STAGE-GATE PROCESS INTEGRATED RISK MANAGEMENT FRAMEWORK FOR OVERSEAS LNG PLANT PROJECTS

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ABSTRACT: The demand of Liquefied Natural Gas (LNG) is on a steady increase, and the estimation of world LNG consumption will be doubled by 2030 compared with 2005. In the wake of increasing demand, numerous LNG plant projects are under construction and many new projects are in the planning stage. However, since there are limited numbers of companies that have a full capability of core technologies and licenses related with LNG plant construction, companies that are less experienced in LNG plant projects suffer from a lack of project management ability, such as process planning, schedule management, and risk management particularly for early stage of project initiation. A number of researches have highlighted the importance of the early design phase in EPC-type plant projects and its consequential impact on project performance. Therefore, this study aims to develop a risk management system to support an efficient decision-making process during the design phase. The research procedure consists of three parts. First, we identified a total of 82 design risk factors composed of typical risk items related to any plant projects and LNG-specified design risks. Second, we developed a risk management framework based on the stage-gate process, composed of three sub-stages: Pre-stage, On-stage and Post-stage of each sub-design phase. Finally, we applied this procedure to plant layout stage. This study is expected to support better decision-making in the design phase of overseas LNG plant projects by integrating the stage-gate process and risk management cycles for making prompt "go/no-go decisions" on the key decision checkpoints.

Keywords: *Liquefied Natural Gas (LNG), Risk Management Framework, Stage-gate Process, Design Phase*

1. INTRODUCTION

The demand of Liquefied Natural Gas (LNG) is on a steady increase, and the estimation of LNG consumption will be approximately doubled by 2030, compared with 2005 [7]. According to Kyoto Protocol, because natural gas produces less carbon dioxide when it is burned than other resources, many governments carry out national policies to reduce greenhouse gas emissions. This may encourage the use of natural gas to replace other fossil fuels [9]. Thus, many LNG plants are now under construction and will be further delivered around the world. For this reason, many global firms, including Korean contractors, are seeking the greatest opportunities in LNG plant projects. Although leading global contractors contain core front-end engineering & design techniques and other relevant licenses, many other contractors are still suffering from a lack of design technique and risk management ability at the pre-project planning & design phase, which is a higher value-added area in the project life cycle.

In general, engineering designs have a strong effect on the overall project costs, and frequently, an unsatisfactory design performance can lead to cost overrun and time delay at the downstream phases [1]. Therefore, the design quality is very imperative in securing the positive outcomes in the whole project life cycle.

The characteristics of LNG plant projects can be summarized as a mix of complexity and diversity of a number of activities. Since many areas, such as mechanical, piping, instrument, electrical, civil and architecture are involved, the connectivity of each activity is very crucial for the success of a project. Thus, the LNG plant projects are exposed to more various and complex risk factors than other construction projects. For this reason, LNG plant projects require considering more detailed risk factors and a tailor-made risk management framework, which are able to reflect the inherent attributes of LNG plant projects.

However, previous studies are lacking in covering these requirements, because they have more focused on general type of construction risks only. These studies identified risk factors based on extensive literature reviews. Some researches focused on categorization of risks in contract phase [6], [15], while others concentrated on identification of delay factors using expert interview or analysis of each phases in construction projects [11], [12]. Also, several studies have been conducted to investigate cost overrun risk factors in overseas construction projects [4], [5]. Another study on LNG plant risks is commonly concentrated on one area, such as safety issues, it cannot cover overall aspect of LNG plant projects [14]. Therefore, this study aims to develop a risk management system to support an efficient decision-making process during the design phase, covering overall attributes and areas of international LNG plant projects.

2. RESEARCH APPROACH

For the purposes of constructing a risk management framework for LNG plant projects at the all design phase, this study firstly identified risk factors by reviewing the literature and firm's internal reports regarding plant design risks, and eliciting expert opinions, including general construction risks and LNG-specific risks. We then composed a three-staged risk management process for each key gate: Pre-stage, On-sage and Post-stage.

