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MANAGING CONSTRUCTION RISKS OF AP1000 NUCLEAR POWER PLANTS IN CHINA

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Abstract

Large and complex construction projects face risk from various sources and the successful completion of such projects depends on effective risk management. This study investigates the risk faced by Chinese firms participating in constructing AP1000 nuclear power plants in China. AP1000 nuclear reactors are new, Generation III+ reactors designed by Westinghouse and to be built first in China. The semi-structured interview approach is used to elicit information from experts involved in the AP1000 projects in China. Based on the interviews, various sources of risk are identified. In addition to general risks that megaprojects normally face, there are unique risks that arise from various sources such as technological, political, organizational, and individual personnel risks. Risk management strategies are proposed to manage general and unique risks identified in the study. The findings of this study would be helpful for Chinese companies involved in the construction of AP1000 nuclear power plants to mitigate the risks associated with the projects.

Keywords: Risk management, construction risks, nuclear power plants, AP1000, semi-structured interview

1. Introduction

The Chinese electricity power industry suffers from different problems such as power shortage and improper choice of sources of energy. Recent rapid growth in the Chinese economy and the huge population lead to the problem of power shortage. Table 1 presents the sources of energy (e.g., fossil, hydro, and nuclear) for electricity generation and capacities of power plants in China from 1970 to 2001, where fossil fuels include coal, lignite, and oil (IAEA 2003). Recently China uses the coal as the main source of energy that represents about 75% of the total power output in China. However, in the world, usage of coal in power generation declines to 26% in 1996, because coal negatively impacts the environment and greenhouse gas emissions. In addition, in the past few years the price of coal has increased significantly. Therefore, based on the fact that the nuclear power is clean, in 2003, the Chinese government decided to use the world's most advanced technology to develop nuclear power to achieve continual economic development, expedite the energy development, optimize energy structure, and protect the environment (Ou 2007).

In China, as shown in Table 2, several nuclear power plants are in operation that supply only 2.3% of the total domestic electricity demand (Corradini 2003, Zhang 2007a), while several nuclear power plants are being constructed as given in Table 3. A number of nuclear power plants are planned or proposed to be constructed in China, which are listed in Appendix A.

All nuclear power plants that are in operation, under construction, or under consideration in China are Generation II or II+ except AP1000 and EPR. The AP1000 nuclear reactor is a two-loop 1000 MW pressurized water reactor utilizing passive safety features designed by Westinghouse Electric Company for nuclear power plants. This is a Generation III+ design that is not yet in operation anywhere in the world. The AP1000 design includes advanced passive safety features and extensive plant simplifications to enhance the safety, construction, operation, and maintenance of the power plants (Schulz 2006, Westinghouse

Table 1 Chinese electricity generation and installed capacity (IAEA 2003)

Year	1970	1980	1990	1996	1997	1998	1999	2000	2001
Electricity generation (TWh)									
Total	115.9	300.6	621.3	1079	1134	1158	1233	1368	1478
Fossil	95.40	242.3	495.8	878.4	924.7	938.8	1005	1108	1202
Hydro	20.50	58.3	125.5	186.7	195.1	203.8	212.9	243.1	257.5
Nuclear				14.3	14.4	14.1	14.8	16.7	17.4
Capacity of electricity generation plants (GWe)									
Total	24.18	65.87	137.9	236.5	254.2	277.3	298.8	319.3	338.6
Fossil	16.00	45.55	101.9	178.7	192.2	210	223.4	237.5	253.1
Hydro	8.18	20.32	35.98	55.59	59.75	65.05	72.97	79.35	83
Nuclear				2.27	2.27	2.27	2.27	2.27	2.27

Table 2 Nuclear power plants in operation in China

Plants	Province	Type	Net capacity (MWe)
Daya Bay (1 & 2)	Guangdong	PWR	2×984
Qinshan (1)	Zhejiang	CNP-300	300
Lingao (1 & 2)	Guangdong	PWR	2×986
Qinshan (2 & 3)	Zhejiang	CNP-600	2×600
Qinshan (4 & 5)	Zhejiang	CANDU 6	2×728
Tianwan (1 & 2)	Jiangsu	AES-91	2×1000

Table 3 Nuclear power plants under construction in China

Plants	Province	Type	Net capacity (MWe)
Lingao (3 & 4)	Guangdong	CPR-1000	2×1080
Qinshan (6 & 7)	Zhejiang	CNP-600	2×650
Hongyanhe (1-4)	Liaoning	CPR-1000	4×1080
Yangjiang (1-4)	Guangdong	CPR-1000	4×1080
Ningde (1-4)	Fujian	CPR-1000	4×1080
Sanmen (1 & 2)	Zhejiang	AP1000	2×1100
Haiyang (1 & 2)	Shandong	AP1000	2×1100
Taishan (1 & 2)	Guangdong	EPR	2×1600

Electric Company 2007).

