KSCE Journal of Civil Engineering (2016) 20(2):509-518

DOI 10.1007/s12205-015-0497-7

Construction Management

pISSN 1226-7988, eISSN 1976-3808
www.springer.com/12205

Analysis of the Probabilistic Cost Variation Ranges According to the Effect of Core Quantitative Risk Factors for an Overseas Plant Project : Focused on a Middle East Gas Plant Project

Hyun-Wook Kang* and Yong-Su Kim**

Received August 13, 2013/Revised June 26, 2014/Accepted April 14, 2015/Published Online July 17, 2015

Abstract

The purpose of this study targets overseas gas plant construction projects with the aim of analyzing the probabilistic cost variation range with consideration of the effect of core quantitative risk factors. C-Project, which is expected to be completed by a domestic construction company in country U, was thus selected as the subject of analysis. By interviewing experts through survey questions, the core quantitative risk factors for the engineering, procurement, and construction phases were derived. Based on these risk factors, the cost variation range, which is caused by the risk factor effects on project cost, was analyzed. Monte Carlo simulation was applied to this quantitative cost variation result, and the probabilistic cost variation range was assessed. The summarized results of this study are as follows: The probabilistic cost variation range for each phase, with consideration of the effect of core quantitative risk factors, is: an engineering cost of -1.95% to 2.49%, procurement cost of -3.07% to 3.91%, construction cost of -2.99% to 3.80%, and a total project cost of -2.58% to 3.50%. The analysis model and analysis result from this study can be used as decision-making tools to help minimize the economic loss resulting from the effect of risk factors during the overseas plant construction process.

Keywords: *probabilistic cost variation ranges, quantitative risk factors, overseas plant project, monte-carlo simulation, triangular distribution*

1. Introduction

The international demand for the excavation and production of natural gas, which is comparatively less damaging to the environment and more economical in terms of energy use than oil energy, is constantly increasing. Thus, in the Middle East, where there are huge deposits of natural gas, gas plant construction projects for the excavation and production of natural gas are actively underway.

Given that overseas gas plant construction projects are implemented under a lump-sum turnkey contract format that includes engineering, procurement, and construction, the scale of project costs is comparably higher than that for other construction projects (e.g., civil engineering or architecture). Additionally, the huge natural gas deposits make the continuous creation of added value possible, such that the profits that depend on natural gas production are high. Hence, domestic and overseas construction companies are establishing strategies for winning contracts for gas plant construction projects and are actively participating in contract bidding.

Based on the practical and technical knowledge gained from the past construction of overseas plants (gas storage/production plants, chemical engineering plants, freshwater plants, oil refining plants, industrial plants, etc.), domestic construction companies have strategically established plans to win contracts and participate in bids. As a result, several overseas contracts for liquefied natural gas plants and floating production storage and offloading have been won so far.

To establish a strategy for winning an overseas contract for a gas plant construction project, the country's environmental conditions (economy, culture, law, etc.) are considered along with the results of a production analysis and forecast conducted according to the characteristics of the natural gas deposit. This practice is employed because an analysis error in production based on deposit characteristics and environmental conditions that differ from those of a domestic construction project can become risk factors that could affect the degree of economic loss and consequently influence the decision as to whether to go ahead with the project. Hence, at the beginning of a project, firms must formulate a project management plan (cost management, process and time management, etc.) that considers the risk factors that are likely to arise during the engineering, procurement, and construction phases and thus are expected to have a significant effect on project cost.

In the case of an overseas gas plant construction project under a lump-sum turnkey contract format that includes all the tasks in

*Ph.D. Candidate, Dept. of Architectural Engineering, Chung-Ang University, Seoul 156-756, Korea (E-mail: khw3800@naver.com)
**Professor, Dept. of Architectural Engineering, Chung-Ang University, Seoul 156-756, Korea (Corresponding Author, E-mail: yongsu@cau.ac.kr)

the engineering, procurement, and construction phases, a cost management plan that considers risk factors is very important. Under a lump-sum turnkey contract format, a construction company is paid only after the work is performed under the optimal single project cost (total project cost) stated in the contract. Thus, the contractor needs to perform economic analysis and assessment while considering risk factors such as inflation, variation in exchange rates, tax regulation, and funding potential, which may arise while the construction is underway. However, given that the optimal single project cost does not consider any variation (increase) in cost that is caused by the effect of risk factors that occur during construction, such cost problems are shouldered by the contractor and may lead to a financial loss.

However, for domestic construction companies, historical data covering the prediction and management of risk factors and their level of effect (intensity) on cost are lacking. Thus, risk management is performed at a level that recognizes only the risk factors. This condition lends difficulty to the analyses or predictions of the effect of risk factors that occur during the construction process and the associated variation in cost.