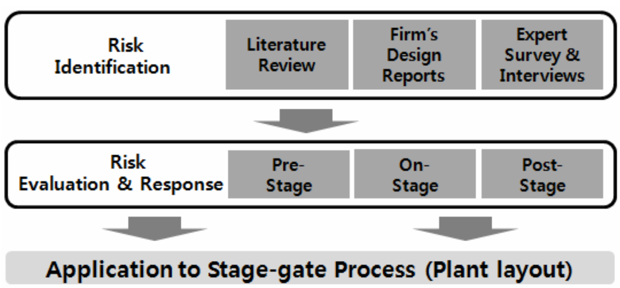

Fig. 1 Research procedure

At the Pre-stage, risk priority is determined by using the Probability-Impact-Coordination (PIC) method. At the On-stage, risk factors, which are ranked as high priority, are managed periodically to reduce the risk level. At the Post-stage, a total risk assessment index is proposed to assess the effect of risk mitigation strategies. Then, this framework is used at the key stage-gate process to support "go or no-go decisions" on the key decision checkpoints of design phase (see Figure 1).

3. RISK IDENTIFICATION

Because overseas plant projects are influenced by the various risk factors, it is very important to understand the target or objective of risk management by identifying risk factors [5], [10]. Firstly, we set up the purposes of risk management for LNG plant projects at the design phase, as follows: 1) compliance with requirement of the host country, such as design criteria and license, 2) prevention of cost increases and quality decreases due to design change, 3) reduction of contract and claim, related to design change, 4) quality management of facilities to acquire performance standards, and 5) management of the design package's interface and connectivity. Based on the purposes of risk management, risk factors were grouped according to specific criteria and sub-criteria considering their level of detail. Risk factors are broadly grouped into general design risks and LNG-specific design risks.

To identify the risk factors, we analyzed existing literature and several firms' design reports related to LNG projects. Especially, LNG-specific design risk factors are identified by 15 expert surveys and 10 expert interviews to reflect the in-depth experience and know-how of practitioners. These experts have been experienced in the construction field more than 10 years. Next, factors referred frequently in existing materials were arranged and similar factors were combined again. Additionally, we conducted follow-up expert interviews to revise classification of risk categories and verify practical usability of risk factors.

Finally, this paper identified a total of 82 risk factors composed of 46 general design risks and 36 LNG-specific design risk factors. General design risk factors were categorized into four main categories, such as host country condition, contract and claim management, and duration &

Table 1 Risk factors at design phase

Level 1	Level 2	Level 3	Level 4 (Risk Factor)
General Design Risk	Host Country Condition	Requirements of Host Country	Lack of reflecting of owner's technical requirement
			Lack of reflecting [safety, environment, quality] criteria
		Conditions of Host Country	Lack of reflecting site information(Soil condition)
			Lack of reflecting local climate
	Contract & Claim Management	Properties of Construction	Difference between provided information and site condition
			Reflection of unsuitable special component
		Contract Factors	Difficulty in acquiring license
			Possibility of adding additional license and loyalty
	Duration & Cost Management	Duration	Lack of workability
		Cost	Lack of reflecting cost
	Outsourcing & Collaboration Management	Connection with Headquarter	Lack of reflecting similar experience of headquarter
		Capability of Project Manager	Lack of reflecting similar experience of PM
		Personnel Management	Lack of reflecting similar experience of employee
		Local Subcontractor	Lack of reflecting similar experience of local subcontractor
		Capability of JV & Consortium	Collaborative design with contractors in JV and Consortium
LNG-Specific Design Risk	Design in common	Common Factors	Inconsistence of code and spec
			Lack of connectivity of other equipment
	Basic Design	FEED	Inconsistency between material balance and PFD
			Lack of reflecting stability of equipment
		Liquefaction Process	Lack of maintaining the temperature of liquefaction
	Detail Design	Mechanical	Suitability of capacity of equipment
		Piping	Lack of considering shrinkage and relaxation
		Instrument	Inadequate location of measuring instrument
		Electrical	Instability of electric power supply
		Civil & Architecture	Insufficient reflection of structure size or earthquake factor
		Low Temperature Materials & Equipment	Lack of reflecting heavy material's condition
			Lack of reflecting impact to other process

[All risk factors are not included due to space limitation]

cost management. Also, LNG-specific design risk factors were categorized into three main categories, such as design in common, basic design and detail design. These categories are further partitioned into eight sub-categories such as FEED, liquefaction process, mechanical, piping and instrument. Table 1 shows the risk factors for LNG plant projects that can be exposed at the design phase.

