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Prioritization of Delay Factors for NPP Construction Risk in International Project by Using AHP Methodology

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1. Introduction

Success in any project is measured by time, cost, and quality which show the performance of the construction parties involved. Completion time is particularly important and it is one of the performance measures of construction projects. Schedule delay can be defined as the time over run either beyond completion date specified in a contract or beyond the date that the parties agree upon for delivery of a project and it is considered as one of the leading common problem in construction projects. Schedule delay can lead to many undesirable effects on the project and its participating parties such as lawsuits between utilities and contractors, increased costs, loss of revenue and contract termination. To the utility, delay means loss of revenue while to the contractor, delay means higher costs because of longer work period, additional material cost, and extra labor cost. Successful management of project requires identification and evaluation of factors causing delay. It is crucial for the nuclear power plant project decision makers and management personnel to identify the actual factors of construction delay and their ranking in order to take preventive actions.

NPP project is complex in nature and the construction phase is one of the most key phase which is subject to many factors result from many sources. From experience, nuclear projects have faced challenges similar to other complex mega projects with additional nuclear specific issues and life time cost of nuclear reactor is concentrated upfront as capital cost, and therefore delays in construction may become intolerable in terms of both lost revenues and interest on the capital [1]. Budget over-runs and delays on next generation new build nuclear projects in recent years clearly demonstrate that the nuclear industry continues to repeat its failed management and project control processes of the past. Similar to major infra-structure projects, actual completion times can vary substantially from initial estimates but this uncertainty is too crucial to the nuclear industry due to high levels of capital at risk, for every year a project is delayed the levelized cost of electricity increases by approximately 8–10% [2].

The main objectives of this study are to identify the causes of delay, to develop a generalized AHP model for delay factors, and to prioritize the risk in different factors in various levels of construction phase in international turnkey NPP project.

This paper describes and prioritizes Nuclear Power Plant (NPP) construction schedule delay factor for turnkey international project. In this work, different levels of factors are grouped according to literature review process and discussions with nuclear industry experts. A questionnaire survey is prepared on the basis of Analytic Hierarchy Process (AHP) and expert judgments were taken for prioritizing the importance of the delay factors. By using Expert Choice 11 software, local and global weights of different main factors, sub factors and sub-sub factors are evaluated as well as sensitivity analysis is accomplished. This study finds top most important 10 sub-sub factors in the lowest level which are: uncompromising regulatory criteria and conflicting licensing documents with existing regulations, robust design documents review procedures, policy changes due to political instability and public intervention, worldwide shortage of qualified and experienced nuclear specific equipment manufacturer, delayed procurement of equipment and bulk material due to unavailability to the global market, redesign due to errors in design and design changes, late changes in the regulatory criteria, delayed in approval of design documents, economic crisis, and delayed procurement contract. This study also determines the different party's importance in percentage behind the construction schedule delay of NPP which constitutes main contractor (28.4%), regulatory authority (27.3%), financial and country factor (23.5%), and utility (20.8%). Decision makers of nuclear industry can understand the significance of different factors on NPP construction phase and they can apply risk informed decision making to avoid unexpected construction delay of NPP.

2. Selection of Contributing Factors to NPP Construction Delay

Many studies are conducted on the causes of delay in construction projects worldwide but it is rare to find research studies which deeply examines factors behind NPP construction delay. Main contractor, Utility, and regulatory authority are the three main actors in nuclear power project. These parties play crucial rule in the construction phase of NPP.

Pre-project activities, project decision making process, plant construction, plant operation and plant decommissioning are five distinct stages of NPP project. NPP construction phase is defined as the period immediately following the closure of a contract for the purchase of a NPP and ends with the completion of the commissioning stage of the plant and its acceptance which allows the Utility starting commercial operation which consists of five stages as follow as: (i) Preparation of site infrastructure (ii) Detailed design engineering (iii) Equipment and components manufacture (iv) Construction, erection and installation (v) Commissioning and plant acceptance [3].

In a turnkey contract, a fairly equal ranking, co-operative but business-like relationship between the Utility and the main contractor is highly desirable and licensing application group of utility need to develop close contact with the regulatory authority as early as possible to understand the requirements of the regulations and to avoid problems of misinterpretation later on. Typical lead responsibilities of different party in Turnkey project of NPP construction phase are given in the table I [3].