The extant literature on overseas plant construction projects in relation to risk factors, cost analysis, and probability analysis has covered the following aspects; (1) Targeting the overseas construction projects at FIATECH, UNIDO, and ICAK, risk factors that should be considered in the engineering, procurement, and construction phases were suggested (FIATECH, 2004; UNIDO, 2006; ICAK, 2003). (2) Using the suggested risk factors from FIATECH, UNIDO, and ICAK, studies on importance, frequency, and the priority in the risk factors of the LNG Plant were carried out (Han, 2011; Kim, 2010). (3) In risk and cost analysis that used probability, the validity of assuming a triangular distribution was proved through case studies (Kwong, 1995; David, 1998; O, 2001).

Such literature can be used as a reference to identify the risk factors that could occur in the early phases of a project. However, the use of such information for analyzing and predicting the effect of uncertain risk factors and the variation in costs needed by domestic construction companies has certain limitations. Such limitations make the available supplementary data insufficient to analyze and predict the effect of risk factors occurring in the construction process and the associated variation in cost.

Therefore, further research is required to address the limitations of the existing literature and the insufficient historical data on the variation in costs caused by the effect of risk factors. This study derived the core quantitative risk factors with a high probability of occurrence and a significant impact on project. Based on this derivation, the probability range of variation in costs considering the effect of these risk factors is analyzed. The details are given below.

1) C-project (gas plant), which is scheduled to be completed by a domestic construction company in country U, was selected as the target of the analysis. The characteristics of the selected project were considered, and the core quantitative risk factors in the engineering, procurement, and construction phases were

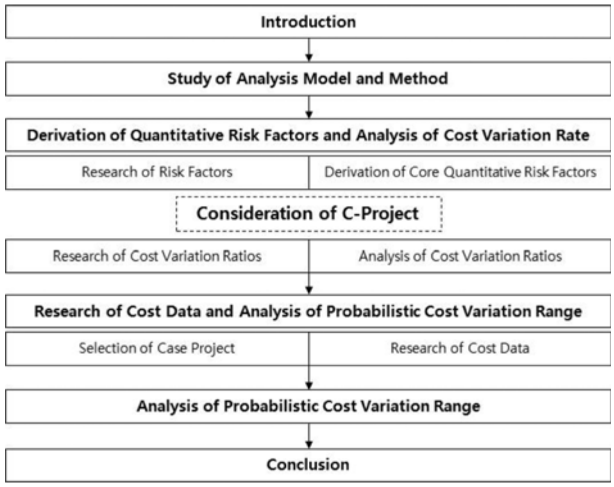


Fig. 1. Research Process and Method

derived. The rate of variation in cost caused by the effect of the risk factors was then assessed.

2) Based on the cost data on the core quantitative risk factors, rate of variation in cost, and three case studies, the quantitative rate of variation in cost was assessed. Using a Monte Carlo simulation, the probabilistic range of variation in cost caused by the effect of these core quantitative risk factors was analyzed.

This study considered the characteristics of C-Project and derived the core quantitative risk factors in the engineering, procurement, and construction phases. The rate of variation in cost caused by the effect of such risk factors was analyzed, and Monte Carlo simulation was used to assess the probabilistic range of variation in cost. The process and method of the study are shown in Fig. 1.

The steps in the research process and method shown in Fig. 1 are explained below, and the specific research methods are explained in the succeeding sections.

1) Explain the analytic model and the analysis method (Monte Carlo simulation, Triangular Distribution, Expert Interviews) implemented to analyze in detail the probabilistic cost variation range based on the impact of the core quantitative risk factors, which is the purpose of this research (explained in detail in Chapter 2).

2) Investigate the risk factors that arise during the engineering, procurement, and construction phases by referring to the relevant data (i.e., FIATECH, UNIDO, and ICAK) on these risk factors to derive the core quantitative risk factors. Extract the core quantitative risk factors that are highly likely to occur and significantly affect the cost by combining and summarizing the investigated risk factors based on their significance and by conducting interviews and surveys among professionals (explained in detail in Chapter 3).

3) Apply the triangular distribution model to examine the probabilistic cost variation ratios according to the core quantitative risk factors derived during the engineering, procurement, and construction phases. Conduct interviews and surveys among the same professionals to analyze the probabilistic cost variation

range by applying such triangular distribution model (explained in detail in Chapter 3).

4) Analyze the probabilistic cost variation range by applying the results of cost variation ratio analysis based on the core quantitative risk factors during the engineering, procurement, and construction phases and the results of quantitative cost variation analysis obtained after applying Monte Carlo simulation to the investigated cost (explained in detail in Chapter 4).

2. Study of Analysis Model and Method

2.1 Suggested for Analysis Model Probabilistic Cost Variation Range

An analysis model is established and proposed based on the research method explained in Chapter 1.2 of this research to achieve the purpose of this study. The proposed analysis model explains the analysis details and results for each phase. The suggested model is shown in Fig. 2.

The most important stage of the analysis model is the Selection of Object Project stage, in which the objects of analysis are selected with consideration of the project characteristics (plant type, total cost, size, scope, region, period, etc.). The core quantitative risk factors are derived from the selected objects of analysis, and the cost variation ratios and the probabilistic cost variation range are analyzed based on the effects of the derived risk factors.

