysis of variance (ANOVA) tests were conducted. ANOVA is a useful tool for testing for significant differences between the means of variables. The CCERI score must be intuitive and easy to use while representing meaningful criteria with statistical significance in reviewing the conceptual cost estimates reliability. First, an ANOVA test was conducted to see if there are statistically significant differences between the scores of Class 1, Class 2, and Class 3 when using a CCERI score of 2000. To identify the proper CCERI score, repetitive ANOVA tests were completed using CCERI scores of 2500, 3000, 3500, and 4000. We now illustrate the results of the ANOVA tests when the CCERI score is 3000.

In the analysis between Class 1 and Class 2, the calculated p-value (0.221) was greater than the significance level of 0.05, thus supporting $H0:\mu1=\mu2$. Therefore, there is no statistical difference between the two sample means. In the analysis

Category / Elements	Weights (W)	Score (S)	Sub-Sum (W*S)	Score Description
Information (Data)				
Availability of data on underground factors	75	3	225	5:much~1:none
Level of site survey	39	2	78	5:high~1:low
Experience with similar projects	61	1	61	5:much~1:none
Level of available data	74	3	222	5:high~1:low
Definition of project				
Level of planning definition	92	2	184	5:high~1:low
Level of quality definition	83	3	249	5:high~1:low
Level of quality of drawings	24	1	24	5:high~1:low
Level of construction start date definition	15	3	45	5:high~1:low
Capacity of architectural team	14	4	56	5:high~1:low
Cost estimator (Team)				
Estimator's career experience (year)	48	4	192	**5: >7, 4: 7-5, 3: 5-3, 2: 3-1, 1:≤1**
Estimator's field work experience (year)	35	4	140	**5: >7, 4: 7-5, 3: 5-3, 2: 3-1, 1:≤1**
Estmator's experience with similar projects	58	2	116	5:much~1:none
Estimator's experience with field work in similar projects	48	3	144	5:much~1:none
Level of estimator's commitment	32	1	32	5:high~1:low
Procedure				
Time to estimate (day)	98	3	294	**5: >8, 4: 8-6, 3: 6-4, 2: 4-2, 1:≤2**
Standard procedure for estimating	57	2	114	5:high~1:low
Uncertainty				
Capacity of client	34	2	68	5:high~1:low
Level of construction difficulty	30	2	60	**5:low~1:high**
Level of competition	47	5	235	**5:low~1:high**
Contingency	36	4	144	**5:none~1:much**
Total-Sum	**1000**		**2683**	**(Maximum:5000)**

Fig. 3. Example of a CCERI score sheet for building projects

Table 4. Result of CCERI scoring

Classification		Class 1	Class 2	Class 3	Total
Range of error rate		±0–5%	±5–10%	over ±10%	–
No. of cases		25	21	25	71
Results of CCERI score	High	4225	3881	3831	4225
	Low	2891	2533	2376	2376
	Mean	3382	3247	2829	3148
	Std. Dev.	369	366	328	425

Table 5. Numbers of data with CCERI score lower than 3000

Classification	Class 1	Class 2	Class 3	Total
Range of error rate	±0–5%	±5–10%	over ±10%	–
No. of cases (A)	25	21	25	71
No. of cases with CCERI score lower than 3000 (B)	2	2	19	23
(%) (100 × B/A)	(8%)	(10%)	(76%)	(32%)

results between Class 1 and Class 3, the difference in means was significant at the significance level of 0.05 (p =0.0001). Similar results were obtained from the analysis between Class 2 and Class 3 with the p-value being 0.0001. In summary, although there is no statistically significant difference between Class 1 and Class 2, Class 3 is significantly different from Class 1 and Class 2. Thus, 3000 is considered as a meaningful CCERI score in evaluating the conceptual cost estimates reliability.

