The Application of CRA Technique in the Education of Trans-national Construction Project

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Abstract

The management of a trans-national construction project often encounters multiple risks. This paper discusses the framework of CRA technique, and applies it to a trans-national construction project. The globalization trend shows that CRA in a trans-national construction projects become more and more important. The paper begins with a typical introduction on BCRA framework then develops a visual presentation that shows how it can be a tool applied in construction education pedagogy. A method of calculating the conditional expected value of perfect information (EVPI) of critical cost elements is proposed to help facilitating the construction decision-making processes during competitive bidding procedures. Finally, an illustrative example of bidding for a turnkey p-plant construction of trans-national project is presented and discussed.

Introduction

Businesses worldwide are facing more and more challenges in the process of international business bidding, due to the increasing competition brought about by the trend towards globalization. The optimum bid for a project is often closely related to its categorized costs, the market supply-demand conditions of the targeted goods and services, and the expected profitability of the project. Most practices of BCRA focus on single location analysis. However, it is becoming a critical issue for the international construction community to establish a framework for the transnational control of BCR practices executed by international cost professionals. International construction project bids are especially influenced by the consequences of price fluctuation, locally and internationally. This is particularly true if the design details of the construction project are still uncertain. The competitive bidding for such projects often bears great risk, and requires risk analysis and simulation tools to provide references that can help justify decisions made in the bidding process. This paper presents a framework of dual-uncertainty concerning trans-national construction projects.

The management of a trans-national construction project often encounters multiple risks. The Building Cost Risk Analysis (BCRA) of a multinational corporation involving trans-national management becomes more and more important in construction education pedagogy, which can also be utilized by both construction cost professionals and academia. The tendering for a turnkey project often categorizes the scope of the work as "local engineering items" and "equipment and technical support depend on foreign import", which formalizes distinctive risk origins with dual uncertainty. These can be classified as "Local Cost" and "Non-Local Cost". The paper also presents an example of a Taiwanese engineering company's bid on a turnkey plant construction project in Mainland China. The paper begins with a typical BCRA then develops a visual presentation that shows the major contributors to the total cost variance and contingency profile. A conditional expected value of perfect information (EVPI) of critical cost elements is explored to help facilitating the decision-making process in competitive bidding procedures. Finally, the paper develops a user-friendly visual presentation of this information.

The Cost Model

A trans-national construction project can categorize the total cost (C) as Local Cost (C_L) and Non-Local Cost (C_N). Overheads, escalation, and profit can also be categorized into Local Cost and Non-Local Cost components. Following the procedure of CRA showed in Figure 1, one can identify critical cost elements of the project base on the hierarchical items of Cost Breakdown Structure (CBS). After identifying Critical Elements and Non-Critical Elements, the total cost estimate can be expressed as the summation of non-critical elements ($\overline{C}$) and critical elements ($\sum C_{crit} = \sum C_{L,crit} + \sum C_{N,crit}$) :

$$C = \overline{C} + \sum C_{L,crit} + \sum C_{N,crit} \quad (1)$$

Whenever any critical cost element fluctuates, the total cost will fluctuate in response. After eliminating interdependencies between critical elements, the expected total cost is the expected value of all critical cost elements categorized as Local Cost and Non-Local Cost.

$$E\left[C\right] = \overline{C} + E\left[\sum C_{L,crit}\right] + E\left[\sum C_{N,crit}\right] \quad (2)$$

The Process of CRA under Dual-uncertainty

Based on the hierarchical CBS of the cost estimate, we examine the variance of each cost-item in each level and follow the top-bottom procedure to identify critical cost elements. A transnational construction turnkey project involves two groups of critical cost elements-- Local Cost and Non-Local Cost. Each group can be affected by a different kind of risk element, and each element shares different variance in proportion to the total cost. After examining the mechanism and the range of the variance, the project team can finally identify a total of twenty critical cost elements of the project under dual-uncertainty. In order to let BRCA work better, the analyst should eliminate interdependencies between critical elements before assigning a Probability Density Function (PDF) to each critical element to describe its variability. Then, a sensitivity analysis can be conducted, as well as a Monte-Carlo simulation of the project (Figure 1).

