Quantitative schedule and cost risk analysis for Nuclear Fuel Plant Construction: A Korea case

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1. Introduction

In the traditional nuclear power plant market, it was common for initial cores and some reloads for new plants to always be supplied from plant vendor. However, beyond this initial period, a competitive markets have recently been developed in which NPP owners are able to switch fuel suppliers, and all the main vendors have the potential to supply fuel for most light-water reactors. For instance, The Czech Republic has changed its fuel supplier for Temelin NPP from its existing Russian fuel company, TVEL, to Westinghouse in the U.S. and Framatome in France, and will supply it for more than 10 years from 2024.[1] In another case, Bulgaria, the fuel supplier of the Kozloduy NPP was changed from Russia to Westinghouse, and supply is scheduled to begin in 2024.[2] As sources of nuclear fuel diversified, interest in its own production for nuclear fuel in countries with NPP increased, which could lead to exports from countries with nuclear fuel plants. In fact, some countries with nuclear power owners, such as Ukraine and the UAE, are promoting the construction of their own nuclear fuel plants. These changes in the nuclear power industry environment can have a positive impact on the competitiveness of Korea's nuclear power plant exports, which is a country with nuclear power plants and nuclear fuel plants, and it means that Korea can also export nuclear fuel plants. Korea has already had numerous nuclear power plant construction experiences and is in a world-class position in nuclear power plant exports, but has no experience in exporting nuclear fuel plants, and only domestic construction experience. Therefore, this study analyzed the schedule and cost risks of power plant construction by referring to the recent expanded nuclear power plant construction in Korea, identified weaknesses or strength factors in Korea's nuclear power plant construction exports in the future, and checked matters to be considered for nuclear power plant construction exports.

2. Literature Review

There are many forms of construction delays that can hinder the success of a construction project. Construction project delays have the potential to have a number of dangerous effects and can negatively impact overall project performance. These impacts can cause a number of problems for the project, such as legal disputes, cost overrun, further project delays, lost productivity, financial losses, and contract failures.

Various studies have been conducted in different parts of the world to determine the main causes of delay. Hayssam et al. [3] identified the significant delay factor as slow decision making(confidence importance index (RII = 0.78), variation orders/change of scope during construction (RII = 0.72), and delay in payments by owner (RII = 0.72). Shah [4] examined case studies from three different countries and found that in Australia the most influential factors were lack of planning and scheduling, construction methods, and effective monitoring and feedback processes, while in Ghana, delays in payment certificates, underestimation of project costs, and project complexity. However, in Malaysia, inadequate planning by builders, poor site management and lack of experience of builders were the most influential factors. On the other hand, Rahman et al. [5] cited inflation and political instability as the main reasons behind Bangladesh's delay. From a global perspective, there are still common causes of delay, and in this paper, risks were set by referring to the common causes of delay mentioned above.[6,7,8,9,10]

3. Research Methodology

3.1 Create Project by Primavera P6

A virtual nuclear fuel plant construction project is created by Oracle's primavera P6 program with reference to Korea's nuclear fuel plant construction to define a work breakdown structure, set milestones, sequence activities, and accurately estimate resource requirements.

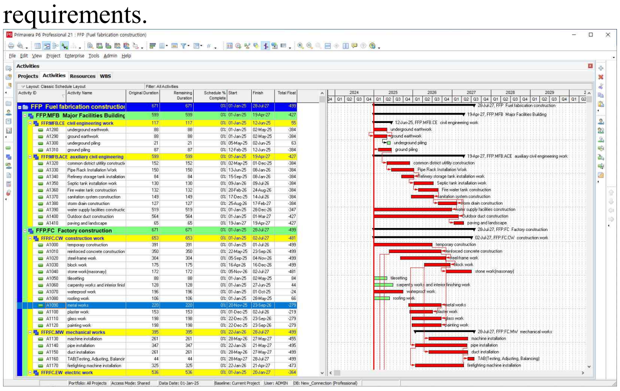

Fig. 1. Developing Nuclear Fuel plant construction project

3.2 Risk Identification and Assessment

The risks from the literature review are selected and the risks related to nuclear fuel plant construction project are defined by interviewing the project team in charge of nuclear fuel plant construction in Korea. Then, risks for this study are defined by integrating and organizing these risks.