Comparing the selection of AP1000 and ERP for the Chinese nuclear power plants, EPR has multiple redundant safety systems and is seen to be more complex and expensive. In addition, regarding to the EPR nuclear power plant at Taishan, Guangdong, the contract for the joint venture company is not expected to involve the technology transfer. The State Nuclear Power Technology Corporation (SNPTC), which is directly under China's State Council (Cabinet) and in charge of technology selection for new nuclear power plants, has selected the AP1000 reactor design and proposed the use of indigenized 1000+ MWe plants with AP1000 designs to be built at Sanmen, Zhejiang Province, and at Haiyang, Shandong Province. Furthermore, the AP1000 plants will give China a leading position with the third generation reactor technology and provide the platform for China's future nuclear technology development. Therefore, the Chinese government's nuclear power policy has two main objectives: 1) to adopt the AP1000 as the main stream of Chinese nuclear power plant type, and 2) to increase the nuclear power generating capacity from 9.11 million KWH to 40 million KWH by the year 2020 (Ou 2007). In May 2007, the National Development and Reform Commission of the State Council announced that its target for national nuclear generating capacity by 2030 is 160 million KWH (Chen & Sha 2007, Zhang 2007a).

Nuclear power plant projects, like other megaprojects in transport infrastructure, oil and gas extraction, and water projects, have a notorious reputation for cost overrun and delay (Flyvbjerg et al. 2003). According to practitioners, it is found that more than half of the nuclear power plant projects result in cost overrun, and almost all project durations are prolonged, while some projects are terminated before completion (Cohen 1990). Failures of constructing nuclear power plants on time and under budget are due to various reasons such as lack of materials, inaccurate estimation of project duration, and poor risk management. Among those, the most influential aspect for the failure is risk management. Therefore, risk management is a crucial part in managing the construction of nuclear power plants. Risk management in projects is a systematic process of identifying, analyzing, and responding to relevant risk factors that are not definitely known with the potential of adverse consequences on project objectives (Project

Management Institute 2009). The overall objective of this paper is to report a pilot study based on the semi-structured interview method to identify construction risks and to propose risk management strategies for the general contractor involved in constructing an AP1000 nuclear power plant in China.

This paper is organized as follows: the AP1000 nuclear power program in China is introduced in Section 2. The methodology that is used to identify the risks is described in Section 3. In Section 4, the two main categories of risks associated with AP1000 nuclear power plant construction in China and the proposed risk management strategies are presented. Some conclusions are discussed in Section 5.

2. AP 1000 Nuclear Power Program in China

As the first step to achieve the objectives of Chinese nuclear power policy, the United States and China signed a bilateral Memorandum of Understanding on December 16, 2006 that granted a deal for four AP1000 reactors to a consortium of the Westinghouse Electric Company and The Shaw Group for the nuclear power plants at Sanmen and Haiyang (Xiaoliang 2007). According to the agreement, the Chinese Nuclear Power Technology Corporation (SNPTC) pays 5.3 billion dollars to the consortium. The objectives of this agreement are: (a) to fully master the advanced third-generation technology (AP1000) by SNPTC, and (b) to build power plants at Sanmen and Haiyang using the AP1000 technology. As a result of the Chinese government's current nuclear power policy, there is going to be a huge development in Chinese nuclear power industry. Therefore, nuclear power plant construction industry in China is one of the lucrative businesses for Chinese architectural, engineering, and construction firms to get involved. Despite the huge opportunity of undertaking projects in the Chinese nuclear power plant construction industry, Chinese firms need to assess the risks associated with the construction of AP1000 nuclear power plants, where risks can be due to the advanced technology utilized in AP1000, the complexity of a project, required skills and resources, culture, and other reasons.