Although there are many continuous probability functions that can be chosen in Statistics to describe the sampling data, such as include uniform, normal, lognormal, β, and triangular distributions. In practice, the triangular distribution function is the most popular and simplest one to conceptualize for the team of design and cost experts [1, 2]. The triangular PDF uses the low estimate (C_a), the high estimate (C_b), and the highest probability of the most likely estimate (C_c) as parameters for triangular PDF. The PDF is built upon the set theory of the state of nature of the events, and is a key concept in applied statistics. The interpretation of the results of simulation extends the concept of confidence interval in statistics on to explain the contingency in the practice of building cost estimates [4,5,6,7,8].

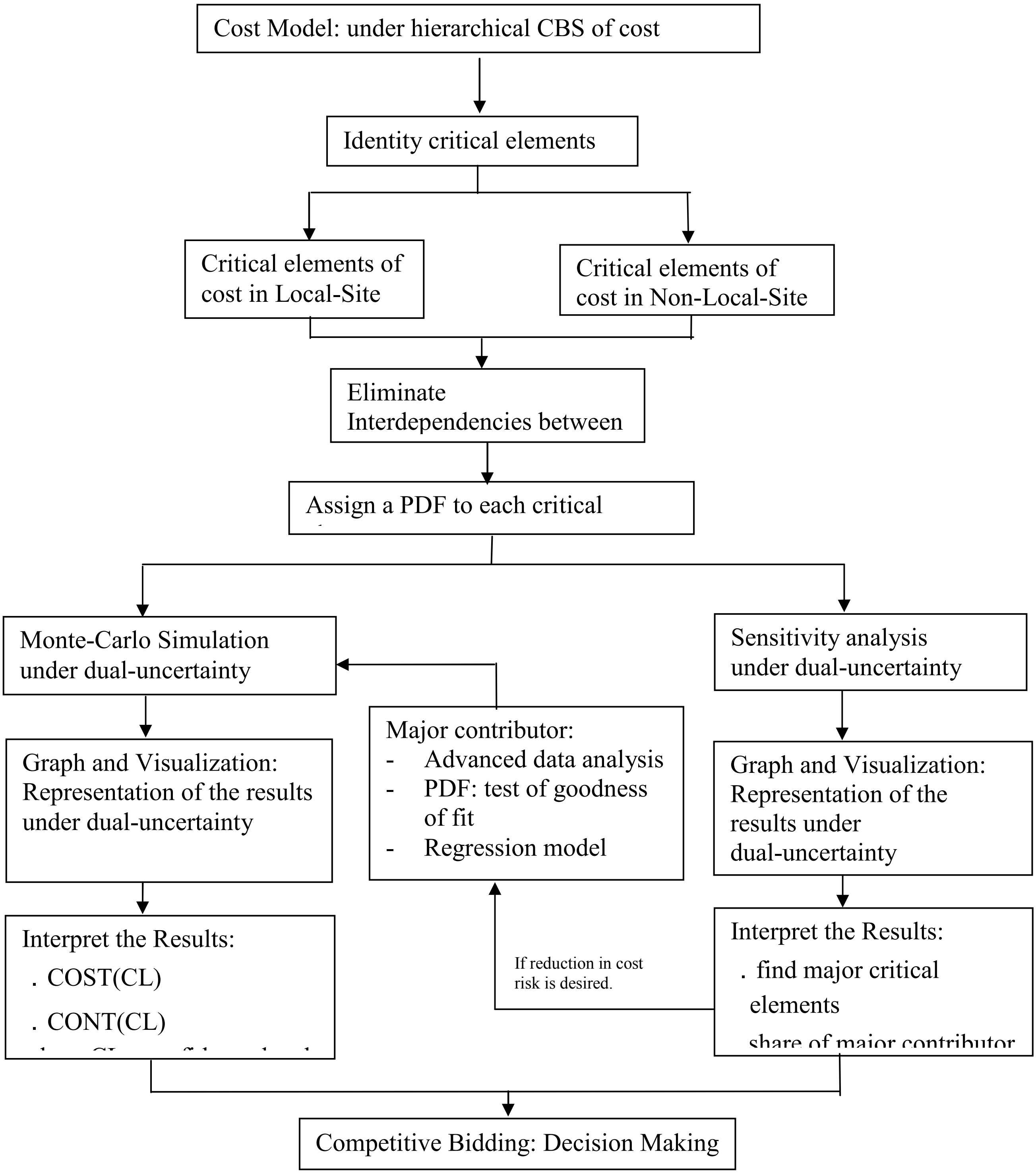

Figure 1: The Process of CRA under Dual-uncertainty

(The criteria of identify critical cost elements : see Note[1])

