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International Project Risk Management for Nuclear Power Plant (NPP) Construction: Featuring Comparative Analysis with Fossil and Gas Power Plants

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Academic Editor: Barry D. Solomon
Received: 18 December 2016; Accepted: 15 March 2017; Published: 21 March 2017

Abstract: The concern of risk management has continuously increased in international construction projects. International projects have a high level of risk and complexity, which results in greater possibilities of cost overruns and schedule conflicts when compared with local projects. Therefore, the goal of risk management is to improve project performance by systematically identifying and assessing project risks, developing strategies to reduce or avoid risks and to maximize opportunities. However, there have been very limited studies in systemized risk management methods due to the unstructured nature of the risk items and knowledge, especially for nuclear power plant projects. In order to address this issue, this paper proposes a standardized risk management methodology for nuclear power plant (NPP) construction with a capability of comparing distinctive risk characteristics among fossil, gas, and nuclear power plants. The proposed methodology includes standard risk classifications and structured risk evaluation techniques in terms of likelihood, impact, and weightings for different types of power plants. It also defines risk packages and risk paths for effective manipulation in a structured manner. The proposed methodology, variables, and initial values were identified by an extensive literature review and expert interviews. Finally, a customizable prototype of risk management system in power-plant construction projects was proposed in order to examine the viability. Implications of this paper reveal that the nuclear power plant has much higher risks in all areas when compared with fossil and gas power plants. It was stressed, throughout this study, that the risk factors of nuclear power plant construction need to be continuously monitored and evaluated in order to explore sustainable nuclear power plants.

Keywords: nuclear power plant (NPP); construction; risk management system; risk breakdown structure (RBS); risk weighting; risk path

1. Introduction

The concern of risk management has continuously increased in international construction projects. International projects have a high level of risk and complexity, which results in greater possibilities of cost overruns and schedule conflicts when compared with domestic projects [1–4]. According to Project Management Body of Knowledge (PMBOK), "risk is defined as an uncertain event or condition that has a potential effect on at least one project objective" [5]. In addition, a previous study [6] evaluating an industry's international capacity based on construction business function found that design management, contract management, and risk management are the most important business functions requiring significant improvement in order to be competitive in the global market.

The goal of risk management is to improve project performance by systematically identifying and assessing potential risks, developing strategies to reduce or avoid them, and maximizing opportunities [7]. As the risk management gains importance in international construction business, several studies have developed risk identification and evaluation methods. Previous studies on the risk management for the construction industry mostly focused on the limited number of business functions for a particular phase of the project life-cycle [8–12] addressing only one single type of plant facility [13,14]. There has been no legitimate study that covers whole business functions throughout entire life cycles for different types of power plants including nuclear, fossil, and gas plants. In order to address this issue, this study has been performed with the objective of *developing a risk management system based on structured risk factors from the national, industrial, and business function's perspectives throughout the entire project life cycle for power plant construction projects*.

To this end, this study proposed a standard risk classification with 191 standard risk factors from the perspectives of nation, industry, and business function throughout project life cycle for three different types of power-plants. It was based on an extensive literature review and expert interviews. Identified risk factors were then quantified through a risk assessment method in order to prioritize these risks by different facility type. By using the result of risk assessment, risk correlations (risk path) were then analyzed among different phases of project life cycle. Finally, a customizable risk management information system for nuclear, fossil, and gas power plants was designed for international construction projects.

In order to meet the research objective defined above, this paper proposed a five-step research framework and methodology as depicted in Table 1. The five steps include: (1) classifying risk factors; (2) numbering risk factors; (3) assessing risks; (4) correlating risk factors; and (5) developing a risk management system. As compared in Table 2, the methodology developed in this paper is unique in terms of 'comprehensiveness' including all different perspectives with full details and the 'comparative capability' of different types of power plants.

Table 1. Research Design: Steps, Variables, and Constituents.

Steps	Variables	Code	Constituents
1. Classifying-risk factors (Table 3)	1.1 Perspective	RTN	Nation
		RTI	Industry
		RTP	Project
	1.2 Project life-cycle [4]	ALL	Entire project life-cycle
		PRE	Planning
		ENG	Design/Engineering
		PRO	Procurement
		CON	Construction
		OSS	Start-up and operation
		DIS	Disposal
	1.3 National environment	T01	Political/Policy
		T02	Economy/Finance
		T03	Society/Culture
		T04	Region/Environment
		T05	System/Law
	1.4 Industrial environment	T06	Market condition
		T07	Contract condition
	1.5 Project management function	F01	Planning
		F02	Design
		F03	Scheduling
		F04	Procurement
		F05	Contracting
		F06	Cost management
		F07	Quality management
		F08	Health, Safety and Environmental
		F09	Human resource management
		F10	Finance/accounting

Table 1. *Cont.*

Steps	Variables	Code	Constituents
		F11 F12 F13 F14 F15	Document administration R&D Owner support Construction Start-up preparation
	1.6 Facility	P010 P020 P030	Power plant—nuclear Power plant—fossil Power plant—gas (LNG)
2. Numbering-risk factors (Figure 1)	2.1 Facets	CLR00 CLR01 CLR02 CLR03 CLR04	Facility (P010, P020, P030)) Perspective (RTN, RTI, RTP) Categories (1.3, 1.4, 1.5 above in this Table 1) Risk items Risk factors
3. Assessing-risk factors (Figure 2)	3.1 Measures	LIK IMP WGT	Likelihood Impact Weighting
4. Correlating-risk factors (Table 7, Figure 4)	4.1 Relation	RLP RLS	Preceding (P) Succeeding (S)
5. Developing systems (Figures 5–10)	5.1 Modeling	MER MPR	Entity-relationship diagram (ERD) Process modeling

Table 2. Perspectives of Risk Management Studies.

Variables	Article	Facility	Perspective of Classification	Key Topic
1.2	Kang and Kim (2012)	Power plant (gas)	Life Cycle phase (except planning)	Qualitative risk identification and assessment by LC
1.2	Kang et al. (2012)	Industrial plant (General)	Life Cycle phase (Design/Procurement/Construction)	Risk identification and assessment in engineering/procurement/construction phases
1.2	Michael et al. (2006)	Facility (General)	Life Cycle phase	Risk classification and management analysis
1.2	Zeynalian et al. (2012)	Facility (General)	Life Cycle (Technique and Management)	Risk Analysis in Cold-Formed-Steel
1.3	Hong et al. (2010)	Facility (General)	National	Identification and assessment of national risk
1.3	Nasir et al. (2003)	Facility (General)	National and Participants	Development of ERIC-S related by project schedule
1.5	Na et al. (2009)	Industrial plant (General)	Business Function (Procurement)	Risk Identification and Respond in Procurement Phase
1.5	Fidan et al. (2011)	Facility (General)	Business Function (Uncontrollable factors and Project Change)	Cost overrun risk and Possibility analysis using ontology
1.5	Jang et al. (2011)	Power plant (gas)	Business Function (Construction mgmt. and Design mgmt.)	Risk Identification and Assessment of Design Phase in LNG Plant
1.2/1.3	CII (2003)	Facility (General)	National and Life Cycle	Risk classification and assessment by project participant
1.2/1.3	Yoo et al. (2012)	Facility (General)	National and Life Cycle	Development of risk management system
1.2/1.5	Han and Kim (2006)	Facility (General)	National and Business Function	Development profitability forecasting model in international projects
1.2/1.5	Hastak and Shaked (2000)	Facility (General)	National and Business Function	Development of ICRAM-1 (feasibility study)
1.2/1.5	Jang et al. (2009)	Power plant (gas)	National and Business Function	Risk identification by expert interview
1.2/1.5	Lee et al. (2012)	Facility (General)	National and Business Function	Identification and assessment of major risk in overseas development projects
1.2/1.5	Tah and Carr (2010)	Facility (General)	National and Business Function	Risk identification and assessment by work-package

As for research validation, it was extremely difficult to have many practitioners who have compressive understanding and experience in the area of international project risk management, especially for all different types of power plants (fossil, gas, and nuclear). Due to the paucity of knowledgeable practitioners, the proposed framework and methodology in this paper was tested by expert interviews and by system prototyping. The process of these interviews and system prototyping enhanced the practicability of the proposed framework and methodology. Five steps of proposed methodology are summarized in Table 1 with major variables. Note that the tables and figures indicated in the parentheses under the title of 'Steps' in Table 1 illustrate the concept of the methodology, while other tables and figures not specified in Table 1 may include partial examples or a complete set of case-evaluation result by expert interviews. The figures and tables for the methodology and the case-evaluation are used together for clear illustrations of the step-by-step processes.