A number of attempts have been made on studying risk management to ensure the best chance of success in various projects. Influence of human being's personality and cultural background on risk management has been analyzed (Dvir et al. 2006, Flyvbjerg et al. 2003, Flyvbjerg 2006, Kutsch & Hall 2005, Nogueira & Raz 2006). Since mega-infrastructure projects are complicated and involved with various aspects during preparation, construction, and operations, activities do not always go according to the plan. There is a risk associated with each and every unexpected or unplanned event in a project because of inaccurate forecast of costs, demand, etc. (Flyvejerg 2006). The risk can be related to social, economic, political, or environmental. Hence, all related risks must be clearly indentified, acknowledged, and well managed. Developing different corporate strategies to minimize significant risks by using general risk management rules has been addressed in the literature. For example, a pilot study can be used to collect data and develop appropriate risk management strategies to avoid significant risk in mega-infrastructure projects (Turner 2005). A partnership between the public and private sectors is another way to transfer risks from the public sector to the private sector in public infrastructure projects. It has been suggested that only intermediate level of risk should be transferred to the private sector through the public-private partnership (Bing et al. 2005). Medda (2007) shows how a game theoretic approach can be used to study negotiation between the public and private sectors in such infrastructure projects. In managing risks with respect to the size of the company, Hyvari (2006) looks into critical factors and finds that project team communication is a critical factor for larger companies whereas adequate funding or resources is a critical factor for smaller companies. Flyvbjerg et al. (2003) suggest several ways to minimize risks: (1) completely eliminate the risk. For example, ensure that the central or local government to compensate for costs of risk; (2) buy risk management services. This approach is usually adopted to deal with the capital market risk; and (3) assign risks to parties who are capable of reducing risks either by mitigating the negative impact or reducing the likelihood of the event. Xie et al. (2006) investigate how management of risks can be integrated into bidding risk so that the risks in a software development project can be eliminated using various risk management strategies throughout the life cycle of the project. Importance of risk management within project teams has been introduced to identify risks and manage projects (Barber 2005, Ghosh & Jintanapakanont 2004, Taylor 2006).

There are studies on risk management in various projects. However, there are no studies that address the risk management strategies in AP1000 nuclear power plant construction. Moreover, there is neither an AP1000 nuclear power plant in operation nor under construction elsewhere in the world. Obviously, none of the firms has experience in constructing AP1000 nuclear power plants. Therefore, the objectives of this study are to identify the risks that firms face when constructing AP1000 nuclear power plants in China, and to propose risk management strategies that could be adopted by those firms.

In order to focus on the construction risks and develop risk management strategies, Figure 1 displays the organizational responsibilities of AP1000 nuclear power plant construction in China. Presently, there are two major owners of AP1000 nuclear power plants: (a) the Sanmen Nuclear Power Company that was set up in April 2005 to own the Sanmen project and to control the construction of it; and (b) the Shandong Nuclear Power Company Ltd. that was established in July 2004 to undertake the development, construction, operation and management of the Haiyang nuclear power project. The owner of a nuclear power plant is responsible to submit the preliminary feasibility study report, project proposal, and environmental impact assessment of the AP1000 nuclear power plant, and to propose the site of the nuclear power plant to various energy/electricity policy makers and regulators in China - NDRC, CAEA, SEPA, and NNSA, as shown in Figure 1. After getting approvals by all relevant agencies and regulators, an infrastructure contractor for preparing the site will be chosen.