The analytic range before the Selection of Object Project stage can be set up for the Commission and Maintenance stages based on the engineering, procurement, and construction phases. Thus, the analytic range is determined according to the work range of the object of analysis, whereas the investigation range of the risk factors is determined by the analytic range. The suggested analysis model based on this content is shown in Fig. 2.

The results are drawn by analyzing the probabilistic cost variation range based on the influence of the core quantitative risk factors, as aligned with the purpose of this research, according to the analysis model suggested in Fig. 2.

2.2 Monte-Carlo Simulation

The analysis of the variation in cost resulting from the effect of risk factors reveals an outcome that could occur in the future. Hence, Monte Carlo simulation, which is a probability analysis method, can be used. Monte Carlo simulation is a method that predicts future uncertainty and enables the derivation of the probability value and probability distribution by considering all possible scenarios. The characteristics of Monte Carlo simulation can be summarized as follows (Kim, 2004):

- Simulates N number of times to predict the value with a high probability of occurrence in the future;
- Derives simulation results as a probability value and a probability distribution;
- Largely unaffected by the amount of input data because the simulation is performed N times; and
- Useful for situations in which data are insufficient to predict future uncertainty.

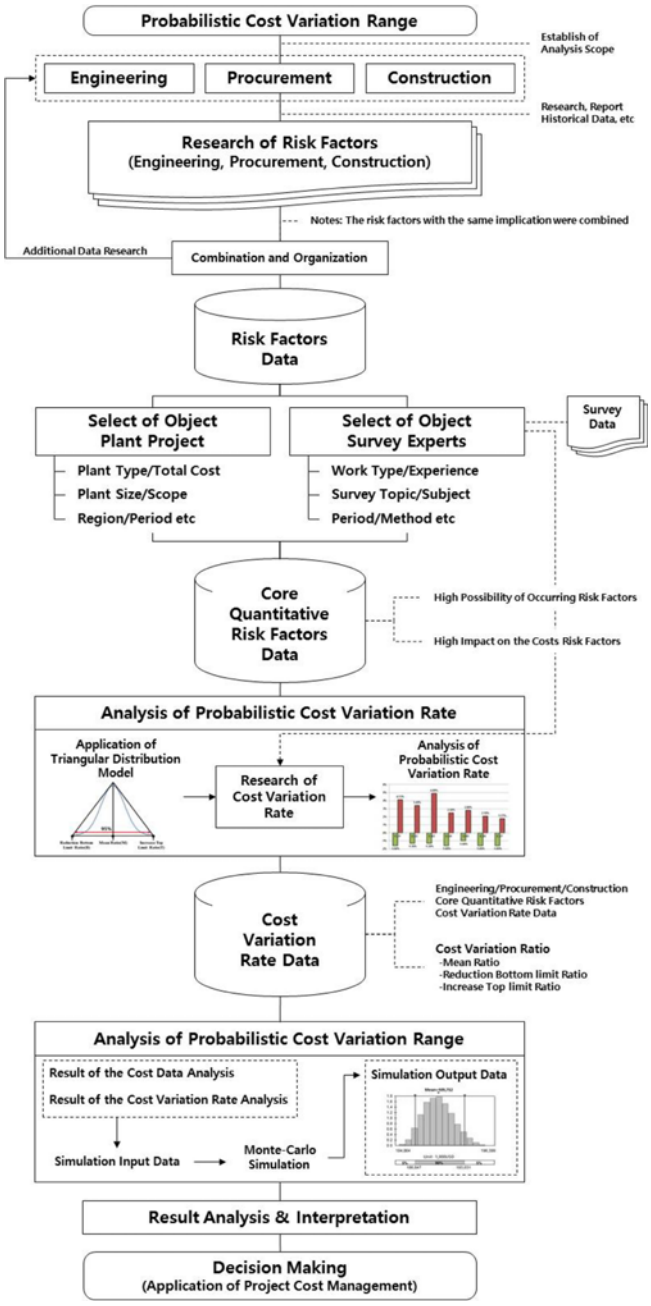


Fig. 2. Analysis Model

On this basis, Monte Carlo simulation was used to supplement the lack of reliable historical data on risk factor effects and variations in cost, as well as to analyze the probabilistic range of variation in cost with consideration of the effect of the core quantitative risk factors.

2.3 Triangular Distribution

From the risk and cost analyses conducted using probability, the criteria for the probability distribution can be summarized as follows (Kwong, 1995; David, 1998; Edward Back, 2000):

- The distribution should be a continuous probability distribu-

tion that considers the diverse risk factors that affect the variation in cost;
- The distribution should be formed with a lower bound (minimum value), an upper bound (maximum value), and a median value;
- A lower bound (minimum value) and an upper bound (maximum value) value should be set to enable the analysis of the rate of variation in cost;
- The ends of the distribution graph should be closed by a lower bound (minimum value) and an upper bound (maximum value);
- The distribution should be in a convex shape because the values that are the most likely to have a high probability are found to be closer to the median value; and
- The distribution should decrease as it moves closer to the lower bound (minimum value) and the upper bound (maximum value).