Table I: Typical lead responsibilities of different party in Turnkey project of NPP

Activity	Responsible Party
Pre-project activities	U
Project management	MC
Project engineering	MC
Quality assurance/quality control	MC + U
Procurement	MC
Application for license	U
Licensing	RA
Safeguard, physical protection	U
Manufacturing	MC
Site preparation	U or MC
Erection	MC
Equipment installation	MC
Commissioning	MC
RA: Regulatory authority, U: Utility, MC: Main contractor	

Inadequate completion of design and engineering work prior to start of construction is detrimental to the implementation of the project as per the schedule which delays the start of construction activities at full speed leading to reschedule manufacturing and construction steps making project management complicated. To avoid delay during construction, all three parties should be familiar with the safety requirements, licensing, regulatory oversight, and inspection practices in both the customer country and in the vendor country. It is necessary to recognize the different circumstances in each country for planning and scheduling of NPP Vendors of nuclear industry and their sub-contractors have lost much knowledge and skill due to experienced experts retirement and a new competency is required for the new technologies. Thus, vendors need to establish new sub-contractor networks from companies with proven skills to avoid delays and difficulties [1].

Start of construction before design completion, design flaws, non-uniform design, unwieldy licensing process and ever increasing regulatory requirements often changing in mid-course leading to regulatory turbulence caused significant construction delays of NPP which increase the cost [4].

The management of interfaces between design, material supply, construction and commissioning has the paramount importance of smooth construction of a nuclear project. There was slippage of schedules of NPP due to numerous revisions of design, site specific problems like excavation, initial concrete pour, component quality problems, transportation of major components to the construction site, procurement problems, lack of a well-developed supply chain, and lack of a fully integrated project schedule, incorrect construction techniques and faulty quality assurance paper work [5].

The main reasons for the delay of Olkiluoto 3 NPP project in Finland are as follow as: first of a kind project, ambitious original schedule, inadequate completion of design and engineering work prior to start of construction, a shortage of experienced designers, a lack of experience parties of managing large construction projects, delays in some heavy components' manufacturing processes, a worldwide shortage of qualified equipment manufacturers, delayed delivery of the construction plan to review, splitting construction plan in many batches, cultural differences in working practices, quality and timing deficiencies in the design documentation, cultural differences in working practices, construction problem due to local condition of Finnish climate, and communication gap among the parties [1,6].

Based on the literatures and discussions with nuclear industry experts and academics, a three level delay factors were prepared with the goal of NPP construction schedule delay risk which is shown in table II. Three levels are grouped by main factor, sub-factors and sub-sub factors. The first level is designed with 4 main factors. Among the four main factors in the first level, main contractor, utility, and regulatory authority are the main actors of nuclear industry in anywhere in the world and financial and country factor is preferred another main factor due to its importance in the NPP construction project.

Table II: Main, sub and sub-sub factors in different levels

Goal	Level 1 Main Factor	Level 2 Sub Factor (ID)	Level 3 Sub-Sub Factor (ID)
NPP Construction Schedule Delay Risk	1. Main Contractor	Inadequate completion of design before start of construction(MC1)	Redesign due to errors in design and design changes(MC11)
			Inadequate drawings and specifications(MC12)
			Shortage of experienced designer(MC13)
		Difficulties in managing the subcontractor chains (MC2)	Inexperienced subcontractor due to lack of nuclear specific practices(MC21)
			Frequent change of subcontractor because of inefficient work(MC22)
		Slow procurement, manufacturing of equipment and delivery to the site for installation(MC3)	Worldwide shortage of qualified and experienced nuclear specific equipment manufacturer(MC31)
			Delayed procurement of equipment and bulk material due to unavailability to the global market(MC32)
		Delayed progress of construction and commissioning related works (MC4)	Shortage of technical professionals due to experienced expert retirement and lack of new competency for advanced construction technologies(MC41)
			Inexperienced construction management team (MC42)
			Rework due to errors and quality control during manufacturing and construction(MC43)
	2.Utility	Improperly organized and delayed licensing application (U1)	Delayed in approval of design documents(U11)
			Delayed licensing application (U12)
		Delayed supervision of manufacturing, construction and commissioning activities(U2)	Design, materials and sequence of the work changes by utility(U21)
			Lack of coordination between central office and site office of utility(U22)
			Slow quality control procedures of utility(U23)
		Delay in utility's scope of supply items(U3)	Delay in material supply due to unavailability in the local market (U31)
			Lack of nuclear specific skilled workers(U32)
			Delayed procurement contract(U33)
		Slow decision making and delayed payment(U4)	Slow decision making due to poor project management system, inadequate planning and scheduling(U41)
			Inexperienced project management team(U42)
			Delayed payment by owner due to financial difficulties(U43)
	3.Regulatory Authority	Delayed regulatory approval (RA1)	Uncompromising regulatory criteria and conflicting licensing documents with existing regulations(RA11)
			Robust design documents review procedures(RA12)
		Regulatory inspection oversight(RA2)	Inexperienced regulatory inspection group(RA21)
			Late changes in the regulatory criteria(RA22)
	4. Financial and Country Factor	Country factor (FC1)	Policy changes due to political instability and public intervention(FC11)
			Lack of communication and coordination among the parties(FC12)
			Cultural gap and language barrier among the workforce(FC13)
			Unforeseen ground condition of site due to unexpected weather(FC14)
		Financial matters (FC2)	Poor economic condition(FC21)
			Inappropriate feasibility and economic analysis(FC22)
			Economic crisis(FC23)