Therefore, the proposed methodology and data structure can be practically used to develop a risk management system for owners and construction companies. It would be particularly beneficial to an organization which is frequently repeating power plant construction projects. The most important feature of standard classifications in this study is to exchange and accumulate project experiences in a structured way to automatically provide better indications for the future projects. For enhanced practicability, this paper identified a full list of risk factors as introduced in Appendix A.

2. Standard Risk Classifications for Power-Plant Construction Projects

For the purpose of systemically and effectively managing project risks, especially in the early planning phase, it is crucial to establish a risk classification along with structured risk factors. Previous studies in the area of risk management revealed that the risk factors often identified from the viewpoint of region (nation) [9,15–23], business function [9,11,13,15,17,19,20,22,24], life cycle [10,14,16,23,25,26], or project participant [21], as shown in Table 2. However, a comprehensive and systematic classification is required in order to develop a practical risk management system.

Based on an extensive literature review and expert interviews, this study proposes a hierarchical structure of standard risk classifications consisting of six variables and thirty-five entities as listed in Step 1 of Table 1. Six variables of risk classifications, including 'perspective, project life-cycle, national environment, industrial environment, project management business function, and facility type', were identified first.

2.1. Step 1: Classifying Risk Factors

As listed in Table 3, this study proposes a standard risk classification for power plants through the analysis of previous studies and by the expert interviews (one from research institute and the other from an engineering company). Standard risk classifications for power plants consist of eight facets: risk perspective (CLR01), risk category (CLR02), risk item (CLR03), risk factor (CLR04), project management business function (CLF), type of power-plant (CLP), project life-cycle (LC), and nation (CLN). These eight elements (or facets) listed in Table 3 form a hierarchical structure in order to effectively manipulate the risk database proposed in this paper. Full details of this classification, entities, and records used in this study are listed in Appendix A.

The most influencing facet (CLR01) includes national, industrial, and project perspectives as illustrated in Tables 1 and 3, and in Appendix A. This classifying facet, as the highest level, makes the proposed methodology distinct for international risk management.

CLR01 in Table 3 consists of three items: national risk (RTN in Table 1) refers to the overall condition such as politics, policy, or culture of the country where a project takes place, industrial risk (RTI) reflects the industrial characteristics and environment of the country and project risk (RTP) involves those occurring during the implementation stage of a project.

CLR02 along with CLF serves as a grouping tool and is composed of seven categories including politics/policy, economy/finance, society/culture, region/environment, and system/law at national level as well as market condition and contract condition, reflecting the risks in industrial condition and environment.

Table 3. Standard Risk Classifications.

Facet	Number of Items (in This Study)	Example
CLR01	3 perspectives	National, Industrial, Project
CLR02	7 categories	Policy, Culture
CLR03	69 risk items	Cost, Schedule
CLR04	191 risk factors	Design change
CLF	15 categories	Design mgmt., Cost mgmt.
CLP	3 types of power plant	Nuclear power plant
LC	6 phases of life cycle	Planning, Engineering
CLN	247 countries	Korea, UAE

CLR03, which is an evaluation level in risk management, is comprised of total 69 risk items as listed under the title of Level 3 in Appendix A Table A1. Among those items, there are 12 risk items resulting from the perspective of nation (RTN) and four items from the industrial environment (RTI), while 55 risks are associated with the detailed business functions that may occur during the implementation stage of a project (RTP).

CLR04 are sub-level risk factors of the risk items (CLR03) which consists of 191 risk factors. Risk factors can be used as reference data in assessing the risks in detail during the actual implementation stage of a project.

For the classification of business-function (CLF), fourteen different business functions in construction management defined by Jung and Gibson [27] were modified in order to reflect industry-specific business functions for power plant facilities. Three additional functions of 'owner support, construction management, and start-up and operation' are added to accommodate the characteristics of risk management. Finally, CLF in this paper consists of 15 items as listed in Table 1 and Appendix A.

CLP is a category for customized risk management for power plants and has three types of plants, which are nuclear (P010), fossil (P020), and gas (P030) power plants.

Life cycle (LC) has a total of six phases [28], which are 'planning (PRE), engineering (ENG), procurement (PRO), construction (CON), start-up and operation (OSS), disposal (DIS) and all stages' which refers to the ranges of risks taking place throughout the entire stages of project life cycle.

CLN adopts the country codes of ISO 3166-1 Alpha-3 and has 247 country categories. Country categories take the meaning as classification in analyzing the characteristics and the nature of each country.

2.2. Step 2: Risk Numbering System (RNS)

Based on the eight facets of standardized classifications, a Risk Breakdown Structure (RBS) and Risk Numbering System (RNS) for power plants is developed as shown in Table 3 and Figure 1. The proposed RBS has a fifteen-digit number. The first three digits (RBS Level 01) represent the 'perspective' (variable 1.1 in Table 1) being composed of national risk (RTN), industrial risk (RTI), and project risk (RTP). The second level (RBS Level 02, three digits) consists of 22 items, which has seven constituents (T01 to T07) from the variables of 1.3 and 1.4 in Table 1, and 15 business functions (F01 to F15) under the variable of 1.5 in Table 1. The third level, 'risk breakdown structure 03 (RBS03)', has 69 risk items of CLR03, and the last level of RBS04 is composed of 191 risk factors of CLR04. The major risk assessment processes conducted in this study evaluates each risk item at RBS03 level, and risk factors at level of RBS04 are used as detail data supporting this evaluation.

In summary, for the purpose of automated and effective risk management, a risk numbering system (RNS) is defined in order to strictly apply the same numbering mechanism to every single record in the database. RNS has a fixed 15-digit numbering system in the order of

CLR01—CLR02—CLR03—CLR04 or CLR01—CLF—CLR03—CLR04 depending on the second level category. By establishing such a risk numbering system, each risk factor in the risk management system is assigned with a unique identification code and thereby improves the automated date accumulation and the analytical efficiency.

It is also noteworthy that the structures of these hierarchical RBS and RNS were designed based on a large number of repeated evaluations and experiments in order to optimized the effectiveness of the proposed system. It has been stressed throughout the research process that an effective numbering system should thoroughly reflect distinct managerial requirements of a specific functional domain.

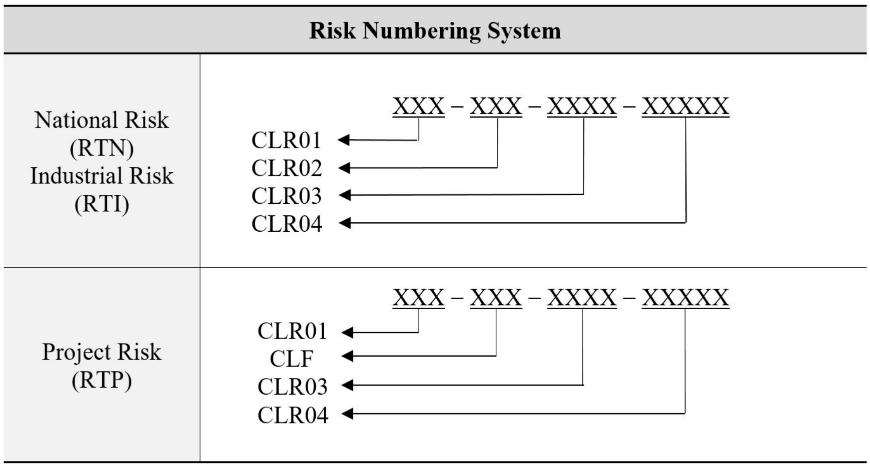

Figure 1. Risk Numbering System (RNS).