A continuous probability distribution that satisfies such conditions is a triangular distribution, the characteristics of which can be summarized as follows (Donald, 1983):
- The distribution graph is composed of three variables: the lower bound (minimum value), the upper bound (maximum value), and the median value;
- The effect of the amount of historical data is negligible because the distribution comprises three variables;
- The graph is composed of a distribution with ends that are enclosed by a lower bound (minimum value) and an upper bound (maximum value);
- The graph forms a convex shape because the value that has the highest likelihood of having a high probability occurrence is often found close to the median value.
- The distribution declines as the lower bound (minimum value) and the upper bound (maximum value) are approached because the value that has the highest likelihood of having a high probability is less likely to exist in this location.

The analysis of the probabilistic range of variation in cost analyzes three variables (the lower bound, the upper bound, and the median value) and applies triangular distribution according to the prediction of the variation range. Additionally, to deal with the problem of difficulty in investigating historical data on the effect of risks in a construction project, the use of triangular distribution is appropriate.

In major literature, the assumption of a triangular distribution in the analysis of costs and risks of a project was proved correct by using the Monte Carlo simulation (Edward Back, 2000). In the present study, triangular distribution was used to investigate the rate of variation in cost from the effect of the risk factors and analyze the probabilistic range of variation in cost.

2.4 Experts Interviews

To derive the core quantitative risk factors in the engineering, procurement, and construction phases, and to analyze the rate of variation in cost affected by the risk factors, interviews with experts were performed according to the procedures detailed below. The purpose of the interviews was to solve the problem of a lack of historical data regarding risk factors and variation in costs.
- The risk factors in the engineering, procurement and construction phases, suggested by FIATECH, UNIDO, and ICAK, were combined and organized;
- By performing interviews with 30 experts, the quantitative risk factors were identified; the identified risk factors were then randomly distributed to the same 30 experts to cross-check; afterwards, the final core quantitative risk factors were derived;
- To investigate the rate of variation in cost affected by the core risk factors, interviews were conducted with the same 30 experts; this was to derive reliable results for the study and ensure characteristics of C-Project were understood (supplementary details on Table 3);
- To investigate the rate of variation in cost, a triangular distribution model was applied; the investigation method was based on the average effect of risk factors predicted in the early project phase; if lower than average, it was classified as the reduction bottom limit ratio with a 95% confidence level, and if higher, it was classified as the increase top limit ratio with 95% confidence; they were then investigated (supplementary details on Table 5).

In summary, expert interviews were conducted to derive the core quantitative risk factors considered in the engineering, procurement, and construction phases, and investigate and analyze the rate of variation in cost associated with their effect.

3. Derivation of Risk Factors and Analysis of Cost Variation Ratio

3.1 Derivation of Core Quantitative Risk Factors

After the investigation on the implication of risk factors in the engineering, procurement, and construction phases, suggested by FIATECH, UNIDO, and ICAK, the risk factors with the same implications were combined and organized. Based on these organized risk factors, the core quantitative risk factors were derived through interviews. The combined/organized results are shown in Table 1, Table 2, Table 3.

The combined and summarized risk factors in the engineering, procurement, and construction phases, as in Table 1, were shared in interviews with experts; the core quantitative risk factors that have a high possibility of occurring and cause a big impact on the costs were then derived. To derive the core quantitative risk factors, this study considered the characteristics of C-Project, scheduled to proceed in country U. The outline of the selected project is shown in Table 4.

Considering the characteristics of C-Project outlined above, expert interviews were conducted to derive the core quantitative risk factors. The experts selected were 20 experienced individuals who had performed overseas plant construction for more than two years in the Middle East and 10 managers who performed safety management for more than two years. In the case of the

Table 1. Engineering Phase Risk Factors

Engineering Phase	Details
· Lack of design technique	Lack of technology level of domestic and overseas design companies
· Basic design error	Error in applying the client's demand to the basic design
· Construction design error	Error in applying the client's demand and site condition to the construction design
· HSE application error	Error in applying the standards regarding health, safety and environment
· Field description review error	Error in site instruction analysis and review
· Local law & regulation error	Error in reviewing of the local construction regulation
· Drawing and specification error	Error in reviewing of blueprint and specification
· Patent use error	Error in reviewing of construction-related patent use
· Unsuitable project organization	Unsuitability of organizational composition of project participants
· Design cost payment delay	Incurrence of financial cost due to the delay in payment
· Miscommunication	Miscommunication of domestic and overseas project participants
· Software technology level	Lack of skill in software use
· Software compatibility level	Incompatible software
· Nonconforming to environmental standards criteria	Nonconforming to the local environmental standard criteria