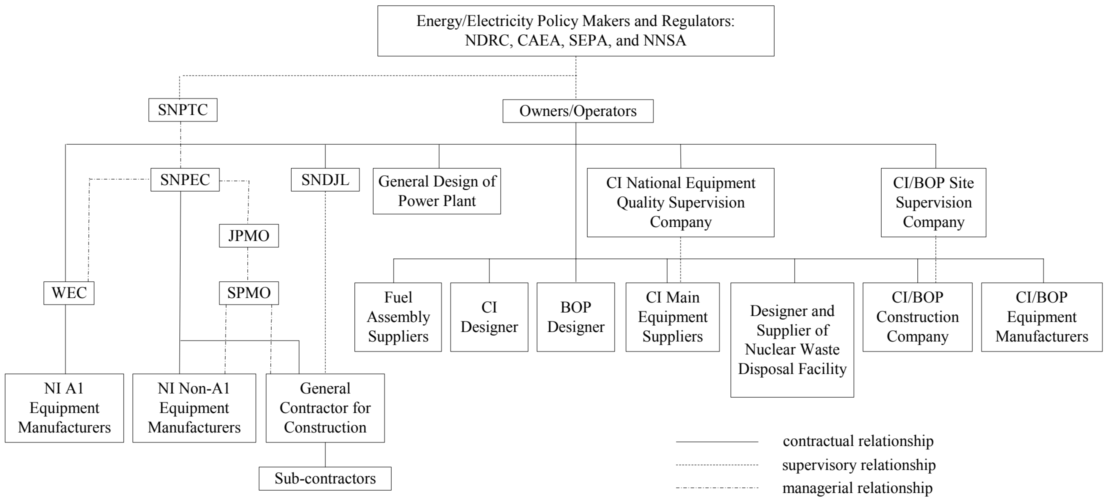
As mentioned earlier, SNPTC is mandated by the Chinese government to develop and implement indigenized AP1000 nuclear power plants by utilizing technology transfer from the Westinghouse Electric Company/the Shaw Group consortium. In these particular projects, the Westinghouse/Shaw consortium is responsible to provide blueprint and some equipment of AP1000 nuclear power plants. The Shanghai SNERDI Consultation and Surveillance Ltd, which is a part of SNPTC, carries out detailed design for the AP1000 nuclear power plants. SNPEC, another subsidiary of SNPTC, is responsible as the project management company for AP1000 nuclear power plants. The China Nuclear Industrial Fifth Construction Corporation (CNF) is responsible for construction of AP1000 nuclear power plants as the general contractor for construction of the nuclear island under the leadership of the China Nuclear Engineering and Construction Group (CNECC). The construction responsibility is shared by four subcontractors: the China Nuclear Industrial Huaxing Construction Corporation, the China Nuclear Industrial 22th Construction Corporation, the China Nuclear Industrial 23th Construction Corporation, and the China Nuclear Industrial 24th Construction Corporation. From the organizational responsibilities, it can be seen that the general contractor for construction of the nuclear island mostly faces the construction risks in AP1000 nuclear power plant construction. Construction risks faced by the general contractor involved in constructing an AP1000 nuclear power plant in China are identified in Section 4 and associated risk management strategies are proposed.

For coordinating owners/operators, SNPEC as the project manager, and the Westinghouse/Shaw consortium as vendors, a Joint Project Management Office (JPMO) has been established having the overall objective of successfully building indigenized AP1000 nuclear power plants in China. For each nuclear power plant site, there is a Site Project Management Office (SPMO). There are three types of relationship among organizations involved in constructing AP1000 nuclear power plants: contractual, supervisory, and managerial, as indicated in Figure 1 by the solid, dashed, and broken lines, respectively.

A nuclear power plant project, similar to other megaprojects, involves many parties. To successfully implement a project, it is crucial for parties to have a very clear means of communication. Regular progress meetings are one way to coordinate parties involved and to resolve conflict that may arise. Since the AP1000 nuclear power plants at Sanmen and Haiyang are the first ones to be built in the world, conflicts among parties are unavoidable. The JPMO/SPMO is mandated to be the overall organization responsible for coordinating various designers, manufacturers, suppliers, contractors and agencies involved in constructing an AP1000 nuclear power plant and to resolve conflict among parties, if the conflict has not been worked out by parties themselves.

3. Research Methodology

Knowledge elicitation techniques are used to identify the significant risks in AP1000 nuclear power plant projects in China. There are several elicitation techniques that aim at extracting knowledge such as observations, interviews, process tracing, and conceptual techniques (Cooke 1994). These methods are discussed briefly as follows.



Legend:

NDRC: National Development and Reform Commission

CAEA: China Atomic Energy Authority

SEPA: State Environment Protection Administration

SNDJL: Shanghai SNERDI Consultation and Surveillance Ltd

SPMO: Site Project Management Office

WEC: Westinghouse Electric Company/The Shaw Group Consortium

NI: Nuclear Island

NNSA: National Nuclear Safety Administration

SNPTC: State Nuclear Power Technology Corporation

SNPEC: State Nuclear Power Engineering Corporation

JPMO: Joint Project Management Office

CI: Conventional Island

BOP: Balance of Plant

Figure 1 Organizational chart of AP1000 nuclear power plant projects in China

Observations are one of the most powerful tools, since much can be learned from observing an expert performing a task (Drury 1990). Observations can be used to identify strategies, to study motor skills, to understand limitations, to extract information required, and to verify an expert's description of the task he/she performs (Hoffman et al. 1995).