Table 5 shows the range of error rates for each Class and the number of cases for which the CCERI score was less than 3000. For Class 3, of the 25 cases, 19 cases had CCERI scores less than 3000 and it means that their errors went beyond 10%. The analysis reveals that a conceptual cost estimate with a CCERI score of less than 3000 has a high probability of exceeding 10% error, and such conceptual cost estimates are unlikely to be reliable.

5. Results and discussion

As shown in Table 6, 10 key factors influencing the conceptual cost estimates were determined from Table 2. These 10 factors accounted for 70% of the influence on the conceptual cost estimates. In particular, the time to estimate was the most important factor of the 20, that is, estimators believed that the quality of conceptual cost estimates would be improved if they had more time to estimate.

In addition, our results show that the key factors in this study are a little different from those of previous studies. In particular, the level of quality definition and the availability of data on underground factors, which were not considered important in previous studies outside Korea, have been included in the important key factors. This may be because residential buildings are a large share of building projects in Korea and underground earthwork has recently been more important in Korea because of the limited construction site areas. Therefore, the key factors presented by this study should contribute to improving the quality of conceptual cost estimates for building projects in practice.

The reliability of conceptual cost estimates in the early stage of a project can be assessed in a very simple, easy-to-use, and easy-to-understand way by using the calculation sheet for the CCERI developed in this study. When the CCERI score is less than 3000, the error of the conceptual cost estimates is highly likely to be over 10%. In that case, therefore, the cost estimator should find an alternative to improve the reliability.

With the CCERI score, a decision maker or a client can recognize the reliability of the conceptual cost estimates and the score can thus support decision making using conceptual cost estimates. In addition, with the CCERI and the key factors mentioned previously, the estimator can determine an alternative, because the weights and scores of the elements show what is required to reduce the error range. For instance, the cost estimator could find a way to increase the CCERI score by modifying the evaluation of the score for the key factors, and carry out some activities that would modify the evaluation of the key factors. The cost estimator would then complete the cost estimating for this project again and the reestimated cost should be more reliable.

Table 6. Key factors influencing the conceptual cost estimates

Rank	Factors	Weight of each factor	Accumulated weight
1	Time to estimate	0.098	0.098
2	Level of planning definition	0.092	0.19
3	Level of quality definition	0.083	0.273
4	Availability of data on underground factors	0.075	0.348
5	Level of available data	0.074	0.422
6	Experience with similar projects	0.061	0.483
7	Estimator's experience with similar projects	0.058	0.541
8	Standard procedure for estimating	0.057	0.598
9	Estimator's experience with field work in similar projects	0.048	0.646
10	Estimator's career experience	0.048	0.694

6. Conclusions

We have proposed a simple, easy-to-use, and easy-to-understand tool for assessing the reliability of conceptual cost estimates, which means whether the expected accuracy is within the acceptable accuracy range, in building construction projects. To develop the assessment method, experts' experience and knowledge has been elicited by using the AHP approach to determine the relative weights of factors affecting the conceptual cost estimates. We developed the CCERI for assessing the reliability of conceptual cost estimates with a simple, easy-to-use, and easy-to-understand method. Data collected from 71 real-world building projects that were cost estimated by Korean general contractors were used in the analysis and validation for the CCERI.

The results showed that conceptual cost estimates with CCERI scores of less than 3000 have a high probability of more than 10% error, and so are unlikely to be reliable. With the CCERI score, a decision maker or a client can recognize the reliability of the conceptual cost estimates for decision making. In addition, with the CCERI and the relative importance weights of factors affecting the conceptual cost estimates, the estimator can find ways to modify a conceptual cost estimate and reestimate it. These alternatives can decrease the risk in the conceptual estimated cost and assist in the successful management of a construction project.

The proposed CCERI is only a guide for the cost estimator or decision maker. It does not ensure successful conceptual cost estimates in the early stages of building construction projects. Therefore, further research should be conducted to incorporate previously studied construction management skills including CCERI to improve the success of early estimates. In addition, although the CCERI was developed for building construction projects, indicators for other types of construction projects should also be studied.

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