Table 2. Procurement Phase Risk Factors

Procurement Phase	Details
· Lack of technical skills of manufacturing company	Lack of technical skills in equipment production
· Delay in procurement schedule	Delay in equipment procurement schedule
· Route of procurement error	Error in the route of equipment procurement
· Occurrence of procurement accidents	Occurrence of accidents of relevant procurement
· Delay in material procurement schedule	Delay in procurement schedule of construction materials
· Delay in procurement cost payment	Arise of financial cost from the delay in payment
· Unsuitable production of equipment	Cost from unsuitable production of equipment
· Change in equipment price	Change in the purchasing price of the equipment
· Change in procurement supply	Change in supply of equipment and material procurement
· Change in equipment specification	Occurrence of equipment specification change
· Lack of local procurement material	Lack of local purchase and procurement material
· Error in tariff cost estimation	Cost incurred due to error in tariff cost estimation
· Occurrence of flaw in equipment	Cost incurred due to the flaw in equipment
· Change in procurement cost	Cost incurred due to the change in procurement cost

Table 3. Construction Phase Risk Factors

Construction Phase	Details
· Occurrence of rushed construction	Cost incurred due to the occurrence of rushed construction
· Lack temporary facilities	Lack of temporary electricity and material
· Occurrence of accidents	Cost incurred due to the accident occurred
· Change in material supply	Cost incurred due to the change in material supply
· Lack of labor force	Lack of locally-hired labor force
· Lack of technical work force	Lack of locally-hired technical work force
· Lack of technical skills	Lack of technical skills of the locally-hired work force
· Lack of subcontract technical skills	Flaw from the lack of subcontract technical skills
· Delay in construction cost payment	Financial cost incurred due to the delay in payment
· Frequent change in design	Costs incurred due to the frequent change in design
· Flaw occurrence	Costs incurred due to the flaws occurred
· Laborer strike	Delay in construction due to the local laborer strike
· Cultural difference	Decrease in constructability due to the cultural difference
· Climate difference	Decrease in constructability due to climate difference
· Problem with accident response	Problem with the emergency response of accidents
· Problem with maintenance of public order	Construction delay and cost incurred due to the public order and security problems
· Insufficient provision of national occasions	Construction delay and cost due to the national occasions
· Violation of the local law and regulation	Problems from violations of construction-related law and regulation

Table 4. C-Project Outline

Category	Details
Project	Gas Plant
Area	Middle East
Duration	2011.10~2014.08
Scope	E. P. C Phase
Contracts	Lump-Sum Turnkey

Table 5. Survey Outline

Category	Details
Topic	· Deriving and reviewing core quantitative risk factors
Subjects	· Individuals experienced in Middle East plant construction project: 20 · Middle East plant construction project safety manager: 10
Period	· 2011. 05 ~ 09
Methods	· Interview/survey through direct visitation

Table 6. Core Quantitative Risk Factors

Engineering Phase	
E-01	Lack of engineering skills
E-02	Error in basic design
E-03	Error in construction design
E-04	Error in patent use
E-05	Delay in engineering cost payment
E-06	Software technology level
E-07	Software compatibility level
Procurement Phase	
P-01	Occurrence of procurement accidents
P-02	Delay in procurement cost payment
P-03	Unsuitable production of equipment
P-04	Change in equipment price
P-05	Change in procurement supply
P-06	Error in tariff cost estimation
P-07	Occurrence of equipment flaws
P-08	Change in procurement cost
Construction Phase	
C-01	Occurrence of rushed construction
C-02	Lack of temporary facilities
C-03	Occurrence of accidence
C-04	Change in material supply
C-05	Lack of labor work force
C-06	Lack of technical work force
C-07	Lack of subcontract technical skills
C-08	Delay in construction cost payment
C-09	Frequent design change
C-10	Occurrence of flaws

experienced individuals on construction projects were selected with a focus on their engineering, procurement, and construction tasks. The outline of the expert interviews is shown in Table 5.

The interviews were divided into primary and secondary interviews. Through the primary interviews, quantitative risk factors were investigated, and the results were integrated. In the secondary interviews, the primary interview results were randomly distributed to the same 30 experts; through crosschecking, the final core quantitative risk factors were then derived. The core quantitative risk factors derived by performing such procedures are shown on Table 6.

3.2 Analysis of Cost Variation Rate

To investigate the rate of variation in cost affected by the core quantitative risk factors, the triangular distribution, explained in section 2.2, was applied. This step applies the probability concept, since there is a lack of historical data on the effect of risk factors and variations in cost and the expert interviews were conducted experientially/intuitively. Additionally, as the range of cost variation was composed of the reduction bottom limit ratio, mean ratio, and increase top limit ratio, the triangular distribution model was applied. The triangular distribution is shown in Table 7.

Based on the triangular model, the rate of variation in cost affected by the core quantitative risk factors was assessed from the expert interviews. The experts selected for investigating the rate of variation in cost were the same ones selected for deriving the core quantitative risk factors. This was done to derive the reliable results for this study and to understand the characteristics of C-Project. The procedure is shown in Table 8.