Table I : Major risk items

No.	Risk Item
1	Delay of equipment design
2	Delay of procurement
3	Permission of redesign
4	Reconstruction
5	Lack of project experience
6	Ineffective planning and scheduling of project
7	Weather effect
8	Environmental restrictions
9	Miscommunication between design and construction
10	Unclear and inadequate details in drawings

3.3 Quantitative Risk Analysis

Nuclear fuel plant construction delays and cost impacts due to derived risks are analyzed through the Primavera Risk Analysis Program.

The selected risk is used for analysis by assuming the changed score after mitigation after risk scoring that quantifies the frequency and impact of the risk by constructing a risk matrix. Among the risks, there may be risks that affect only specific activities.

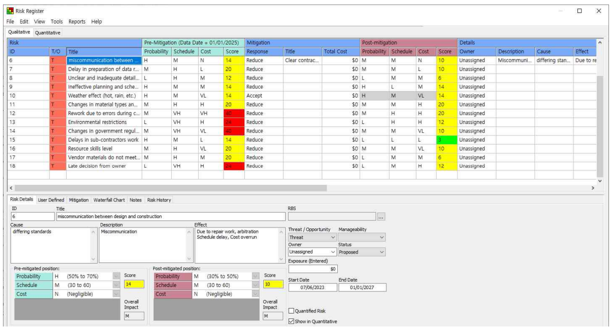

Fig. 2. Risk Scoring

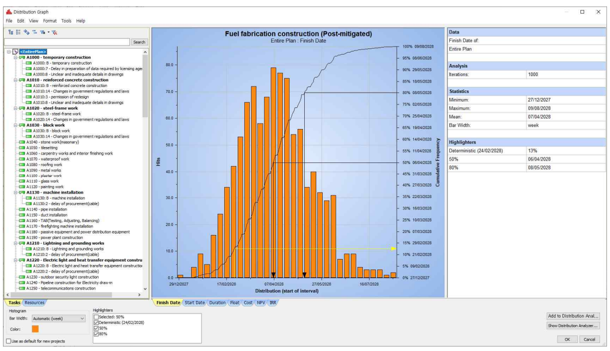

Fig. 3. Build impacted risk plan

4. Result

4.1 Schedule Delay Analysis

The project created for this paper consists of 90 activities, and the project was organized by referring to Korea's nuclear fuel plants construction. Therefore, the construction of facilities and buildings related to the back-end fuel cycle, which is a cycle that Korea cannot handle, was excluded from this study. In addition, some activities were also excluded from the composition of the project because it was impossible to fully disclose the Korea's nuclear fuel plant construction process to the public.

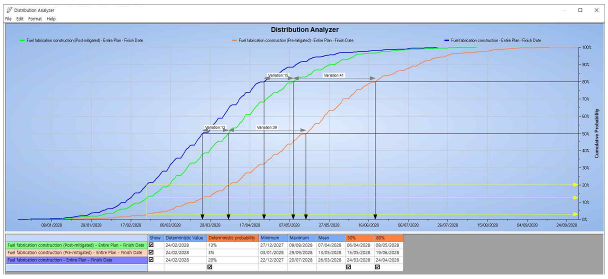

Fig. 4. Analysis and comparison of schedule delay before and after mitigation

Table II: Result of Schedule Delay Analysis

Duration(Day)	Min.	Max.	50%	80%
Pre-mitigated	1,098	1,368	1,231	1,266
Post-mitigated	1,091	1,317	1,192	1,224
Zero risk(Original)	1,150			

As a result of Schedule Delay Analysis, finish date applied pre-mitigation is resulted as Jun 19, 2028(1,266 days) with an 80% probability, which is different from the original finish date of Feb 24, 2028(1,150days).