3. Risk Assessment in Terms of Weightings of Facility Types

Construction Industry Institute (CII) in the United States proposed a risk assessment and management method through the report of "International Project Risk Assessment (IPRA)" [16]. By using the judgment of experts (or someone in charge of risk management), 'likelihood' of risk occurrence and its 'impact' are assessed based on the five-point scale to identify the main risks that require prior attention. Based on the IPRA's risk assessment method, this study added one additional measure of 'weightings' for different types of power plants, thus risk factors were in this paper assessed in terms of likelihood (LIK), impact (IMP) and weighting (WGT) at the level of RBS03.

3.1. Step 3: Risk Assessment

All 69 risk items identified in this paper were first evaluated in terms of likelihood (LIK) and impact (IMP) by an extensive literature review and expert interviews. A five-point Likert scale was used for both likelihood (LIK) and impact (IMP) as shown in Figure 2. The results of this evaluation identify the most influencing 35 major risk items with high likelihood score of 4 or 5 and high impact score of D or E as illustrated in a red dotted box in Figure 2. For example, risk item number R023 'Design change' was found to have the highest score of 5 for likelihood of occurrence with the highest score of E for impact. Nine country risk items (RTN), one industry risk item (RTI), and 25 project risks (RTP) items are located in the red dotted box.

As for national risks (RTN), 75% of all RBS03 level items were selected as the major risks which implies that the conditions in the nation where a project takes place has a huge impact on the overseas power plant projects. Only one (R015 Bidding) out of four items in the industry risk (RTI) was selected as the major risk, and it indicates that the form of bidding risk in the bidding stage has a large influence on the projects. About 47% of the total project risk items (RTP) were categorized as the major risks, and the design change (R023) risk turned out to be the risk with the highest likelihood of occurrence and the highest impact among 69 risks in the RBS03 level. This is probably because most of power plant projects have an EPC (Engineering-Procurement-Construction) contract, thus a design change has a major impact on the projects due to its influence to fast track construction process. Other major risk items include most of the project risks including planning (R019, R020, and R021), scheduling (R026 and R027), cost (R034 and R035), construction management (R060, R061, R062, and R066) and others.

Impact of the risk factors assessed can later be used as a baseline for the risk management in the initial stage of a project. As the major risks have a considerable impact on the projects, it is necessary to recognize them in an early stage of the project as well as to give them close attention.

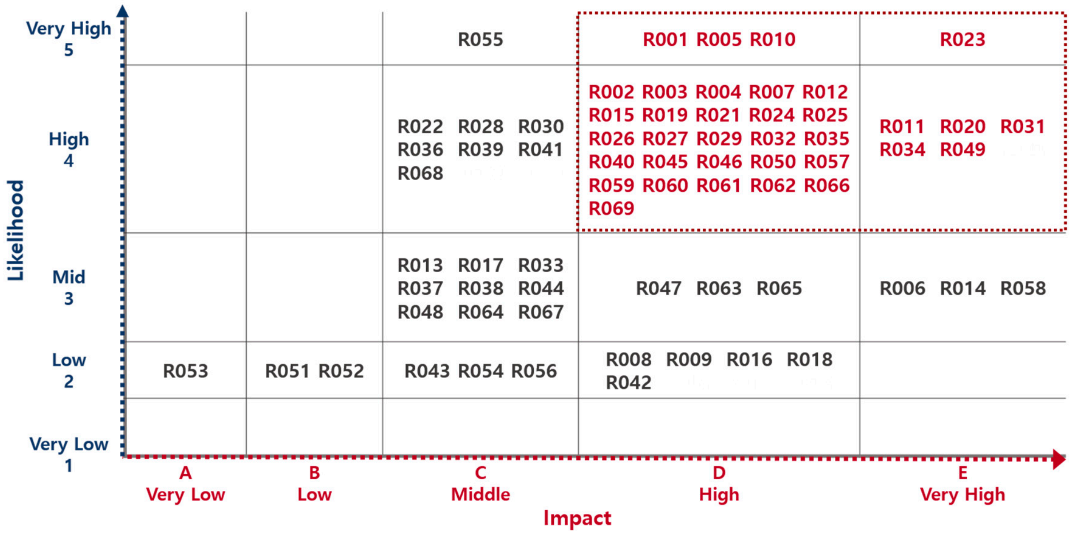

Figure 2. Risk Assessment (Case Evaluation).

3.2. Weightings of Risk Items for Different Types of Power Plants

The risk assessment in Section 3.1 was conducted from a general perspective of different types of power plants. Given the characteristics of the power plant facilities, however, the impact of risks may be different for a different type of a facility (e.g., nuclear, fossil, and gas). As such, this study has analyzed the degree of comparative impact (defined as risk 'weighting' among three different types) of risks by facility type for the nuclear, thermal, and LNG power plants. Therefore, the 'weighting' of a risk item in this paper can be used as an adjustment factor to the values of 'likelihood' and 'impact' evaluated in the previous step in Section 3.1. For example, the weighting values for the risk item of 'R009 Environment' are 10, 8, and 5 for nuclear, fossil, and LNG plants, respectively. This example illustrates that the same impact value of R009 can be adjusted depending on the power plant type. Therefore, different conditions can be quantitatively accumulated in the database management system proposed in this paper. It is particularly important that the structured database in this way can perform automated reasoning for a future project based on a large number of historical databases.

Unfortunately, experts who have experienced all three power plant types are very rare. Therefore, the expert evaluation was conducted by a risk manager from a research institute and by an engineer who have experience in design and risk management of all three facility types. It was evaluated by two-step interviews of the two experts using 10-point scale (where the scores of 1 and 10 indicate very low and very high, respectively) at the RBS03 risk item level. Results from the interviews are briefly introduced.

As for nuclear power plant, most risk items in national perspective (RTN) have high weightings except for the system/law (T05) category. Project risks generally had high weightings (Table 4 and Figure 3). In particular, nuclear power plants scored a high-risk weighting for region/environment (T04), political/policy (T01), and HSE (F08), which is probably because the safety issue for radiation in conjunction with the international relations and environmental permit of the country are critical in nuclear power plant projects.

Same as the nuclear power plants, the fossil power plants also showed a high weighting in region/environment (T04) and quality control (F07). However, for the industry risks, the fossil fuel power plants demonstrated a lower than average weighting of risk items for construction environment (R013) and market volume (R014). This is probably because, for the fossil power projects, the market condition is less influenced compared to other types of power plants (Table 5 and Figure 3).

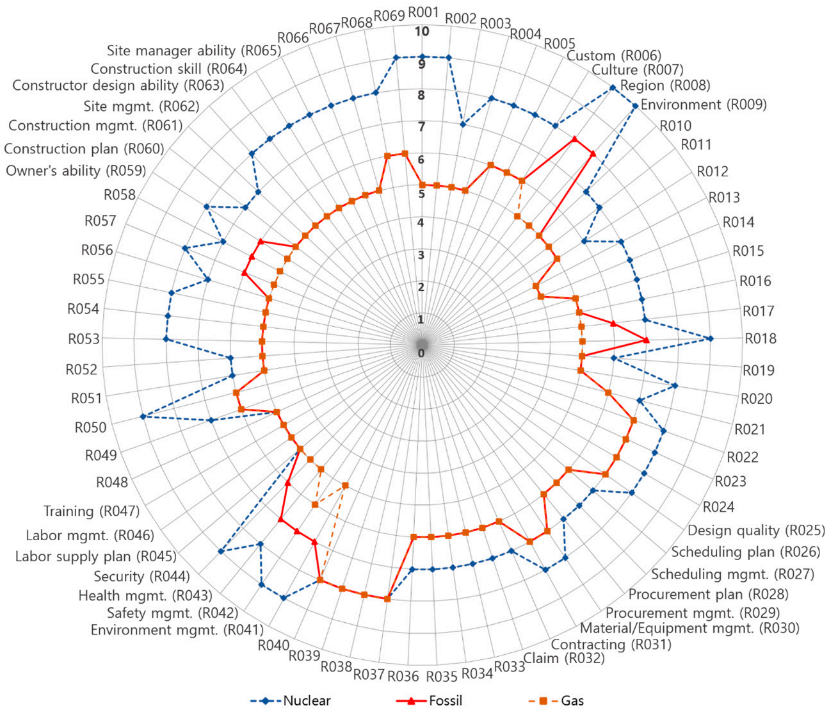

Figure 3. Weight Distribution by Facility Type (Case Evaluation).