The analysis of the rate of variation in cost affected by the core quantitative risk factors in the engineering, procurement, and construction phases is as follows: since the reduction bottom limit ratio is identified as smaller than the increase top limit ratio relative to the mean ratio, the distribution graph is distributed narrowly in the reduction bottom limit ratio direction and distributed widely in the direction of the increase top limit ratio. As explained in the introduction, the increase top limit ratio would be distributed more widely than the reduction bottom limit ratio because the optimal single project cost (the total project cost) did not consider risk factors.

The average variation ratios of the core quantitative risk factors during the engineering, procurement, and construction phases are analyzed by assuming the same weight value (the degree of importance) for all factors, without considering the weighted value (the degree of importance) of individual risk factors.

Table 7. Triangular Distribution Model

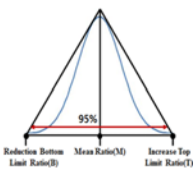
Triangular Distribution	Details
	Investigation standard of the rate of variation in cost affected by the core quantitative risk factors – Mean ratio (M): the standard of average impact affected by the risk factors predicted at the early project phase – Reduction bottom limit ratio (B): the lower value within the 95% confidence level when the effect of risk factors predicted at the early project phase is lower than the mean ratio – Increase top limit ratio (T): the upper value within the 95% confidence level when the effect of risk factors predicted at the early project phase is higher than the mean ratio

Table 8. Rate of Variation in Cost Analysis Result

Engineering Phase		Reduction Bottom Limit Ratio (B)	Increase Top Limit Ratio (T)
E-01	Lack of engineering skills	-1.60%	4.13%
E-02	Error in basic design	-1.30%	3.40%
E-03	Error in construction design	-1.30%	4.90%
E-04	Error in patent use	-1.60%	2.50%
E-05	Delay in engineering cost payment	-1.00%	2.80%
E-06	software technology level	-1.60%	2.10%
E-07	Software compatibility level	-1.60%	1.77%
	Average variation ratio	-1.43%	3.09%
Procurement Phase		Reduction Bottom Limit Ratio (B)	Increase Top Limit Ratio (T)
P-01	Occurrence of procurement accidents	-2.23%	4.30%
P-02	Delay in procurement cost payment	-1.33%	3.80%
P-03	Unsuitable production of equipment	-3.20%	6.13%
P-04	Change in equipment price	-2.47%	5.87%
P-05	Change in procurement supply	-2.33%	5.20%
P-06	Error in tariff cost estimation	-1.93%	3.33%
P-07	Occurrence of equipment flaws	-2.33%	4.33%
P-08	Change in procurement cost	-2.20%	5.67%
	Average variation ratio	-2.25%	4.83%
Construction Phase		Reduction Bottom Limit Ratio (B)	Increase Top Limit Ratio (T)
C-01	Occurrence of rushed construction	-2.53%	4.47%
C-02	Lack of temporary facilities	-1.53%	3.67%
C-03	Occurrence of accidence	-3.13%	6.40%
C-04	Change in material supply	-2.87%	6.73%
C-05	Lack of labor work force	-1.93%	4.20%
C-06	Lack of technical work force	-2.20%	3.47%
C-07	Lack of subcontract technical skills	-2.13%	5.87%
C-08	Delay in construction cost payment	-3.40%	6.20%
C-09	Frequent design change	-1.20%	2.73%
C-10	Occurrence of flaws	-1.33%	3.13%
	Average variation ratio	-2.23%	4.69%

4. Analysis of Probabilistic Cost Variation Range

4.1 Case Outline and Cost Investigation

Based on the results, the cost data was examined to identify the quantitative range of variation in cost. The analysis utilized three cases, similar to C-Project (gas plant) in terms of contract, size, region, and range of work, as the study's targets. The outline of the three cases selected is shown in Table 9.

The three cases selected were past gas plant projects operated in the Middle East by domestic construction companies. Since this data was from the past, it was converted to the present value (year, 2011), and the average cost was extrapolated. The average engineering, procurement, and construction costs of the three cases are summarized in Table 10.

The costs identified in the three cases include labor costs (domestic and overseas technical labor costs), outside order costs (related subcontract costs), and general costs (direct and indirect costs). A detailed explanation about the average cost analysis from the three cases follows.

In the case of engineering costs, the labor costs and outside order costs were identified as high. This was attributed to the fact that the domestic construction company, awarded the overseas

Table 9. Case Outline

Category	Case - 1	Case - 2	Case -3
Project	Gas Plant	Gas Plant	Gas Plant
Area	Middle East	Middle East	Middle East
Duration	2002.032004.05	2004.052007.09	2002.022005.10
Scope	E. P. C Phase	E. P. C Phase	E. P. C Phase
Contracts	Lump-Sum Turnkey	Lump-Sum Turnkey	Lump-Sum Turnkey
Total Cost Range	170,000 ~ 190,000		

Table 10. Average Cost Analysis Result (Unit: 1,000 USD)

Engineering		Average Costs	Ratio (%)
	Labor Costs	3,805	2.02%
	Outsourcing Costs	2,943	1.56%
	Overhead Costs	212	0.11%
	Total	6,960	3.70%
Procurement		Average Costs	Ratio (%)
	Labor Costs	3,631	1.93%
	Outsourcing Costs	72,449	38.50%
	Overhead Costs	8,863	4.71%
	Total	84,942	45.14%
Construction		Average Costs	Ratio (%)
	Labor Costs	10,472	5.56%
	Outsourcing Costs	79,258	42.11%
	Overhead Costs	6,563	3.49%
	Total	96,293	51.17%
Total Costs		188,195	100%

gas plant construction project, produced the basic blueprint of the plant facilities, while the detailed blueprint of the equipment, piping, and electricity that make up the plant was produced in collaboration between domestic and overseas specialty companies.