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[1] The criteria of identify critical cost elements can be written as [1, 7]:
if $V > V_{crit-i}$ where $P(V_{crit-i}) = 0.5\%$, $i=1\text{-}n$ and $n < 20$, then V is critical element.

The Contribution Variance of Critical Elements to Total Cost

If a critical element follows triangular distribution, the expectation and variance of the random cost of critical element (C_{crit}) can be represented as

$$E[C_{crit}] = (C_a + C_b + C_c)/3 \tag{3}$$

$$Var[C_{crit}] = \left(C_a^2 + C_b^2 + C_c^2 - C_aC_b - C_bC_c - C_aC_c\right)/18 \tag{4}$$

Equation 3 and 4 provide a direct method for calculating the variance of each critical element. In order to avoid complex interdependency problems that would weaken the meaning of output from BCRA, one should eliminate interdependencies between critical elements [1]. In this situation, one can use the addition property to summate the total variance of the total cost for the project. Thus, for critical elements, the total variance of the total cost (S^2) can be broken down into the variance of Local subtotal cost ($S_L^2 = \sum_i S_{L,crit-i}^2$) and the variance of Non-Local subtotal cost ($S_N^2 = \sum_j S_{N,crit-j}^2$):

$$S^2 = S_L^2 + S_N^2 \tag{5}$$

$$f_L + f_N = 1 \tag{6}$$

Where $f_L = \dfrac{S_L^2}{S^2}$; $f_N = \dfrac{S_N^2}{S^2}$. Applying this concept to the problem of competitive bidding on a trans-national construction turnkey project, it's easy to calculate the contribution share of each critical element to the total variance of the total cost of the project. (Figure 2)

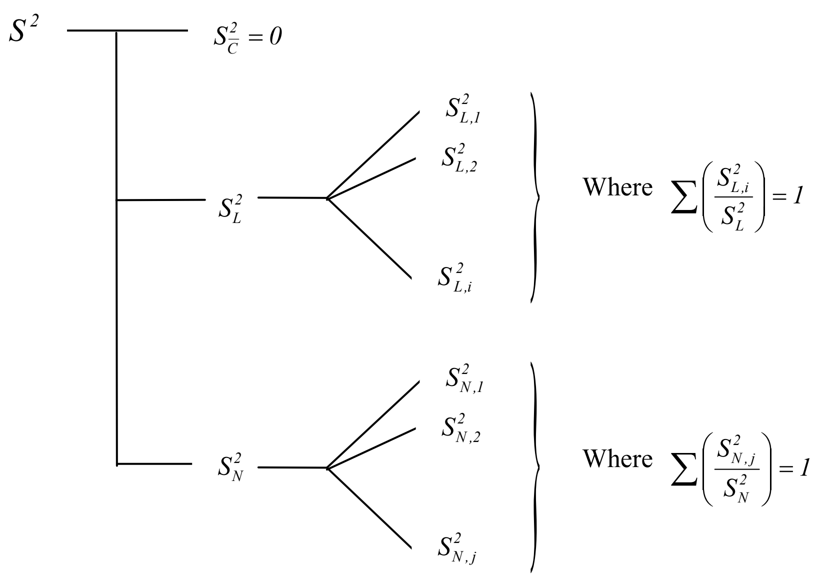


Figure 2: Composition of variance contribution in total cost estimate

In contrast with the large number of estimates required in Monte-Carlo Simulation, the single value of equation 10 can be used to compare the variance contribution of each element. Then all the variance composition of critical elements can be represented as pie-chart which can effectively condense the output information, and give more visual impact in practice. This can capture these important critical elements for advanced analysis and, for example, enable the contingency to be plotted against the CDF of critical elements, and the EVPI of the variable to be calculated.