Table 4. Higher Weighting Risks for Nuclear Power Plant (Case Evaluation).

RBS01	RBS02	RBS03	Weight
Industrial Risk (RTI)	Region/Environment (T04)	Region (R008) Environment (R009)	10 10
National Risk (RTN)	Political/Policy (T01)	Political (R001) Policy (R002)	9 9
Project Risk (RTP)	Planning (F01)	Environmental assessment (R018)	9
	HSE (F08)	Environment mgmt. (R041) Safety mgmt. (R042) Security (R044)	9 9 9
	Accounting mgmt. (F10)	Financing (R050)	9
	Start-up and Operation Prepare (F15)	Start-up (R069)	9

Table 5. Higher Weighting Risks for Fossil Power Plant (Case Evaluation).

RBS01	RBS02	RBS03	Weight
National Risk (RTN)	Region/Environment (T04)	Region (R008) Environment (R009)	8 8
Project Risk (RTP)	Quality mgmt. (F07)	Quality mgmt. plan (R037) Quality assurance (R038) Quality test (R039) Quality mgmt. (R040)	8 8 8 8

LNG power plants showed an average weighting in general except for quality control (F07). Just like fossil power plants, the risk for construction environment (R013) and market volume (R014) has a lower than average weighting (Table 6 and Figure 3). Same as the fossil power plants, this is probably because the market condition (T06) is not one of the main points of consideration for LNG power plants.

In summary, all three types of power plants showed high weightings in common for region/environment (T04) along with quality control (F07) (Figure 3). It is found that this is because the risks associated with a nation where a project takes place can exert a significant influence on the projects due to the nature of overseas construction projects and, given the nature of power plant facilities, good quality is demanded.

Table 6. Higher Weighting Risks for Gas Power Plant (Case Evaluation).

RBS01	RBS02	RBS03	Weight
Project Risk (RTP)	Quality mgmt. (F07)	Quality mgmt. plan (R037)	8
		Quality assurance (R038)	8
		Quality test (R039)	8
		Quality mgmt. (R040)	8

4. Risk Correlations (Risk Paths)

The occurrence of risks is closely related to a project life cycle. Some risks occur in a particular stage in the life cycle whereas others occur in several stages or throughout the entire life cycle. It allows for more intuitive and efficient risk management to be aware of the risks that take place in each stage of life cycle. Therefore, this study attempts to define the interrelationships in between the risk items by categorizing them into the phases of project life cycle as listed in Table 7.

Table 7. Risk Factors Grouped by Project Life Cycle.

<table>
<tr><th colspan="2">Life Cycle Phase</th><th>RBS03</th><th>Life Cycle Phase</th><th>RBS03</th></tr>
<tr><td rowspan="4">Planning
(PRE)</td><td>Pre-
Bidding</td><td>Bidding (R015)
Project development (R017)
Project program (R019)
Feasibility study (R020)
Estimation (R021)</td><td rowspan="2">Construction
(CON)</td><td>Schedule plan (R026)
Schedule mgmt. (R027)
Cost mgmt. (R035)
Performance mgmt. (R036)
Safety mgmt. (R042)</td></tr>
<tr><td rowspan="3">Post-
Bidding</td><td>Region (R008)
Environment (R009)
Construction Environment (R013)
Market volume (R014)
Contract environments (R016)
Environmental assessment (R018)
Budget planning (R033)
Cost forecasting (R034)
Quality mgmt. plan (R037)
Environment mgmt. (R041)</td><td>Health mgmt. (R043)
Security (R044)
Technology research (R055)
Construction plan (R060)
Construction mgmt. (R061)
Site mgmt. (R062)
Constructor design ability (R063)
Construction skill (R064)
Site manager ability (R065)
Local company mgmt. (R066)</td></tr>
<tr><td>Safety mgmt. (R042)
Labor supply plan (R045)
Labor mgmt. (R046)</td><td>Start-up (OSS)</td><td>Labor/Resource/Equipment
Procurement (R068)
Start-up (R069)</td></tr>
<tr><td>Training (R047)
Organization mgmt. (R048)
Finance/Fund (R049)
Financing (R050)
Technology mgmt. (R053)
Technical training (R054)
Information system (R056)
Owner's attitude (R058)
Owner's ability (R059)</td><td>Entire Life Cycle
(ALL)</td><td>Political (R001)
Policy (R002)
Economy (R003)
Finance (R004)
Society (R005)
Custom (R006)
Culture (R007)
Governmental system (R010)
Law (R011)</td></tr>
</table>

Table 7. *Cont.*

Life Cycle Phase	RBS03	Life Cycle Phase	RBS03
Engineering (ENG)	Design technique (R022) Design change (R023) Design approval (R024) Design quality (R025) Owner's requirement (R057)		Tax (R012) Contracting (R031) Claim (R032) Quality assurance (R038) Quality test (R039)
Procurement (PRO)	Procurement plan (R028) Procurement mgmt. (R029) Material/Equipment mgmt. (R030)		Document mgmt. (R051) Administration mgmt. (R052)

4.1. Risk Factors by Life-Cycle

The risks, occurring throughout the entire phases of a project life cycle, were divided into a total of sixteen groups. As most of the national risks (RTN) take place throughout the entire life cycle, it is crucial to manage risks from the early stage of the project planning phase.

Considering the nature and impact of the risks, planning phase (PRE) is divided into pre-bidding and post-bidding, and five risk items of bidding (R015), project development (R017), project program (R019), feasibility study (R020), and estimation (R021) are included in the pre-bidding stage. Most of these risks are part of the business functions for bidding and are critical in winning the projects. In the post-bidding stage, along with some country risks (RTN) and the industry risks (RTI), several project risks (RTP) such as costs, quality, and organization management are included. Twenty-eight risk items arising in the planning stage account for 40% of overall risks, so it is very important to manage the risks in this stage (Table 7).

In the engineering phase (ENG), there are five risk items of design technique (R022), design change (R023), design approval (R024), design quality (R025), and owner's requirements (R057) as listed in Table 7. As observed in the risk assessment of the overall power plants in Figure 2, it is necessary to put an effort to minimize design change (R023).

Procurement phase (PRO) in the plant construction projects is of great importance because some risk items in procurement may affect not only the risks in construction but also risks for the entire project life cycle. In the procurement phase, three risk items of procurement planning (R028), procurement management (R029) and materials/equipment management (R030) are included in Table 7.

Sixteen risk items were listed in the construction phase (CON) including costs, schedule, and construction management (Table 7). In particular, construction should be performed in such a way that takes extra caution for safety during the construction planning and construction management processes. This group has the most number of risk items in the project life cycle following the planning stage.

In the start-up and operation phase (OSS), risk management for labor/resource/equipment procurement (R068) and start-up (R069) are important (Table 7). It is noteworthy that risk management is of utmost importance in the start-up stage, as the facility is transferred to an owner or an operator.

4.2. Step 4: Risk Path

In addition to the timing of risks, there is a preceding or succeeding relationship among risks. By identifying this relationship among risks, it becomes possible to analyze and trace the cause of risks. Therefore, the inter-relationships of risk items named as 'risk path' is proposed in this study. Some of these risk paths are illustrated in Table 8 and Figure 4.

For the sixty-nine risk items in the level of RBS03, relationships among risk items were defined in terms of preceding (P) and succeeding (S). For example, governmental system (R010) risk is associated with the law (R011), administration management (R052), and design approval (P024) risks. Law (R011) risk occurs prior to the governmental system (R010) risk. In addition, the governmental system (R010) risk affects the administration (R052) and design approval (R024) risk (Table 8). That is, law affects the administrative system, which in turn affects the design approval along with the administrative management.

Once these relationships are arranged by the phases of project life cycle, they can be organized by time sequence as shown in Figure 4. The risk items that last throughout the entire life cycle have a complex relationship with others. For these reasons, a group of risk items with close relationships can be effectively managed as a 'risk package' as illustrated in Table 9. This study proposed a concept of risk package in this sense. Introducing the concept of risk path/package to the risk management system would enable the risk managers to more effectively handle risks. The concept of risk path/package also serves as a tracking mechanism of the many related risks together.