In the case of procurement costs, the outsourcing costs were identified as high. This was attributed to the fact that these costs included major equipment and piping materials as well as electricity for the plant, along with the production and procurement of specialized equipment. Additionally, equipment is sometimes produced overseas, according to the project owner's level of demand regarding specific materials and equipment. Therefore, the outsourcing cost was also identified as high.

In the case of construction costs, the outsourcing costs were identified as high. This was attributed to the inclusion of costs for all materials and equipment required for the architecture, civil engineering, piping, and electricity. The average engineering, procurement, and construction cost analysis result was used to assess the quantitative range of variation in cost affected by the core quantitative risk factors.

4.2 Analysis of Probabilistic Cost Variation Range

The analysis procedure for the probabilistic cost variation range affected by the core quantitative risk factors in the engineering, procurement, and construction phases is summarized in Table 11.

Table 12. Simulation Input Data (Unit: 1,000 USD)

Category	Reduction Bottom Limit Ratio (B)	Average Costs	Increase Top Limit Ratio (T)
Engineering	-1.43%	6,960	3.09%
Procurement	-2.25%	84,942	4.83%
Construction	-2.23%	96,293	4.69%
	↓	↓	↓
Category	Reduction Bottom Limit Costs(B)	Average Costs	Increase Top Limit Costs(T)
Engineering	6,861	6,960	7,175
Procurement	83,029	84,942	89,044
Construction	94,150	96,293	100,806
Total	184,040	188,195	197,025

For the analysis of the probabilistic cost variation range affected by the core quantitative risk factors, the Monte-Carlo Simulation, that included the "@RISK" program, was used. The input data for the Monte-Carlo Simulation are shown in Table 12.

The probabilistic cost variation range was assessed by using the quantitative cost variation range analysis result shown in Table 12 (the minimum cost, average cost, and maximum cost) as input for the Monte-Carlo simulation. The probability distribution for the analysis of the probabilistic cost variation range applied triangular distribution, as explained in Section 2.2. Additionally, the simulation iteration was set at 10,000. The probabilistic cost variation rate affected by the core quantitative risk factors, which is the result obtained through this procedure, is summarized in Table 13.

The analysis result can be explained as follows: The rates of variation in engineering, procurement, and construction costs were assessed to range from -1.95% to 2.49%, -3.07% to 3.91%, and -2.99% to 3.80%, respectively. A comparison between the probabilistic cost variation rate derived by the probabilistic range of the cost variation analysis result and the rate of variation derived from expert interviews is shown in Table 14.

In the case of the reduction bottom limit ratio (-range), the reduction ratio derived from the probability analysis is greater than that predicted through the interviews. This finding revealed that the reduction bottom limit rate had a wider range of variation when derived from the probability analysis than when derived

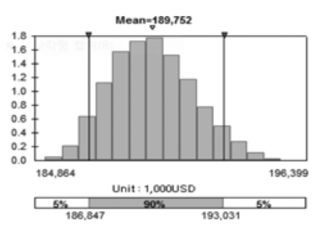
Table 11. Procedure of Probabilistic Cost Variation Range Analysis

Category	Details
Step 1: Deriving Core Quantitative Risk Factors	Through expert interviews/surveys, the core quantitative risk factors in the engineering, procurement and construction phase were derived
Step 2: Cost Variation Rate Analysis	Through expert interviews/surveys, rate of variation in cost affected by the core quantitative risk factors was analyzed (triangular distribution model applied)
Step 3: Cost Data Investigation	Cases similar to the analysis target were selected, and then, its engineering, procurement, and construction cost data were collected and analyzed
Step 4: Quantitative Cost Variation Range Analysis	The quantitative cost variation rate was analyzed using the cost variation rate and cost data
Step 5: Probabilistic Cost Variation Range Analysis	Probabilistic cost variation rate was analyzed using Monte-Carlo Simulation of the scenarios

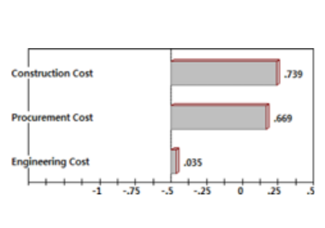
Table 13. Probabilistic Cost Variation Rate Analysis Result (Unit: 1,000 USD)