The second level is designed with 12 sub factors. 4 from main contractor, 4 from utility, 2 from regulatory authority, and 2 from financial and country factor constitute twelve sub factors. Regarding the third and the bottommost level of this study, 32 sub-sub factors were considered which are thought as the root causes of NPP construction delay. Among these 32 sub-sub factors, 10 were associated to main contractor group, 11 were associated to utility group, 4 were associated to regulatory authority group, and 7 were associated to financial and country factor group. The table 2 shows the name of each factors, sub factors and sub-sub factors in different levels with their short identity.

3. AHP Model Development for NPP Construction Schedule Delay Risk Factor Prioritization

3.1. AHP Methodology

The Analytic Hierarchy Process (AHP) is developed by Saaty in 1980 which is one of the most popular and powerful multi-criteria decision-making technique. AHP is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales that measure intangibles in relative terms [7].

To make a decision in an organized way to generate priorities, AHP technique need to decompose the decision through following steps: Firstly, the problem is defined, and the scope of the problem is determined. Secondly, the well-structured hierarchy is formed with the goal at the top, then subsequent levels contain the factors and sub-factors while alternatives lie at the bottom of the hierarchy. Thirdly, a set of pairwise comparison square matrices is constructed with each element in an upper level is used to compare the elements in the level immediately below with respect to it by using the fundamental importance scale. Finally, the relative weights of the factor of each level with respect to a factor adjacent to upper level are computed as the components of normalized eigenvector associated with the largest eigenvalue of their comparison matrix. Then for each element in the level below add its weighed values and obtain its local and global priority. Global weights are calculated by multiplying the local weight with factors, sub factors and sub-sub factors. The composite weights of the decision alternatives are then determined by aggregating the weights through the hierarchy [8].

The pairwise comparisons are made using a scale of absolute judgments that represents, how much more, one element dominates over another with respect to a given attribute. The comparison of elements of matrixes with one another is made according to 1-9 scale of AHP [7].

Individual judgments from different experts can be aggregated to united judgment by different ways in AHP method. Aggregation of individual judgments (AIJ) and the aggregation of individual priorities (AIP) are widely used two methods in AHP while either an arithmetic or geometric mean can be used for AIP, but the geometric mean is more consistent with the meaning of both judgments and priorities [9].

In AHP, priority vector or principal eigenvector is obtained via the solution of the $(A - \lambda max\ I)\ W = 0$ equality. Where, A indicates pairwise comparison matrix, W indicates eigenvector and λmax indicates the maximum eigenvalue of matrix A. Principal eigenvector which is ultimate weight is calculated by multiplying the n elements of each row then take the nth root and finally normalized the result. Consistency ratio (CR) is the ratio of the consistency index for the set of judgments to the random index (RI) for the corresponding random matrix in AHP method. A CR value higher than 10% indicates that the judgments are at the limit of inconsistency and the weights may lead to imprecise conclusions. In that case, pairwise comparisons are required to be reviewed and renewed by the decision maker [7].

3.2 Framework for NPP Construction Delay Risk Factor Prioritization

In this study, three phases were used to accomplish this research. In the first phase NPP construction schedule delay factors in different level was finalized by literature review and discussions with the NPP construction professionals representing various stakeholders involved in in nuclear power project in Korea and United Arab Emirates. In the second phase, a pairwise questionnaire survey for AHP methodology has been conducted to find the importance priority of factors in each level of NPP construction delay for the turnkey international project. Heterogeneity of respondents is important criteria in capturing the impact of factor of different stages of NPP construction. Expert judgment was collected and matrix is formed. If any inconsistency occurs in the judgment matrix that specific responded judgment was not used for this study. Congregation was completed through geometric mean and final matrix was formulated for every level of factors. In the third stage, Expert Choice software was used to calculate local and global importance of each level of each factor and Sensitivity analysis was conducted. The study was concluded through discussions and with the proposal of future research. The figure 1 shows the framework for this study.

3.3 Hierarchical Structure of NPP Construction Schedule Delay Factor

The hierarchical structure in AHP may vary according to the complexity and nature of the problem and the number of factors, sub-factors, sub-sub factors. After the finalization of NPP schedule delay factors in different level, AHP hierarchy structure with the goal of NPP construction schedule delay risk is formed which is shown in the figure 2. In this study, the bottommost level constitutes sub-sub factors of NPP construction delay risk.