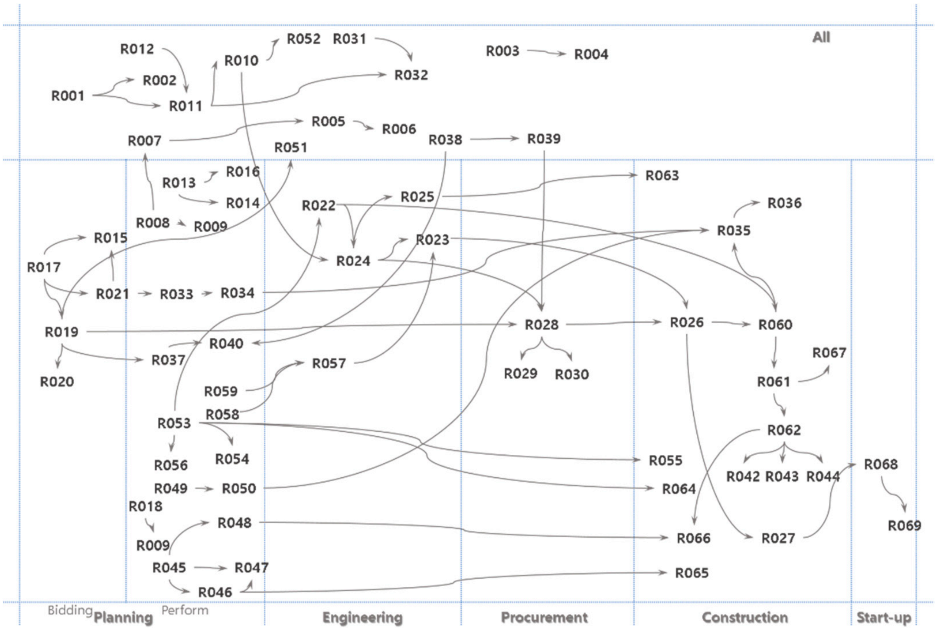

Figure 4. Risk Path Diagram.

Table 8. Risk Paths (Partial Example).

RBS03	* Risk Path	RBS03
Political (R001)	S S	Policy (R002) Low (R011)
Policy (R002)	P	Political (R001)
Economy (R003)	S	Finance (R004)
Finance (R004)	P	Economy (R003)
Society (R005)	P S	Culture (R007) Custom (R006)
Custom (R006)	P	Society (R005)
Culture (R007)	P S	Region (R008) Society (R005)
Region (R008)	S S	Culture(R007) Environment (R009)
Environment (R009)	P	Region (R008)
Governmental System (R010)	P S S	Low (R011) Administration Mgmt. (R052) Design Approval (R024)

* P: Preceding, S: Succeeding.

Table 9. Risk Packages (Partial Example).

Risk Package	Life Cycle				
	Planning	**Engineering**	**Procurement**	**Construction**	**Start-up**
Package 1	R053	R022 R024 R023		R026 R027	R068 R069
Package 2	R017 R021 R033 R034			R035 R036	
Package 3	R053	R022 R024	R028	R026 R060 R061 R067	
Package 4	R053	R022		R060 R061 R062 R042	
Package 5	R053 R054			R055 R064	
Package 6	R049 R050			R035 R036	
Package 7	R058	R057 R023		R026 R027	R068 R069
Package 8	R017 R019		R028 R029 R030		
* Package 9	R001, R002, R011, R010, R052				
* Package 10	R007, R005, R006				

* Occur through all life cycles.

4.3. Responding Actions to Risk

It is important to come up with appropriate responses after a risk takes place. It is required to choose a proper response to each risk item as one single solution cannot be uniformly applied. Accordingly, this study uses five different types of action based on definitions by previous studies; including risk acceptance, risk transfer, risk avoidance, risk sharing, and risk reduction as listed in Table 10.

Table 10. Risk Respond.

An et al. (2010) [29]	CII (2003)	Michael et al. (2006)	Choudhry and Iqbal (2012)	This Paper
Retention	Retention Acceptance	Assumption	Retain	Accept
Transfer	Transfer/Deflect	Transfer	Transfer	Transfer
Avoid	Avoidance	Avoidance	Avoid	Avoid
Submit	-	Sharing	Sharing	Share
-	Control Reduction	Reduction	Reduce (likelihood, Consequences)	Reduce

5. Power-Plant Risk Management System (PRMS)

Based on the research steps and variables defined in Table 1, Steps 1 through 4 of the proposed methodology for developing "Power-plant Risk Management System (PRMS)" have been discussed in previous chapters. This section introduces the data modeling and process modeling in order to physically develop a PRMS by using the dataset introduced in this paper. The two models in Figures 5 and 6 were fully developed as a validation process of the proposed methodology. A limited number of examples of user-interface screens (in Figures 7–10) are also illustrated using Microsoft Access to easily elaborate the proposed PRMS process.

5.1. Step 5: Risk Management Systems

A computerized risk management system is a tool for quantitative analyses of the risks and decision-makings. There are many well-known systems in the literature, and each has different purpose, method, and scope. For an example, in South Korea, there is a leading risk management system called "Fully Integrated Risk Management System (FIRMS)" provided by the International Contractors Association of Korea. FIRMS has been developed with an objective of assessing the risks for international projects. However, it has a limited capability in tracking and managing the changes in risks in the early planning stage of a project, and it has a complicated risk assessment process, and is thereby limited in terms of practical effectiveness [23,30]. Another leading risk assessment methodology in the U.S. is the "International Project Risk Assessment (IPRA)" developed by CII in 2003. IPRA has been developed to increase the profitability and minimize the loss in construction and thereby improve the overall business performance. However, the changes of risk factors and the remaining risks cannot be easily tracked and objectivity is lacking in risk assessment [23,30].

This study has developed the Power-plant Risk Management System (PRMS) that covers the entire project life cycle. Distinct characteristics of the proposed PRMS in this study include the use of a standard risk numbering and breakdown system, embedded weightings for different types of facilities, and standardized risk paths and packages.

5.2. PRMS Data Modeling

PRMS in this study utilizes a set of standardized attributes defined under the column entitled 'Code' in Table 1. Each attribute accumulates historical data with evaluated values by pre-defined standard formats. This research developed this database by using a commercial relational database management system (Microsoft Access). Figure 5 is the entity-relationship diagram (ERD) of the relational database (RDB) developed for PRMS. The entities located in the yellow dotted box in

Figure 5 are a set of eight standard classifications discussed in Section 2.1. The purple box has entities for standard numbering system in Section 2.2. Entities in green, burnt orange, and blue boxes are for risk paths and packages in Section 4, weightings in Section 3.1, and actions in Section 4.3, respectively. Finally, the entity in the black dotted box has all historical risk item records with scores as discussed in Section 3.1, which is the accumulated knowledge to update this system in order to have better capability for risk evaluation.

Classifications are linked with RBS and the weightings by facility type. The risk paths are linked based on RBS03. Risk responses are linked to the project example cases (Historical Database). As shown, all items are linked using the core Risk Numbering System (RNS) which allows for automated evolvement and feedback for the future projects.