Category	Engineering	Procurement	Construction	Total
Minimum	6,862	83,046	94,177	184,864
Average	6,999	85,671	97,082	189,752
Maximum	7,173	89,020	100,768	196,399
Mode	6,960	85,167	95,507	186,392
5%	6,900	83,786	94,994	186,847
10%	6,917	84,101	95,343	187,377
20%	6,940	84,545	95,838	188,088
30%	6,957	84,886	96,218	188,642
40%	6,974	85,196	96,560	189,162
50%	6,991	85,531	96,930	189,655
60%	7,011	85,902	97,339	190,148
70%	7,033	86,323	97,803	190,703
80%	7,059	86,822	98,354	191,351
85%	7,074	87,120	98,682	191,769
90%	7,093	87,473	99,072	192,301
95%	7,117	87,933	99,580	193,031

Distribution Graph



Sensitivity Graph



from the interviews. However, in the case of the increase top limit ratio (+range), the range of variation derived from the probability analysis is smaller than that derived from the interviews. This result revealed that the increase top limit ratio had a narrower range of variation when derived from the probability analysis than from the interviews.

Hence, the probabilistic cost variation range analyzed using Monte Carlo simulation (with N number of simulations) and the variation range analysis indicate that if the impact of risk factors predicted at the initial stage of the project is less than the average impact (average ratio), the reduction range is wide, whereas if the value is higher than average, the range is narrow.

4.3 Application of Analysis Result and Analysis Model

The results of the core quantitative risk factors with consideration of the engineering, procurement, and construction phases are used to distinguish in advance the risk factors that have a high impact on project costs. Additionally, the results of the probabilistic cost variation range analysis can be used as decision-making data for profit prediction and economic analysis with consideration of the impact of risk factors at each phase of the project.

The model built in this study can be used for the research and development of risk and cost analysis tools. Such tools can reflect the type of project (plant type), characteristics (size, region, etc.), and project costs. From such tools, a result that is suitable for a client's purpose can be derived. A standard analysis tool can be constructed through continuous research and development after starting from a prototype model. Additionally, when this tool is interconnected with the Web, it can be used in real-time, depending on the client's request.

Therefore, the results of this study can provide a reference for analyzing and predicting the occurrence and impact of risk factors, as well as for establishing a response plan to minimize the financial loss caused by the effect of such risk factors.

5. Conclusions

This study, which targets overseas gas plant construction projects, was conducted to assess the probabilistic cost variation rate affected by core quantitative risk factors. To facilitate the study, C-Project, which is scheduled to be completed in country U by a domestic construction company, was selected for the analysis. With consideration of the project's characteristics, core quantitative risk factors were derived, and the rate of variation resulting from the effect of these characteristics on project costs was analyzed. Thereafter, three cases that were similar to the analysis target were selected, and their cost data were investigated.

The derived core quantitative risk factors, the analyzed cost variation ratio, and the cost data were used to assess the quantitative cost variation range. Monte Carlo simulation was then used to analyze the probabilistic range of cost variation affected by the core quantitative risk factors. The results derived from the study are summarized below. (1) According to the results obtained by deriving the core quantitative risk factors, seven factors in the engineering phase, eight in the procurement phase, and ten in the construction phase are highly likely to occur and would have a significant impact on cost variation. (2) According to the results obtained by analyzing the probabilistic range of cost variation affected by core quantitative risk factors, the engineering cost had

Table 14. Cost Rate of Variation Comparison Result

Category	Expert Interview/Survey		Probabilistic Range of Cost Variation		Comparison Result	
	Reduction Bottom Limit Ratio (B)	Increase Top Limit Ratio (T)	Reduction Bottom Limit Ratio (B)	Increase Top Limit Ratio (T)	Reduction Bottom Limit Ratio (B)	Increase Top Limit Ratio (T)
Engineering	-1.43%	3.09%	-1.95%	2.49%	-0.52%	0.60%
Procurement	-2.25%	4.83%	-3.07%	3.91%	-0.82%	0.92%
Construction	-2.23%	4.69%	-2.99%	3.80%	-0.76%	0.89%

*Analysis Result: Expert interviews (B/T) and Probabilistic range of cost variation (B/T) a range of -1.95% to 2.49%, procurement cost had a range of -3.07% to 3.91%, and construction cost had a range of -2.99% to 3.80% relative to the average cost. The total project cost was then assessed to be within the range of -2.58% to 3.50%.

The proposed analysis model and analysis result can be used as decision-making information to minimize the financial loss incurred because of the effect of these risk factors. Furthermore, the uncertainty over the effect of risk factors can be analyzed and assessed in advance.

This study has certain limitations. The cost variation analysis should consider the weighted value (the degree of importance) of individual risk factors during the engineering, procurement, and construction phases. Moreover, the gas plants studied are located in the Middle East. Therefore, a study that considers diverse regions and diverse plant construction projects is required. Furthermore, a study of the risks and costs, with consideration of the life cycle of a plant construction project, is likewise necessary.

Acknowledgements

This research was supported by a grant from the LNG Plant R&D Center funded by the Ministry of Land Transportation and Maritime Affairs(MLTM) of the Korean Government.

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