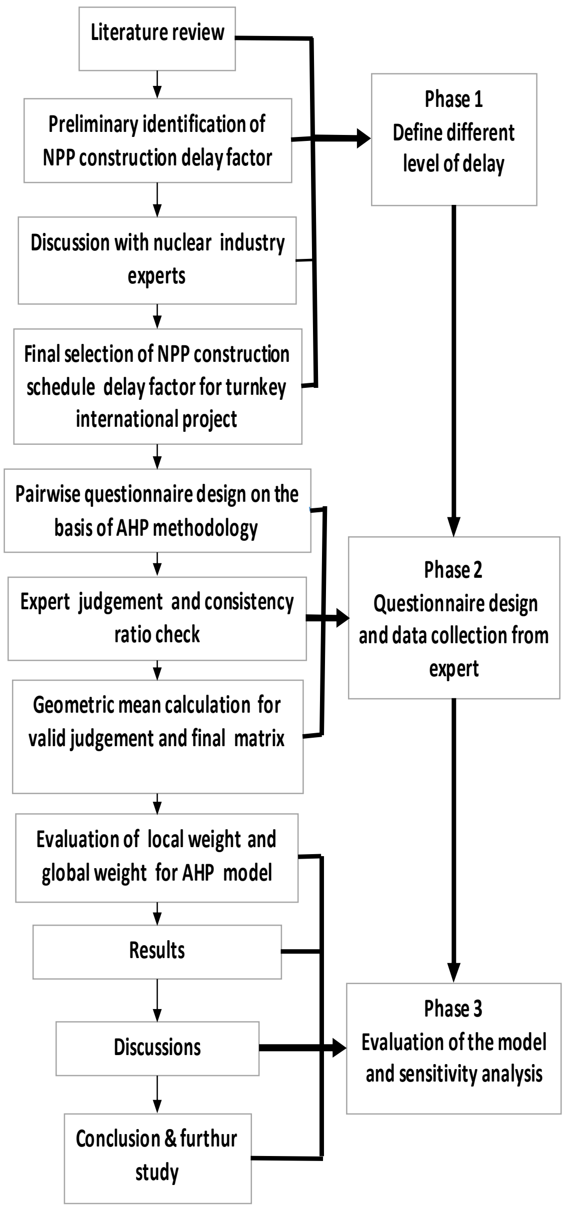


Fig.1. Framework for NPP construction delay risk factor prioritization

3.4 Questionnaire Design

A pairwise questionnaire was designed based on the delay factors considered and goal of this study which is the prioritizing of NPP construction schedule delay risk factors in different level through AHP model. The pairwise comparisons were made using a scale of absolute judgments from 1-9 that represents, how much more, one element dominates over another with respect to a given attribute in each level of hierarchy. The questionnaire survey was developed to get the expert judgment from the well and long experienced nuclear industry professionals. The questionnaire is classified into two sections which are as follow as:

- SECTION A: Profile of experts
- SECTION B: Expert judgment on different level of delay factor

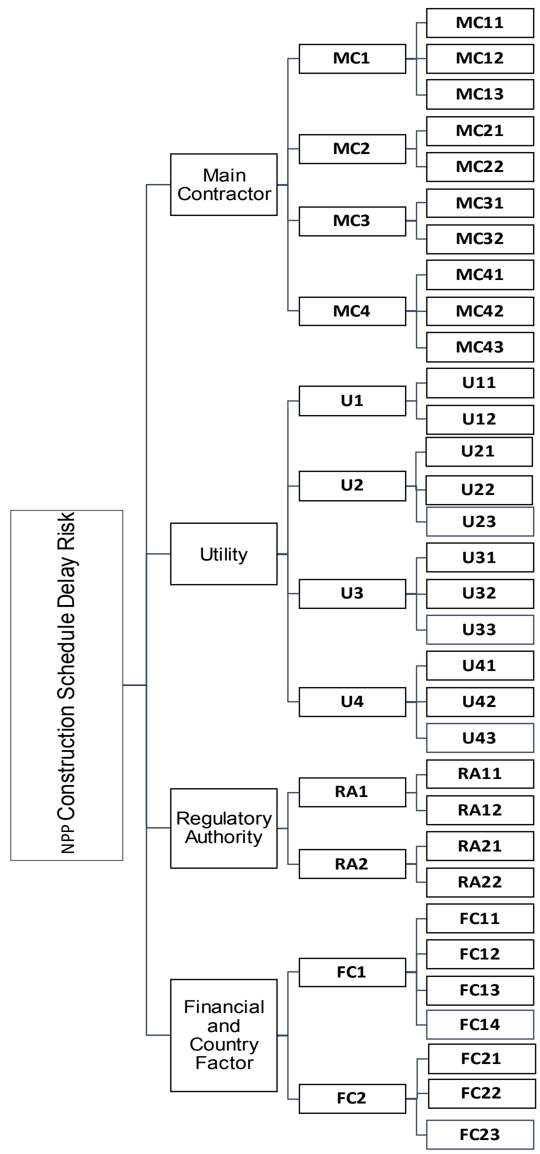
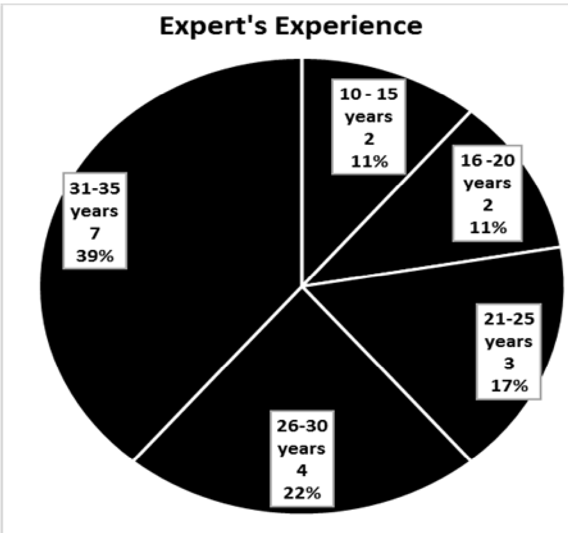