Illustrative Example

As an example of employing the CRA Technique in Trans-national Construction project, consider a competitive bidding for the P-Plant Turnkey Project took place in Mainland China before design details were approved. It was inevitable that there would be a contingency after the successful bid was announced. Contingency allowance should be part of the estimate to cover unforeseen conditions arise before and during the construction period. The rapidly expanding economy in China is likely to bring high levels of inflation when the project proceeds. Also, the rapid growth of construction projects nationwide has also brought about inflation in labor rates and the price of materials. After reviewing the cost estimate base of CBS hierarchy, the project team assigned max variance to each cost item. The process shown in Figure 1 was followed and used the Delphi technique to converge the consensus of parameter for each critical cost element. Then, refer the past experience and historic data of project in China, the project team identify critical cost elements and assign the minimum cost, maximum cost, and most likely value to each critical element. These results were tabulated in Table 1 as input data for the Sensitivity Analysis and Monte-Carlo Simulation.

After applying equations 3, 4, 5, 6 to each critical element, the results of the Sensitivity Analysis in Figure 3 and Figure4 showed the share of each critical element's contribution to total cost variance. The total variance contribution from Local Cost was 14,580,277 million RMB^2, which constituted 79.21 % of total cost variance. Only 20.79 % of total cost variance came from Non-Local Cost elements. Figure 3 shows that the major Local Cost elements were:

(1) Profits (20.99 %),
(2) Electrical Equipment (13.85 %),
(3) Equipment and Machinery (8.01 %).

Figure 4 shows that the major Non-Local Cost elements were:

(1) Equipment and Machinery (HVAC) (28.12 %)
(2) Instrument and Bulk Material (25.09 %)
(3) Electrical Equipment (22.87 %),

which were imported from abroad.

The example also carries out 10,000 iterations of the Monte-Carlo Simulation. Because all the inputs of triangular distribution skewed to the right hand side, the mean value of the total cost was larger than the deterministic base cost estimate. The simulation results show that the expected total cost was 291.87 million RMB, which was higher than the deterministic base total cost estimate 285.75 million RMB. The coefficient of variation was 1.47 %. Figure 5 shows the PDF of total cost, and Figure 6 shows the CDF of total cost. In Table 1, COST（95%）= 298.96 million RMB shows that the probability of a cost overrun of 298.96 million RMB will not be more than 5%. The deterministic base cost estimate C^* is 285.75

million RMB.