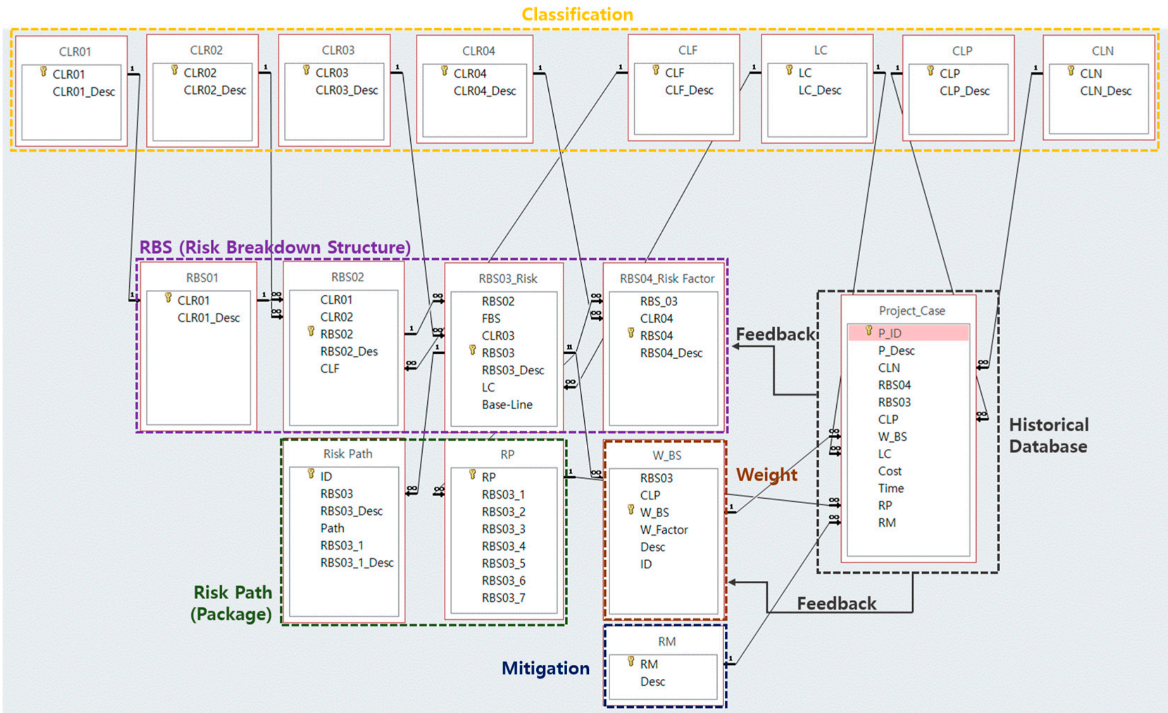

Figure 5. Entity Relational Diagram for Prototyping (Microsoft Access).

5.3. PRMS Process Modeling

A process model of PRMS is illustrated in Figure 6. The process starts by selecting a facility type in order to retrieve a template. Then, the user assesses the risk items at the level of RBS03 (base-line), automatically provided by the standards, with scores of likelihood of occurrence and impact. It also provides with RBS04 level information (detail risk factors listed in Appendix A). Moreover, the 'project costs' and the 'probability of success for responses' are evaluated using three criteria, low, medium, and high. Each risk factor (in RBS04 level) is marked with the actual project cost (actual cost). As a follow-up evaluation, once a risk assessment is over, it leads to a subsequent assessment on the related risk factors based on risk path (Figure 6). In other words, the risk register consists of the parts that are directly copied from the template and cannot be modified (code/items/risk-factors/Base-line) and those that are for the actual project details to be entered by the user.

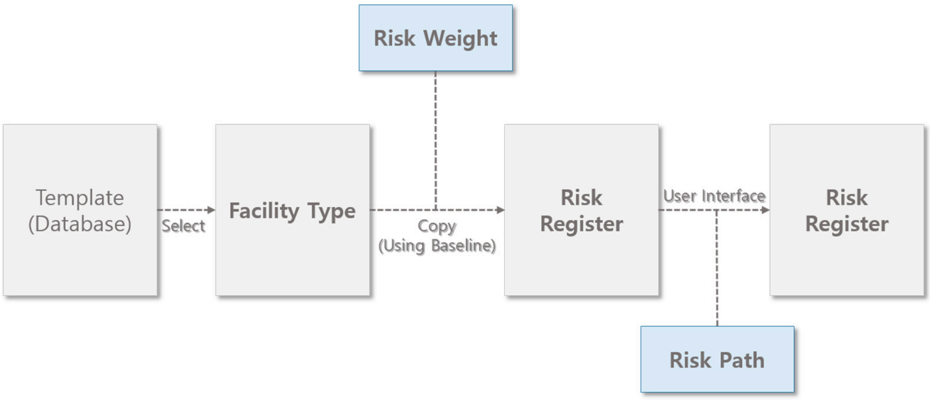

Figure 6. PRMS Process Model.

5.4. PRMS User Interface

The basic user interface screens of PRMS are configured in Figures 7–10 by using Microsoft Access Forms based on the RDB in Figure 5. Firstly, an user logs in to the PRMS using ID and password (Figure 7). In the next screen, the structure of risk factors in the PRMS is displayed. In other words, the hierarchical structure of RBS01, RBS02, RBS03, and RBS04 is visualized (Figure 8). Next shows the optional items in the template in which the facility type and the country of a project are selected. Once the selection is made, the weightings of the facility type is displayed with items and is also presented in a graph (Figure 9). It can be used as the reference data for risk assessment and helps with the risk management plan development. Furthermore, by showing the impact in a diagram, it helps to intuitively understand the impact by facility prior to a risk assessment. Last screen (Figure 10) is the risk register where the user performs the project risk assessment. The user inputs the likelihood of occurrence, impact, cost impact, responses, success probability of the responses, excess in cost, and employee in charge of the risk based on the codes, factors, and values copied from the template. In this case, the risk register is grouped as a risk package based on the risk path and run for risk assessment. The factors assessed this way can be automatically updated with the template.

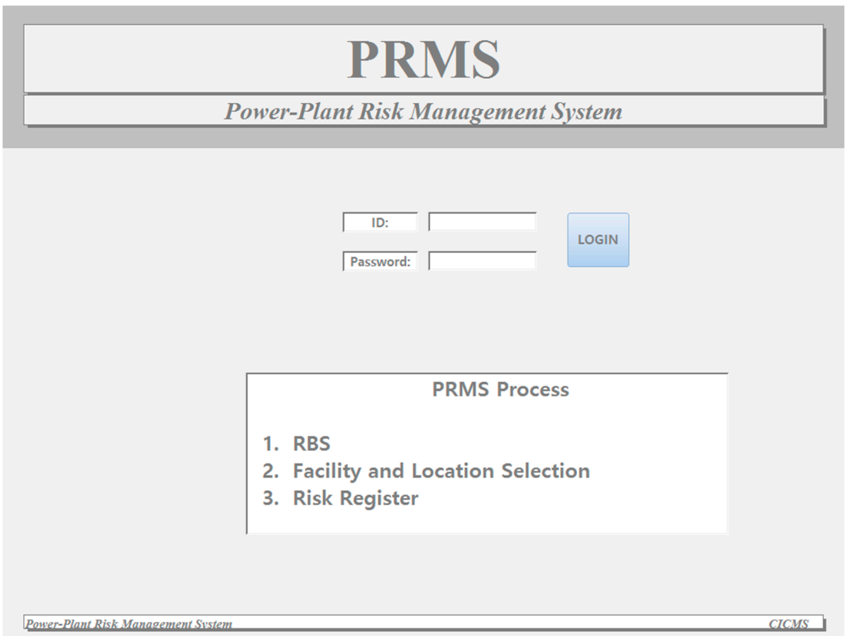

Figure 7. Log-in.

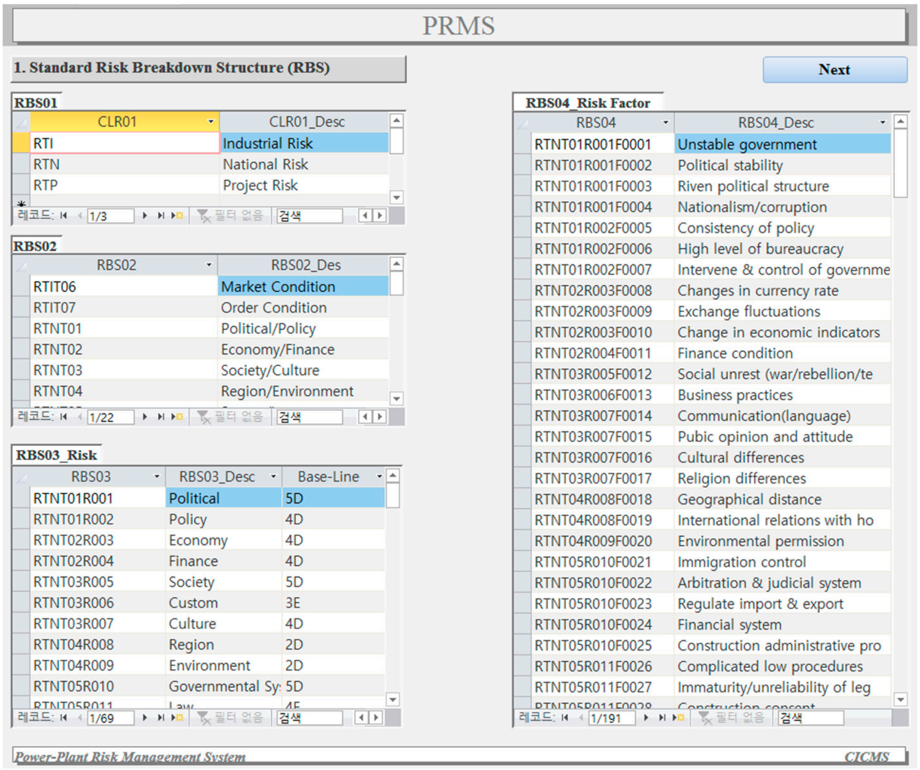

Figure 8. Risk Factors.