Fig. 2. Hierarchy structure of NPP construction schedule delay factor for turnkey international project

3.5 Expert Participation

This expert judgment survey is conducted by face to face survey and by email. A total of 20 questionnaires were sent to NPP industry professional who is currently involved Korean and overseas nuclear industry. Among the 20 questionnaire, 19 responses was received and 1 responses were not considered for this study due to inconsistency ratio was greater than 10%. Finally 18 expert's answer was used for this study. Concerning number of years involved in NPP industry, the experts have the following statistics: 11% of respondents have experience from 10-15 years, 11 % of those have from 16-20 years, 17 % of those have from 21-25 years, 22% of those have 26-30 years, and 39 % of those have from 31-35 years' experience. Regarding nature of works of NPP projects involvement, 34 % respondents were involved in construction industry, 33% respondents were involved in utility, 22 % respondents were involved in main contractor, and 11 % respondents were involved in regulatory authority. The figure 3 shows the characteristics of experts' for this study.



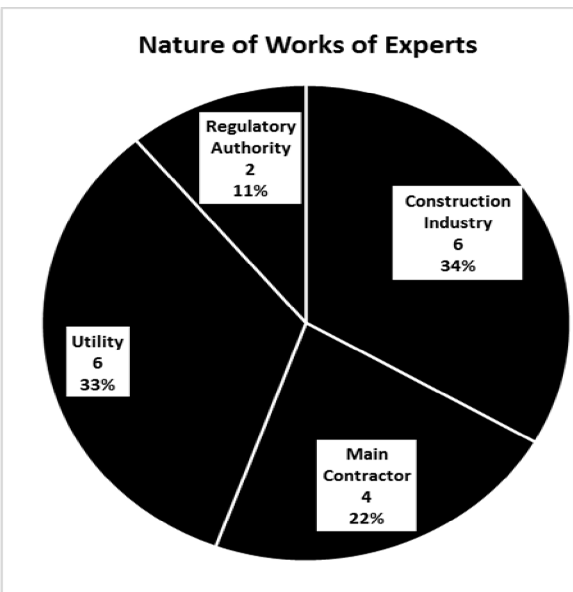


Fig. 3. Characteristics of experts

3.6 Calculation of Local Weights and Global Weights

After getting the survey result from each of the experts, inconsistency is checked through expert choice software. If the responses of the experts with inconsistency less than 10 % are found, that judgment are considered for this model and geometric mean was calculated. The geometric mean value for every pair were given input to the respective matrix and finally local weight and global weight are calculated for each factor of each level through expert choice software. Global weights are calculated by multiplying local weight with its previous level's factors. In this study, global weight of the lowest level-3 sub-sub factors' are calculated by multiplying corresponding local weights of level-3, level-2 and level-1.

4. Results

The table III shows the local and global weight of each factors in each level of the hierarchy structure of NPP construction schedule delay factor for turnkey international project. The table III also illustrates the ranking of sub factors and sub-sub factors according to global weight. Local weights indicate the relative importance levels of factors within the group they exist in and global weights point to the prioritizing of factors with respect to the main goal NPP construction schedule delay risk.

Overall inconsistency of this AHP model is 1.4% with respect to its main goal which indicates that the judgments are highly consistent

This study found that in the first level of main factors, main contractor with local weight of (0.284) had been prioritized as the first factors followed by regulatory authority (0.273), financial and country factor (0.235), and utility (0.208).

This study also found top most important five sub-sub factors in the lowest level which are: uncompromising regulatory criteria and conflicting licensing documents with existing regulations, robust design documents review procedures, policy changes due to political instability and public intervention, worldwide shortage of qualified and experienced nuclear specific equipment manufacturer, and delayed procurement of equipment and bulk material due to unavailability to the global market.