4. RISK MANAGEMENT FRAMEWORK

4.1. STAGE-GATE PROCESS

The-stage gate process was firstly introduced by Cooper in 1986 and is a conceptual and operational roadmap for moving a new product project from idea to launch. Stage-gate divides the overall process into distinct stages, separated by management decision gates [2]. In the stage-gate process, every stage can act as a series of activities and gates can play as decision checkpoints.

Figure 2 shows an example of the stage-gate process integrated with risk management process at the design phase. First, risk factors suitable for each stage-gate are extracted out of the 82 total risk factors to manage the following 3 stages. At the Pre-stage, risk priority is determined by using the PIC method (refer to equation 1) to select more critical risks, which require more intensive monitoring and controlling due to a high level of risk exposures. Then, the periodic risk response and mitigation strategies were conducted for the registered factors to reduce the risk level at the On-stage. At the Post- stage, the total risk assessment index was calculated by comparing the risk score at the Pre-stage with the On-stage to determine whether the design process can proceed to next stage or not. If the total risk assessment index does not meet the minimum criteria, the risk evaluation process is repeated again to reduce the risk level at the checkpoint.

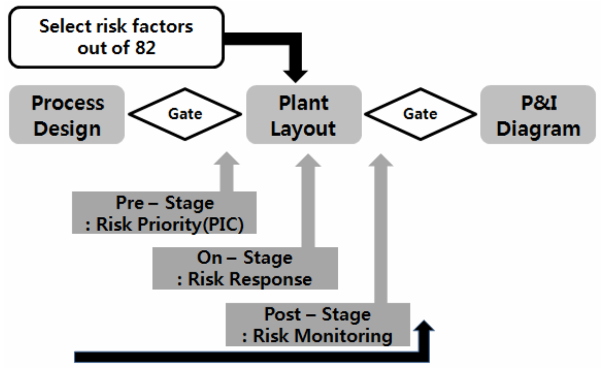

Fig. 2 Stage-gate process based risk management

4.2. PRE-STAGE: RISK PRIORITY

The most common and popular method to determine relative priority among risk factors is the Probability-Impact (PI) method. This method determines priority by using two criteria, probability and impact [13]. However, since using two criteria limits the characteristics of risk into only probability and impact, it lacks in perceiving the actual degree of risk loss [5]. Cox (2008) also presented some limitations of the PI method, which is of poor resolution, error-prone, suboptimal risk allocation and ambiguous input and outputs [3]. Particularly, the PI method is limited to apply for LNG plant projects, because the plant projects require having a more detailed risk priority method considering its diverse and complex characteristics. In LNG plant projects, activities are organized along the lines of projects with contractual links between all parts of the links [8]. Therefore, it is essential to communicate, coordinate, and adjust between every part for acquiring connectivity between loads of activities. For this reason, we added one supplementary dimension, ambiguous input and outputs [3]. Particularly, the PI method is limited to apply for LNG plant projects, because the plant projects require having a more detailed risk priority method considering its diverse and complex characteristics. In LNG plant projects, activities are organized along the lines of projects with contractual links between all parts of the links [8]. Therefore, it is essential to communicate, coordinate, and adjust between every part for acquiring connectivity between loads of activities. For this reason, we added one supplementary dimension, coordination index (CI), to existing probability and impact for quantifying risk priority [10]. The coordination index can be defined as the number of sub-activities, sub-processes and experts required to solve problems. We can intuitively understand that the more the experts, activities and processes are required, the more the time and effort are consumed to solve problems. So far, these risk factors should be handled in advance earlier than others, if the probability and impact remain same. The proposed PIC method in this research is shown in Equation 1.

The experts who involved in the interviews agreed that the PIC method can identify the risk priority, which cannot be distinguished by using the PI method. Also, it can help the optimal allocation of resources to solve problems by providing a detailed risk priority.

$$PIC\ risk\ priority = \sqrt{P^2 + I^2 + C^2} \quad \text{...........} \quad (1)$$

P: Probability, I: *Impac*t, C: *Coordination*

Based on Equation 1, risks that have high values are recognized as top priority factors and these risks need to be carefully managed in the following step, On-stage.