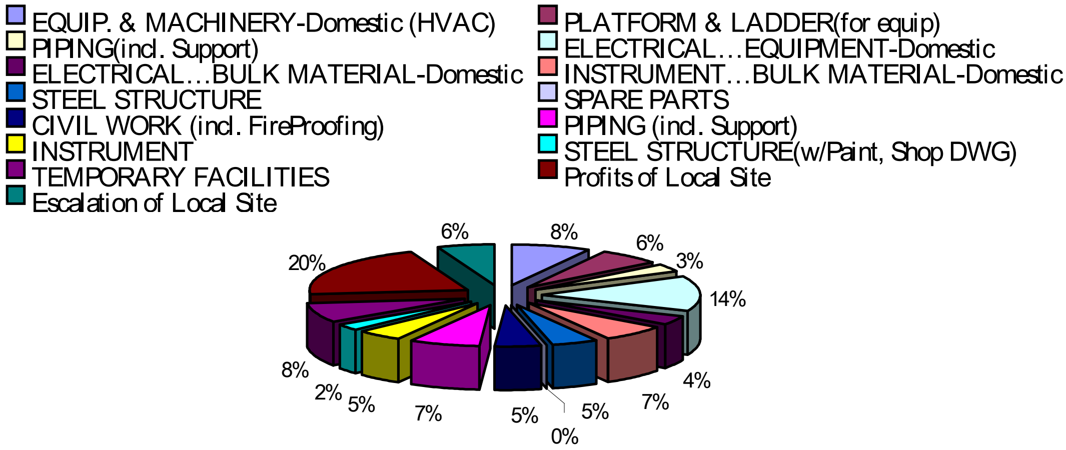


Figure 3: Contribution of Variance of Critical Cost Elements : Local Cost

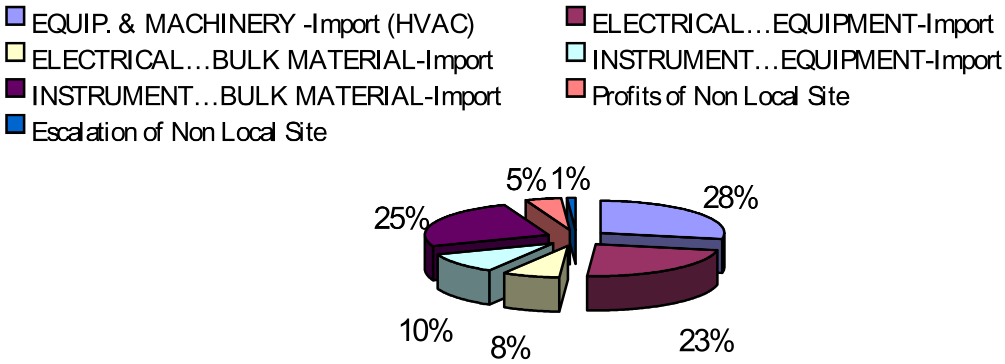


Figure 4: Contribution of Variance of Critical Cost Elements: Non-Local Cost

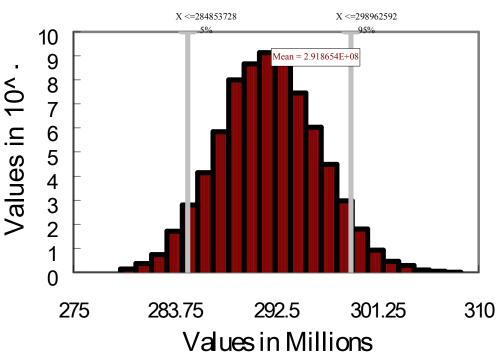
The contingency for a given confidence level can be expressed as

$$CONT(CL) = C^* - COST(CL) \tag{7}$$

That is the project will not overrun the contingency under a specific confidence level which is designated as CONT(CL). The Total Cost Overrun Profile and the Contingency Profile of the case study in this paper will show in Table 1. Where CONT(95%)=13.21 million RMB indicates that to achieve a 95 % level of confidence, the project required a contingency of 13.21 million RMB, which was 4.8% of the deterministic base total cost (285.75 million RMB). In the deterministic cost estimate model, the contingency used in the competitive bidding set as 5% of the total deterministic cost estimate was 14.29 million RMB. However, the results of the Monte-Carlo simulation also showed that the contingency used in the total deterministic cost estimate corresponded to a confidence level of 97.4 %. That means the percentage method use 5% total deterministic cost estimate as contingency in practice overstate when competitive bidding. The results of Monte-Carlo can narrow the scope of the project's contingency.

Table 1: The Contingency Profile of Total Cost (Unit: Million RMB)

CDF	Total Cost-- COST (CL)	Contingency of Total Cost CONT(CL)
5%	284.85	0.90
10%	286.36	-0.61
15%	287.40	-1.65
20%	288.24	-2.49
25%	288.92	-3.17
30%	289.54	-3.79
35%	290.15	-4.39
40%	290.68	-4.93
45%	291.25	-5.50
50%	291.79	-6.04
55%	292.35	-6.60
60%	292.90	-7.15
65%	293.48	-7.73
70%	294.13	-8.38
75%	294.76	-9.01
80%	295.51	-9.75
85%	296.36	-10.61
90%	297.40	-11.65
95%	298.96	-13.21
The deterministic Base Cost Estimate		285.75
Contingency used in deterministic cost		14.29
Mean		291.87
Standard deviation		4.28
Coefficient of Variation		1.47%