Table III: Local and global weights of schedule delay factors with rank

Factors	Local/ Global weight	Sub factors	Local weight	Global weight	Rank	Sub-sub factors	Local weight	Global weight	Rank
Main Contractor	0.284	MC1	0.328	0.093	3	MC11	0.391	0.036	6
						MC12	0.291	0.027	15
						MC13	0.318	0.030	11
		MC2	0.145	0.041	12	MC21	0.657	0.027	16
						MC22	0.343	0.014	26
		MC3	0.322	0.091	4	MC31	0.565	0.050	4
						MC32	0.435	0.040	5
		MC4	0.205	0.058	8	MC41	0.247	0.014	27
						MC42	0.337	0.020	22
						MC43	0.416	0.024	18
Utility	0.208	U1	0.290	0.060	7	U11	0.541	0.033	8
						U12	0.459	0.028	13
		U2	0.209	0.043	11	U21	0.492	0.021	21
						U22	0.231	0.010	32
						U23	0.277	0.012	29
		U3	0.261	0.054	9	U31	0.226	0.012	30
						U32	0.204	0.011	31
						U33	0.570	0.031	10
		U4	0.240	0.050	10	U41	0.359	0.018	24
						U42	0.359	0.018	25
						U43	0.282	0.014	28
Regulatory Authority	0.273	RA1	0.767	0.210	1	RA11	0.526	0.110	1
						RA12	0.474	0.100	2
		RA2	0.233	0.064	6	RA21	0.455	0.029	12
						RA22	0.545	0.035	7
Financial and Country Factor	0.235	FC1	0.664	0.156	2	FC11	0.538	0.084	3
						FC12	0.177	0.028	14
						FC13	0.166	0.026	17
						FC14	0.119	0.019	23
		FC2	0.336	0.079	5	FC21	0.298	0.024	19
						FC22	0.302	0.024	20
						FC23	0.399	0.032	9

5. Discussions

Prioritization is one of the most strongest and simplest decision making process and it turns to more powerful when judgment is made by the well experienced professionals in the respective field. Considering judgments of those who are directly involved in project management of the construction phase of NPP is an effective way to find out the important parameters for the determination of priority of risk factors for each level. Different factors, sub factors and sub-sub factors were defined for each level in this study. These classifications were mainly based on different literature review and discussions with nuclear industry experts.

In this study, in order to obtain more realistic and reliable comparison matrices, all experts' judgments were converted to group judgments by using geometric mean. Expert Choice software was then used to calculate the local and global weights in each pairwise comparison matrix and to conduct dynamic sensitivity analysis. Microsoft Excel was used to show the result and analysis of this study graphically. Overall inconsistency of this AHP model is 0.014 with respect to its main goal which is less than 0.10. It is concluded that pair wise comparison judgments to obtain the attributes weight are reasonably consistent.

The figure 4 shows the global weight in distributive mode of level 2 sub factors with respect to the goal of the developed model hierarchy in this study According to global weight, It is clearly demonstrates in figure 4 that the second level of sub factors, delayed regulatory approval (0.210) had been ranked as the first followed