Compared to the original schedule, the risk-reflecting schedule was 116 days behind the original schedule and was analyzed as being able to shorten the 40-day schedule delay through post-mitigation.

4.2 Cost Overrun Analysis

Like the activity that constitutes a schedule, there are limitations in defining the cost of the activity. Although the construction of a nuclear fuel plant in Korea was referenced, detailed construction costs could not be disclosed to the public, so construction costs were assumed by referring to interviews with nuclear fuel plant construction managers. In addition, the cost required for each activity varies depending on the characteristics of the activity or the technical skills of construction workers, but the impact of risk on the cost can be analyzed, so a certain cost was applied to the same category of activity in this study.

Fig. 5. Analysis and comparison of cost before and after mitigation

Table III: Result of Cost Analysis

Cost($)	Min.	Max.	50%	80%
Pre-mitigated	253,389,468	316,574,676	284,210,668	292,944,168
Post-mitigated	256,258,397	308,015,519	278,107,377	285,733,778
Zero risk (Original)	265,432,000			

From a cost point of view, the cost with pre-mitigation is $292,944,168 with an 80% probability, which is an increase compared to the original cost of $265,432,000 and the cost with post-mitigation is $285,733,778 which is also increased compared to the original cost. However, due to the effect of mitigation, it can be seen that certain costs are reduced and the schedule is optimized.

5. Discussion

The purpose of this study is to define the risks that may occur in the construction of a nuclear fuel manufacturing plant and to find out how the risks derived through virtual project simulation affect the project schedule and cost. Project simulation can vary depending on which risks are defined, and the defined risks include project delivery methods (Design-Bid-Build, Turn-key, etc.), construction permits, construction experience, labor skills, etc. Or it may change depending on the external environment. The risks of constructing a nuclear fuel manufacturing plant in Korea are as follows.

First, Korea does not have much experience in constructing nuclear fuel manufacturing plants. Therefore, design changes and the resulting reconstruction were defined as the biggest risks. This risk mitigation will be possible if advanced design technology is secured.

Second, Korea has not localized the entire equipment required for nuclear fuel manufacturing and has a risk of equipment procurement. There is a need for construction competitiveness that can differentiate itself from countries with equipment manufacturing technology.

Third, there is a risk of procuring special raw materials (such as flame retardant cables, etc.). In the event of a delay in the supply and demand of special materials that need to be custom-made due to external environmental factors (ex. Covid-19, Ukrainian-Russian War), measures are needed to minimize this.

In addition to the risks covered in this study, Korea does not handle enrichment and back-end fuel cycles among the entire fuel cycle, and related construction technology is insufficient. Customized export strategies based on construction competitiveness in the fields handled by Korea should be considered.

6. Conclusion

In this study, the post-mitigation cost was less than the pre-mitigation cost, and the post-mitigation schedule was shorter than the pre-mitigation schedule. In general, construction costs such as manpower and equipment are increased to shorten schedule delays, and schedules are often prioritized over costs for various reasons from the perspective of overall project management, so shorter schedules are likely to cause cost overruns. However, this is a general case, and the results of this study may come out if the risks that have a significant impact on both schedule and cost are mitigated.

The limitations of this study, which are not applicable to the whole activities and actual costs that make up a construction project, are a good example of the limitations associated with the use of advanced risk management tools. Preparing and inputting basic data needed to use these tools is a challenging task, and the performance of advanced risk management tools depends heavily on this input data, so accurate data must be obtained.

This study derived and simulated risks based on projects conducted in Korea, and rather than focusing on how much schedule delay and cost overruns were reduced through risk management, it identified risks that could arise from exporting nuclear fuel manufacturing projects in Korea, and presented tools to help project managers and stakeholders identify and manage risks and uncertainties in advance.

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