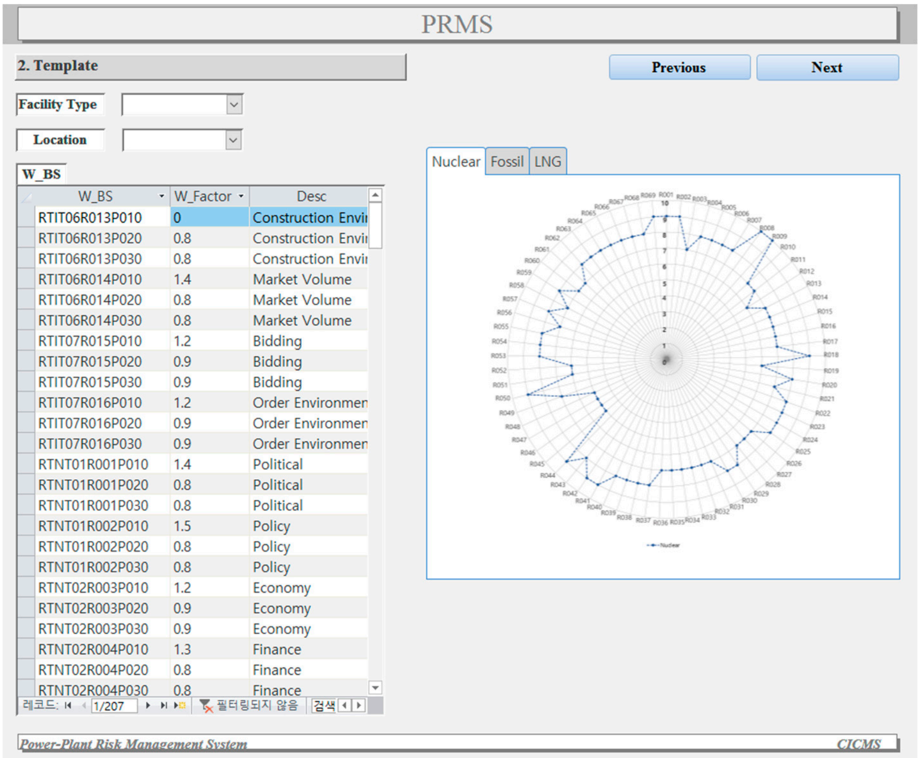

Figure 9. Selection of a Facility.

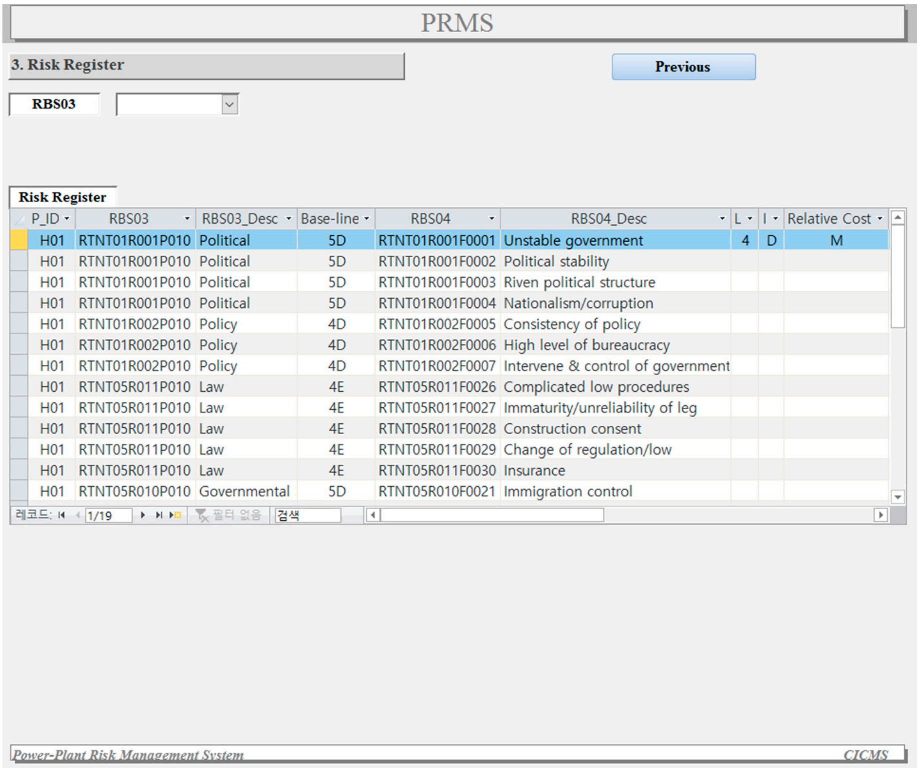

Figure 10. Risk Resister.

5.5. PRMS Discussions

A prototype of PRMS was developed in order to validate the viablity of proposed framework and methodology. It was proved that the methodology comprehensively covers all necessary risk factors at level four (with 191 risk factors under CLR04 as listed in Appendix A) and that processes in Figure 5 effectively manipulate risk information in order to meet the system objective descibed in the introduction of this paper. The system objective is *developing a risk management system based on structured risk factors from the national, industrial, and business function's perspectives throughout the entire project life cycle for power plant construction projects*.

An organization (e.g., an owner or a construction company) may want to develop further details under the level four risk factors that would fit in with each organization's distinct business requirements. It enables significant enhancement of competitive advantages of a specific organization in the globalized power plant industry. Therefore, each organization may have somewhat different likelihood (LIK) and impact (IMP) values for some risk factors. Nevertheless, higher level items in this paper (CLR01 through CLR03) can serve as a universal classification for all different organizations. This involves the issues of automatic information exchange among organizations [28] at the industry level. Information confidentiality issues among competitors could be major barriers to this promising concept.

Again, details of any type of information need to be designed and used to fit in with corporate strategy and business requirements of a specific organization [27]. Having said that, the automated information exchange inside a specific project, among owners, consultants, engineering companies and so on, would significantly foster the richness of data for the proposed system. In turn, the accuracy and reliability of the proposed PRMS will continuously be improved, as are repeated international power plant projects.

6. Conclusions

A standard risk classification system was proposed in this study for the purpose of developing a power-plant risk management system which encompasses three different levels of perspectives (national/industrial/project), entire project life cycle as well as three different facility types. Through an extensive literature review and expert interviews, major risk items have been identified that are likely to occur often in power plant construction.

Three measures, likelihood, impact, and weightings, were defined and utilized in order to quantify risks in a comparative manner for different types of power plants. The proposed concept of risk path along with risk packages would enhance the capability of tracking and assessing the interrelated nature of risk factors.

This paper utilized a case-evaluation in order to validate the viability of the proposed methodology. The case-evaluation is also used for easier illustrations of the methodology. Though it is case-specific to this paper, the experts strongly claimed that the nuclear power plant has much higher risks in all areas when compared with fossil and gas power plants. The implications of this study reveal that the risk factors of nuclear power plant construction need to be continuously monitored and evaluated in order to explore sustainable nuclear power plants.