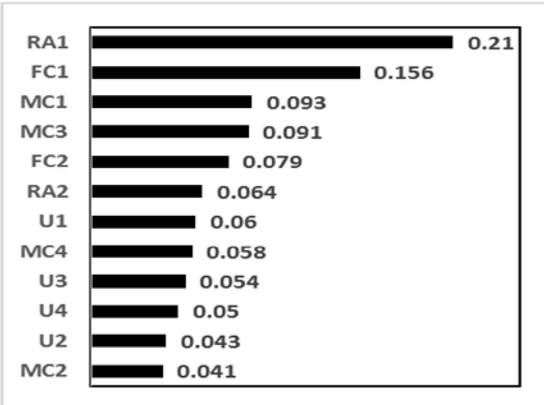


Fig. 4. Global weight level 2 sub factors with respect to goal

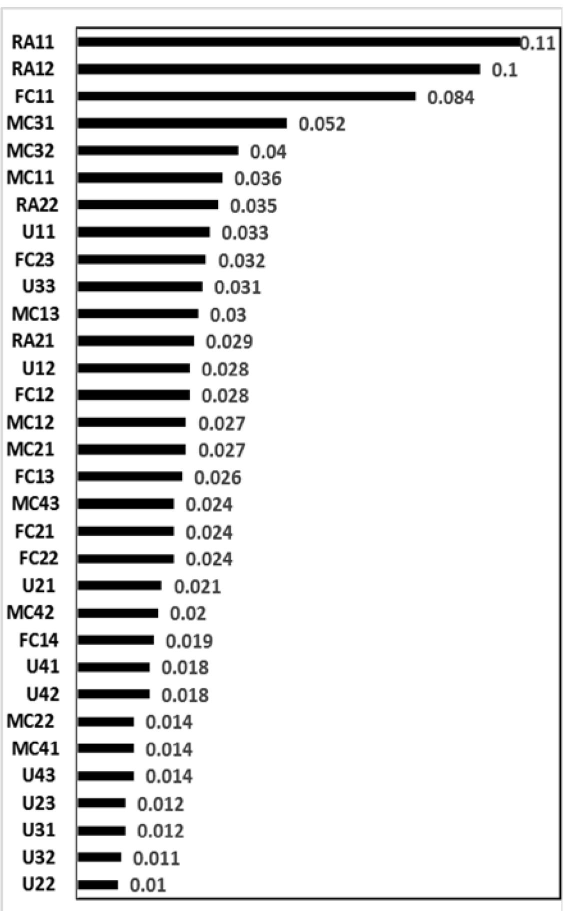


Fig. 5. Global weight level 3 sub-sub factors with respect to goal

by country factor (0.156), inadequate completion of design before start of construction (0.093), slow procurement, manufacturing of equipment and delivery to the site for installation (0.091), and financial matters (0.079). Among the top 5 sub factors there is no one from the main factors utility. The priority weight difference among the last five is trivial.

The figure 5 shows the global weight in distributive mode of level 3 sub-sub factors with respect to the goal of the developed model hierarchy. Among the 10 top most delay factors, 3 factors originated from each group of regulatory authority and main contractor while 2 factors are originated from each group of financial and country factor, and utility. Regulatory authority related sub-sub factors uncompromising regulatory criteria and conflicting licensing documents with existing regulations, and robust design documents review procedures have scored the first and second position with global weight 0.11 and 0.1 respectively. On the other hand, financial and country related sub-sub factors policy changes due to political instability and public intervention has scored the third position with weight 0.084. Worldwide shortage of qualified and experienced nuclear specific equipment manufacturer, and delayed procurement of equipment and bulk material due to unavailability to the global market related to main contractor group have ranked the 4th and 5th position.

Sensitivity analysis identifies the impact of changes in the main factors weight of level 1 on the sub-sub factors weight of level 3 of the developed AHP model. If a decision-maker of NPP construction industry thinks that main factors might be more or less important than originally showed in the result, he or she can see the change of weights by using dynamic sensitivity analysis. In this study, the priority of main factors from the original result were changed which make the drastic change of importance percentage of lowest level sub-sub factors. The figure 5 shows the dynamic sensitivity analysis graph for this model where varying the priorities of the main factors observe how the priorities of the sub-sub factors are changed.

The dynamic sensitivity of left side of upper portion of figure 6 shows the different party's importance in percentage behind the construction schedule delay of NPP which constitutes main contractor (27.2%), regulatory authority (22.1%), Financial and Country Factor (19.9%), and utility (30.8%) while the right side upper portion of the same figure constitutes main contractor (21.4%), regulatory authority (28.7%), Financial and Country Factor (24.1%), and utility (25.7%). As a result of changes the priority in main factors in level 1, the ranking and global weight of sub-sub factors of level 3 are changed which are shown in the lower portion of both left and right side in figure 5. The decision makers or NPP construction management team members of different party can see the weight in different viewpoint and they can take proper steps.