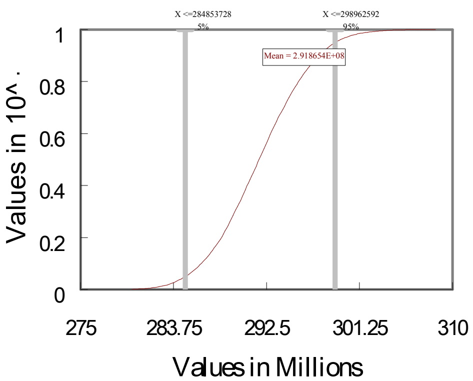


Figure 5: Sample Total Cost: PDF Resulting from Monte Carlo Simulation

Figure 6: Sample Total Cost: CDF Resulting from Monte Carlo Simulation

The Calculation of EVPI on Contingency

Eschenbach and Gimpel (1990) has proposed that the conditional expected value of perfect information (EVPI) can be represented as "equivalent to the expected opportunity loss (EOL)" and can be "calculated by summing over the products of each possible loss and the probability of occurrence of that loss"[10:319]. Applying the concept of stochastic sensitivity analysis [9,10] to the contingency cost estimate, one can plot the contingency against the CDF of the critical cost elements in Local Cost and Non-Local Cost.
So, part of the area lies below the horizontal axis (the deterministic base cost estimate) shows the EVPI for the contingency in relation to the critical elements in Local Cost and Non-Local Cost. (Figure 7)

Comparing the EVPI of Local Cost and Non-Local Cost in Figure 7, we can confirm that most of the variance comes from the Local Cost. The graph gives more visual impact (and also implied mathematical meaning) than numerical calculation results. Also, we can select the most important Local Cost elements, and plot the contingency against CDF for the specific critical element. Because the X-axis is defined based on CDF(C_{crit}), the conditional P(loss) for the max-critical-element shows 0.42 with negative CDF curve. The manager can examine this value and decide whether or not to collect the data for advanced analysis on that critical element, and then seek strategies to lower the risk of this critical element when proceeding with the construction bidding, and subsequent project management.

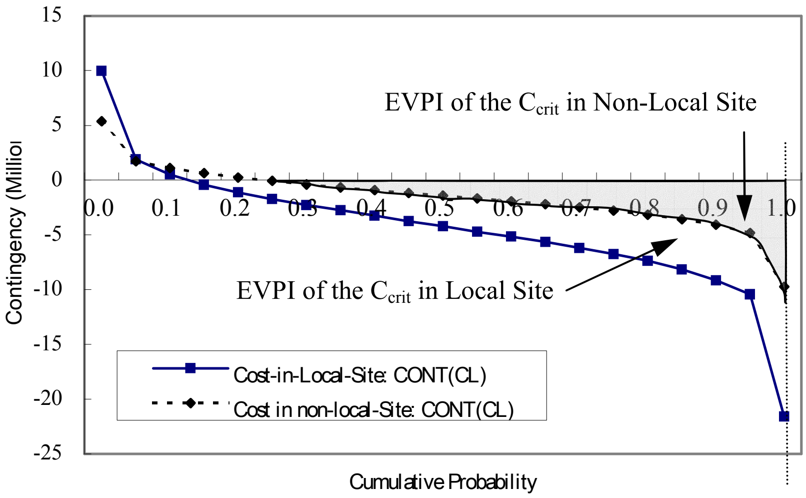


Figure 7: Local Cost and Non-Local Cost: CONTINTINGENCY vs. CDF

Conclusion

Businesses worldwide are facing more and more challenges in the process of international business bidding, due to increasing competition brought about by the trend towards globalization. The management of a trans-national construction project often encounters multiple risks. The tendering for a turnkey project often categorizes the scope of the work as “local engineering items” and “equipment and technical support depend on foreign import”, which formalizes distinctive risk origins with dual uncertainty. This paper derives a framework of dual-uncertainty in trans-national projects first. Then it proposed a graphical representation of composition before advanced analysis, which can effectively condense the output information, and give more visual impact in practice. A method of calculating the conditional expected value of perfect information (EVPI) of critical cost elements in Local Cost and Non-Local Cost were developed that may help to facilitate the decision-making processes in competitive bidding procedures, then manages the risk in design and construction phase more efficiently. Finally, an illustrative example bidding on a turnkey p-plant construction project was presented and discussed.

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