Major limitations of this study include the small number of participants for expert evaluation. Even though it is practically acceptable, high statistical power derived from a large number of cases would find critical implications from real-world implementations. It is also planned to combine self-evolving mechanisms into the proposed system in future research.

Acknowledgments: This study was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT, and Future Planning (MSIP) under Grant No. 2014R1A2A2A01006984.

Author Contributions: Min Kim and Youngsoo Jung conceived and designed the framework and methodology; Min Kim performed the case-evaluation through literature review and expert interviews. Min Kim, Ikhaeng Lee, and Youngsoo Jung analyzed the data and wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Risk Breakdown Structure (RBS).

Level 1	Level 2	Level 3	Level 4 (RBS04)
National Risk (RTN)	Political/Policy (T01)	Political (R001)	Unstable government, Political stability, Riven political structure, Nationalism/Corruption
		Policy (R002)	Consistency of policy, High level of bureaucracy, Intervene and control of government
	Economy/Finance (T02)	Economy (R003)	Changes in currency rate, Exchange fluctuations, Change in economic indicators
		Finance (R004)	Financing condition
	Society/Culture (T03)	Society (R005)	Social unrest (war/rebellion/terrorism/hostilities)
		Custom (R006)	Business practices
		Culture (R007)	Communication (language), Public opinion and attitude, Cultural differences, Religion differences
	Region/Environment (T04)	Region (R008)	Geographical distance, International relations with host country
		Environment (R009)	Environmental permits
	System/Law (T05)	Governmental system (R010)	Immigration control, Arbitration and judicial system, Regulate import and export, Financial system, Construction administrative procedures

Table A1. *Cont.*

Level 1	Level 2	Level 3	Level 4 (RBS04)
		Law (R011)	Complicated law procedures, Insurance, Immaturity/unreliability of legal system, Construction approval, Change of regulation/low
		Tax (R012)	Tax/customs, Value added tax/technique tax/income tax
Industrial Risk (RTI)	Market Condition (T06)	Construction environment (R013)	Relation industry business forecast, Construction mature of host country, Infra condition
		Market volume (R014)	Market situation (material, equipment, labor etc.), Market Volume
	Contract Condition (T07)	Bidding (R015)	Bidding volume index, Competitive/negotiated bidding
		Contract environments (R016)	Strategic contract, Uncertain change of contract conditions
Project Risk (RTP)	Planning (F01)	Project development (R017)	Business plan, Business method, Project development plan, Project development constitution
		Environmental assessment (R018)	Environmental evaluation issues, Interventions by environmental agencies
		Project program (R019)	Project scope, Business objective, Project scope change, Consultant, Advance information of host country
		Feasibility study (R020)	Model of economic/feasibility study
		Estimation (R021)	Uncertainty of estimate, Shortage of estimate experience, Shortage of estimate experience period, Shortage of estimate reference
	Design mgmt. (F02)	Design technique (R022)	Complexity of design, Low constructability, Technical incompetency of engineer, Unclear specifications, Design criteria and standard
		Design change (R023)	Design change
		Design approval (R024)	Delay of design approval
		Design quality (R025)	Design quality and completeness, Design errors
	Scheduling (F03)	Schedule plan (R026)	Sufficient schedule plan, Plan of process plan, Process to ensure schedule
		Scheduling mgmt. (R027)	Poor project time mgmt., Delay/interruption, Third party delays, Fast track schedule, Influence of precedence construction, Countermeasure of schedule revival
	Procurement mgmt. (F04)	Procurement plan (R028)	Confirmation of material limit, Unavailability of local material, Determine type of procurement
		Procurement mgmt. (R029)	Increase in unit cost of resources, Delays in material supply, Purchase plan (order time), Accident occurrence under transport
		Material/equipment mgmt. (R030)	Bulk material, Material storage, Loss of material, Equipment mgmt. plan, Change in availability of equipment
	Contracting mgmt. (F05)	Contracting (R031)	Contract change, Contract error, Contract type and condition, Apply form and standard, Contract translation
		Claim (R032)	Lawsuit, Claim of participant, Dispute settlement method/process/arbitration period, Insufficient of dispute organization/utilization ability, Absence of expert organization

Table A1. *Cont.*

Level 1	Level 2	Level 3	Level 4 (RBS04)
Project Risk (RTP)	Cost mgmt. (F06)	Budget planning (R033)	Reasoning of process in budget planning, Contingency, Budget mgmt.
		Cost forecasting (R034)	Uncertainty of cost estimation
		Cost mgmt. (R035)	Poor cost mgmt., Increase in unit cost of work, Cost overrun, Change of labor expenses/productivity
		Performance mgmt. (R036)	Payment of price method and plan, Delay in progress payments
	Quality mgmt. (F07)	Quality mgmt. Plan (R037)	Absence of quality mgmt. system, Quality of local companies
		Quality assurance (R038)	Quality assurance
		Quality test (R039)	Quality test
		Quality mgmt. (R040)	Strict quality requirements, Decrease in work quality
	HSE (F08)	Environment mgmt. (R041)	Strict environment regulations
		Safety mgmt. (R042)	Incongruity of evacuation program, Negligent accident, Insufficiency of safety education/management system
		Health mgmt. (R043)	Hygiene management and management system
		Security (R044)	Site security
	Human Resource mgmt. (F09)	Labor supply plan (R045)	Insufficiency of human network and participants infra, Labor resources, Availability of skilled and unskilled workers
		Labor mgmt. (R046)	Communication mgmt., application employee knowledge, lack of faith in participants, labor level, technique and mgmt. ability of site employee
		Training (R047)	Professional employee training in overseas project
	Accounting mgmt. (F10)	Organization mgmt. (R048)	Organization propriety and collaboration system, JV type, Collaboration system between company and site
		Finance/Fund (R049)	Financing method and lack of mgmt. skill, Deterioration of financial condition and lack of finance ability
		Financing (R050)	Financing plan, Financing cost
Project Risk (RTP)	Document and Administration mgmt. (F11)	Document mgmt. (R051)	Document mgmt., Data share system
		Administration mgmt. (R052)	Administration procedure mgmt.
	R&D (F12)	Technology mgmt. (R053)	Technology protection, Profit of technical investment
		Technical training (R054)	Technical training and mgmt. system
		Technology research (R055)	Market suitability of advanced technology, Technical support
		Information system (R056)	Poor information mgmt. system
	* Owner Support (F13)	Owner's requirement (R057)	Requirements reflection, Specific requirements, Unreasonable design change by owner, Performance requirement change, High rework/order change
		Owner's attitude (R058)	Relation with owner, Owner attitude
		Owner's ability (R059)	Change of finance, Change of owner organization/staff, Owner structure of possession, Project understanding and project performance ability of owner
	* Construction mgmt. (F14)	Construction plan (R060)	unavailability of infra facility (temporary facilities), Identifying limitations of available labor for any trade, Site analysis, Insufficiency construction plan and error
		Construction mgmt. (R061)	Weather, Contractor Technique, Constructability, Decrease in productivity, Increase in amount of work, Labor, Traffic, Design of contractor, Licensing and completion
		Site mgmt. (R062)	Uncertainty of geotechnical condition, Change of site condition

Table A1. *Cont.*

Level 1	Level 2	Level 3	Level 4 (RBS04)
		Constructor design ability (R063)	Lack of design ability and experience, Shop drawings
		Construction skill (R064)	Reflection of company's technique ability, Reflection of local subcontractors' technical ability, Complexity of construction method and applicability
		Site manager ability (R065)	Reflection of manager's technical ability, Lack of manager's project mgmt. ability
		Local company mgmt. (R066)	Unfriendly local subcontractor and friction, Coordination with utility companies, Local subcontractor ability, Information of local subcontractor
		Uncontrollable (R067)	Physical damage to project by riots, terrorist act, and so forth
	* Start-up and Operation Prepare (F15)	Labor/Resource/Equipment Procurement (R068)	Labor resource, Material resource, Decline of operation rate, Problem of equipment supply
		Start-up (R069)	Commissioning and performance test, Low quality of equipment, Commissioning plan, Fuel supply, Start-up schedule, Transfer facilities

* Additional business function in this research.

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