4.3. ON-STAGE: RISK RESPONSE

To manage risk factors, it is crucial, not only to determine risk priority, but also to present a risk response plan. At the On-stage, a registered factor, which is considered a relatively high risk priority compared with others, should be monitored periodically. Overall, we proposed responsibility and a detailed action plan to systematically manage risk factors. The risk response plans for each of 82 risk factors are linked together in our framework.

Figure 3 displays an example of the managing registered factors. If a risk factor, “insufficient reflection of structure size or earthquake factor”, is assessed as a high risk factor at the Pre-stage, it is registered at the On-stage to monitor and reduce the risk level. Next, a design manager is nominated as the person in charge to assume responsibility for this risk factor. Also, the detailed responsible person is selected for each action. For example, a designer takes action to reduce risk levels such as “review on host country’s safety standards” and “review on distance length of layout.” After taking action, the risk level is re-evaluated

Registerd Factor	Pre stage PIC	Overall Responsibility	Action Plan		On-stage PIC			
			Responsibility	Action	Cycle	1st	2nd	3rd
Insufficient reflection of structure size or earthquake factor		Design Manager	Procurement manager	Suitability of Equipment	1 week			
			Designer	Review on host country's safety standards				
			Designer	Review on distance length of layout				

Fig. 3 Example of risk response plan

by using the PIC method until the risk level is lowered to a desirable threshold.

4.4. POST-STAGE: RISK ASSESSMENT

This stage evaluates the degree of risk reduction by using a summation of PIC scores that are evaluated at the Pre-stage and On-stage. In this research, a total risk assessment index (TRAI) is designed to assess the degree of risk reduction. Equation 2 shows how the degree of risk reduction is calculated. The TRAI is defined as a ratio of the sum of the PIC score at the Pre-stage and the sum of the PIC score at the On-stage. Thus, the lower the total risk assessment index is, the better the risk reduction is.

$$Total\ Risk\ Assessment\ Index = \frac{\sum PIC_{on-stage}}{\sum PIC_{pre-stage}} \ldots (2)$$

This index may be utilized to support decision making at the key checkpoints whether to go to the next step of design process or not.

5. APPLICATION

In order to describe the overall procedure of risk management, we applied our framework to the plant layout stages. In this application, PIC score for the pre-stage was calculated based on the 15 expert surveys while PIC score of the On-stage was determined based on hypothetical assumption. First, the 18 risk factors that are considered as important factors at the plant layout stage are drawn from the 82 risk factors. Then, the risk management framework is applied to the three consecutive stages with the selected 18 risk factors. In Pre-stage, the five risks that have high PIC score are registered as top priority factors that require intensive management in the following step (see Table 2). In On-stage, experts are assigned to each of the five factors and they are monitored periodically to reduce risk level. Finally, The TRAI is calculated to assess the degree of risk reduction. Based on the expert opinion, if the TRAI is computed to be higher than 0.6, risk is considered to impose significant threat and thus requires to be dealt with before proceeding to the next stage. Since the TRAI is calculated as 0.56 in the plant layout stage, the process can proceed to the P&I Diagram stage as shown in figure 2.

Table 2 Application to plant layout stage

Registered factor	PIC (Pre-stage)	PIC (On- Stage)
Lack of reflecting duration	6.324	3.464
Lack of reflecting quality criteria	6.067	4.690
Lack of reflecting cost	5.816	3.000
Lack of reflecting safety criteria	5.384	3.464
Lack of reflecting design change	5.313	2.449
...	…	…
Sum	78.363	43.557
Post-Stage (TRAI)	43.557/78.363 = 0.56	

6. CONCLUSION

In the wake of increasing demand, numerous LNG plant projects are under construction and many new projects are in the planning stage. However, many companies are suffering from a lack of project management capability such as process planning, schedule management, and integrated risk management with the key decision points. This paper identified risk factors and developed an integrated risk management framework for LNG plant projects at the design phase.

This framework is expected to support contractors to proactively manage design risks and effectively decide a go/no-go at the key decision checkpoints. However, this study does not consider owner's and licenser's perspective to manage risk factors at a broader aspect. Also, a case application to real LNG project is required to validate its usability and usefulness. The future research will concentrate on a case application to verify applicability of the proposed framework. Also, this risk management framework will be extended to include the whole integration of stage-gate process and risk management cycles covering design, procurement, construction, and commissioning phase of LNG plant projects.

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