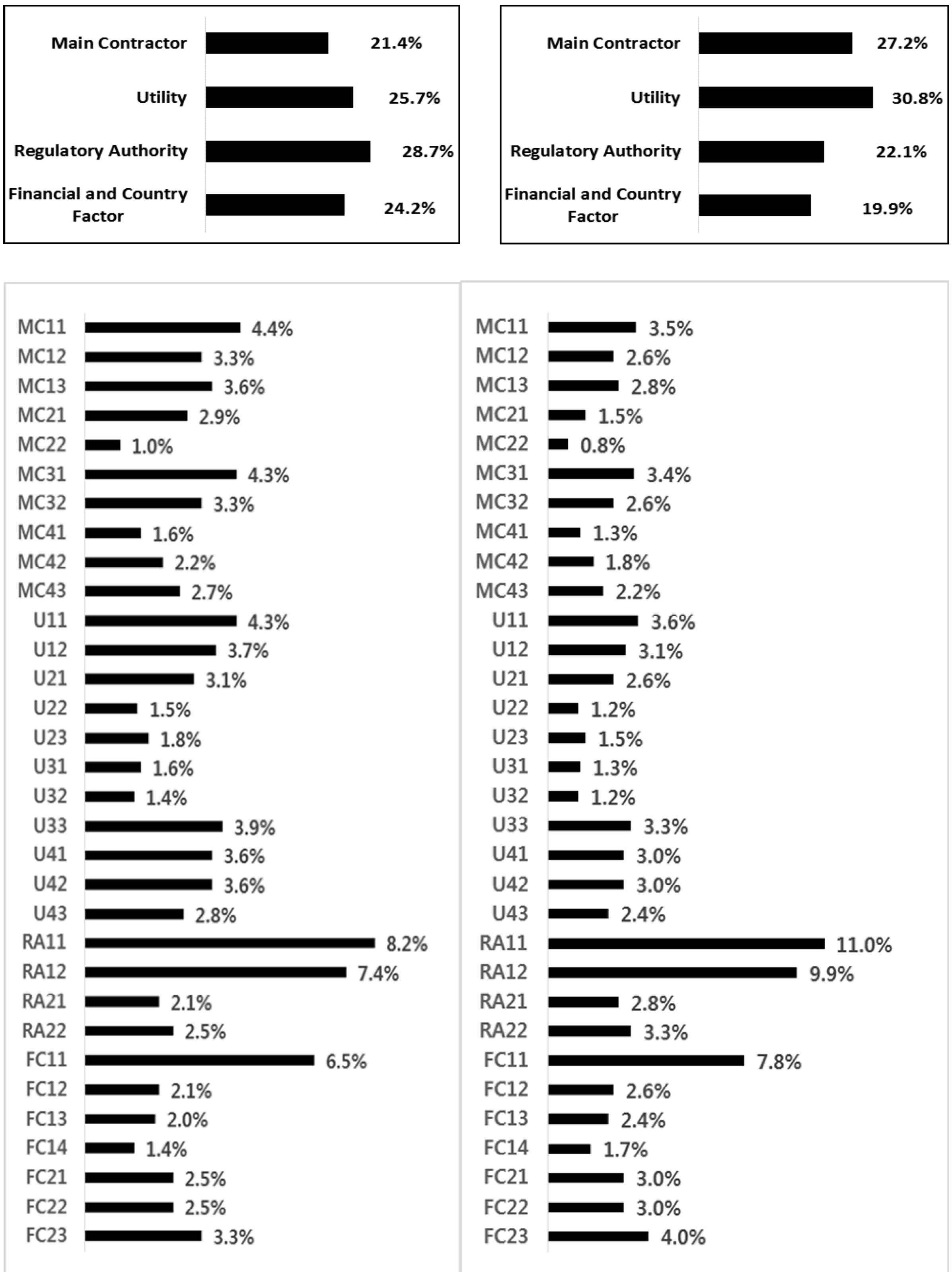


Fig. 6. Dynamic Sensitivity Analysis

6. Conclusion

The main contribution of the work was the identification of main cause of NPP construction schedule delay for turnkey contractual approached international project in different level. The second contribution was a development of a multi-criteria decision making model for the prioritization of NPP construction delay risk factors. Finally, prioritization of delay factors in different levels of NPP construction delay risk factors were accomplished. The model is developed by using the AHP methodology. This study has produced results and insights that involve one of the most vital aspect which is the quantitative weights and ranking of factors that affect delay in NPP construction. Undoubtedly, it is a necessity in the NPP construction industry for the use of quantitative terms when it comes to schedule delay risk.

The outcomes of this study confirm that the model is capable to support decision-makers to examine the strengths and weaknesses of factors in different level of the NPP construction phase. Decision makers of nuclear industry can understand the significance of different factors on NPP construction phase and they can apply risk informed decision making to avoid unexpected construction delay of NPP.

This study finds the different party's importance in behind the construction schedule delay of NPP which constitutes main contractor (28.4%), regulatory authority (27.3%), Financial and Country Factor (23.5%), and utility (20.8%).The results show that the top most important 5 sub factors according to global weight in level 2 are delayed regulatory approval, country factor, inadequate completion of design before start of construction, slow procurement, manufacturing of equipment and delivery to the site for installation, and financial matters.

This study finds top most important 10 sub-sub factors in the lowest level which are uncompromising regulatory criteria and conflicting licensing documents with existing regulations, robust design documents review procedures, policy changes due to political instability and public intervention, worldwide shortage of qualified and experienced nuclear specific equipment manufacturer, delayed procurement of equipment and bulk material due to unavailability to the global market, redesign due to errors in design and design changes, late changes in the regulatory criteria, delayed in approval of design documents, economic crisis, and delayed procurement contract. Among the top 5 factors of level 2 and level 3 there is no factors from the utility.

The experts' panel of this study is mostly from the Korean nuclear industry which is a limitation of this paper. Therefore, care should be taken while making an attempt at the generalization of the results. In this study, only 12 sub factors and 32 sub-sub factors were included in this study and more factors and sub factors of NPP construction schedule can be considered. The developed model has not been implemented yet in a specific NPP construction project.

In further studies, construction schedule delay risk assessment methodology for turnkey international NPP project will be developed through severity and frequency of occurrence of the selected hierarchical structure.

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