Interviews are the most frequently employed of all knowledge elicitation techniques (Cullen & Bryman 1988). An expert offers his/her assessment based on information retrieved from past experience. The conversations are usually audio-taped or video-taped for later analysis. Interviews can be categorized into unstructured and structured interviews. Unstructured ones refer to free-form interviews where content or sequence is not predetermined. Structured interviews refer to interviews that follow a predetermined format, ranging from highly-structured to semi-structured (Shaw & Woodward 1990).

Process tracing techniques are used for specific tasks. Unlike informal observations, the data to be recorded is of a specified type. The most popular techniques include verbal protocols, non-verbal protocols, and protocol analysis (Shadbolt & Burton 1990). With the verbal protocols methodology, cognitive processes are inferred based on the expert's ability to articulate his/her knowledge. Non-verbal protocols need an elicitor's special techniques such as analysis and interpretation skills of an expert's eye movements, hand movements, face expressions, and gestures. Protocol analysis methods are utilized in analyzing the resulting verbal or non-verbal protocols (Sundstrom 1991).

Conceptual techniques are largely suited for eliciting knowledge about concepts and their relationships, providing an opportunity to focus on the conceptual structure of the domain. They center on data reduction, hopefully able to reveal the most salient features of the domain (Schvaneveldt 1990).

Extracting knowledge is a complicated task. As pointed out by Sasse (1991), internal knowledge is not directly observable. Researchers have shown that there are inconsistencies between extracted knowledge. For example, a study by Evans et al. (2001) shows how different knowledge elicitation techniques produce different results. Hence, it is important to choose the most suitable knowledge elicitation technique with respect to the study objectives and required cognitive aspects. Since no AP1000 nuclear power plant is in operation anywhere in the world, the semi-structured interview method is selected in this study to elicitate knowledge from experts who have been involved in constructing other types of nuclear power plants. The semi-structured interview method gives an interviewer the opportunity to actively interact with the participants (Cooke 1994). The directed-thinking approach including interviewing and brainstorming is one of the best approaches to identify risk (Chapman & Ward 1997).

According to Dixon et al. (2001), there is no generally acceptable rule to define how many participants should be included in the knowledge elicitation process. However, in order to understand and create a framework, it would be sufficient to select key participants from the source community. The selection can be based on several factors including depth of knowledge and willingness to participate. However, in general six to ten participants are adequate at the stage of understanding and creating a framework. In this research, 16 participants were selected.

The first part of the interview with each participant was a conversation where the interviewer explained the objectives of this study and asked some general questions and the participant also talked about his/her experience briefly. Profiles of the 16 participants are given in Table 4. A participant's years of experience include training. Each participant was informed that he/she would be contacted again. Afterwards, each participant was interviewed with 18 domain-specific questions given in Appendix B. Interview questions were designed with the purpose of gathering information on the risks in building AP1000 nuclear power plants in China. A semi-structured interview with each participant was conducted, which lasted approximately 90 to 120 minutes. The interview with each participant was designed to cover the predetermined questions, but was not intended to be administered in a highly structured manner. Throughout the interview, the interviewer gathered some information and further questions were formulated to better address the different aspects of the specific domain. From the semi-structured interviews, the information gathered is synthesized and the sources of risk are identified and categorized into two groups: general and unique risks. The results from the interviews are summarized in Table 5 where different sources of risk for each category are identified. The interview results are discussed in detail in the next section.

4. Interview Results: Identification of Risks and Proposed Risk Management Strategies

In a project, managing risk is a continuous and complex process. Chinese firms undertaking construction of an AP1000 nuclear power plant are likely to face with various risks such as design related risks, construction related risks, third party related risks, and so forth. These risks are categorized into two groups: general risks and unique risks.

4.1 General Risks

4.1.1 Identification of General Risks

The risks that are common in all types of projects including AP1000 power plant projects are defined as the general risks. For instance, the risk due to inadequate safety in a project is a general risk. Based on the interviews conducted, general risks of an AP1000 project in China are identified as follows:

1. Safety: It is an important aspect to successfully complete the project on time. An accident results in both suffering for the injured person and costs to the company. If any safety issue cannot be dealt with quickly, it has serious impact on progress of the project. For example, an accident may cause injury to a worker without directly affecting the progress of the project, if the company would be able to replace the injured worker. However, in this situation, if the project manager does not deal with the accident timely, then it may cause emotional undulation among other team members and the project may suffer from poor morale of other members, and this may bring an interruption in the progress of the project.
2. Complexity of the project: Due to the complexity of an AP1000 construction project, there are many parties involved in the project such as various contractors, suppliers, and outside agencies. As the number of parties increases, the chance of conflict increases. This makes it difficult to deal with uncertain issues with various groups involved in the project and increases the potential risk of conflict. For example, a meeting is held to discuss the possibility of replacing a certain type of material that is used to fabricate a piece of equipment. If there are only two parties participating in the meeting - equipment supplier and the designer - then it becomes obviously a technical issue and is easy to deal with. If an owner’s delegate also participates in the meeting, then it would be a little bit difficult to deal with, because the issue may include the cost of replacing the material. If one more representative of the construction company also participates in the meeting, then the issue becomes more complex, because the possibility of delay in replacing the material may arise.

Table 4 Participants, organizations and their positions

Participant	Organization	Years of experience Traditional nuclear power	 AP1000	Position
Participant 1	Company A	17	2	Consultant
Participant 2	Company A	25	2.5	Consultant
Participant 3	Company B	14	3.5	Manager
Participant 4	Company B	18.5	5	Project manager
Participant 5	Company C	19	4.5	Engineer
Participant 6	Company C	27.5	5	Project manager
Participant 7	Company D	25	3	Manager
Participant 8	Company D	33	4	Architect
Participant 9	Company E	17	3.5	Manager
Participant 10	Company E	35	4	Architect
Participant 11	Company F	15.5	2	Engineer
Participant 12	Company F	23	5	Project manager
Participant 13	Company G	31	4	Architect
Participant 14	Company G	26	5	Project manager
Participant 15	Company H	16	3.5	Manager
Participant 16	Company H	29	0	Project operation officer

Table 5 Summary of construction risks for AP1000 nuclear power plants in China

Risk categories	Sources of risk
General risks	Due to: Safety, Complexity of the project, Worksite conditions, Limited resources, and Delay in completing tasks.
Unique risks	Technological risks: Modularization, Lack of experts, Dispute among partners, Lack of operational skills, and Related activities versus duration. Political risks: Policy for equipment procurement, Policy for technology import and indigenization, and Policy for project implementation. Organizational risks: Operations strategy, Bidding strategy, Attitude towards risk, and Management authority. Individual personnel risks: Human errors, Concealing new design, Cultural and political influence, and Habitual relationships.

3. Worksite conditions: It is impossible to completely predict the actual worksite conditions in advance. The AP1000 nuclear power plants are completely new and there is no previous experience to draw from. Hence, there would be many unforeseeable problems that would emerge and need to be solved in the construction process. For example, during the construction of a building, when the actual cumulative tolerance deviates from the designed cumulative tolerance, modifications to accommodate the difference can be done easily. However, in case of AP1000, for example, during the fabrication of the containment vessel, when the actual cumulative tolerance deviates from the designed cumulative tolerance, modifications to accommodate the difference cannot be easily implemented because of the modular design technology, and this may cause delay in completing the project.
4. Limited resources: The contractors are committed to complete the project in the three-year period, while they are meeting the challenges from the booming Chinese economy. In other words, the contractors have to allocate their limited resources to meet the requirements of the AP1000 nuclear power plant construction as well as other projects that they are undertaking because of the booming Chinese economy. The AP1000 plant has been designed to make use of the modern modular construction techniques to shorten the duration of the project to three years. If a contractor fails to undertake the committed portion of the project by restructuring the limited resources, then the project is unlikely to be successful completed on time. In order to get involved in the Chinese nuclear power plant construction, two main construction companies have restructured their resources and others will be doing it in the coming years.
5. Delay in completing tasks: In AP1000 nuclear power plant construction, many modules have to be manufactured in factories. The most important characteristic of modularization is to allow the construction of many modules in parallel, so that the project duration can be shortened. This process may result in a significant risk if any module fails to meet specifications or gets delayed. For example, in AP1000 nuclear power plant projects, fabrication of the containment vessel and CA20 module, construction of the building, and installation of the equipment take place simultaneously. Hence, if there is any delay in any module, the overall project duration would be affected.

4.1.2 Proposed Risk Management Strategies for General Risks

Once the general risks in AP1000 nuclear power plant construction are identified, the significant risks can be highlighted. Then, the risk management team can focus on the significant risks to develop risk management strategies. Since it is impossible to reduce the impact of risks to zero, based on the policy of the individual company involved in the AP1000 nuclear power plant construction, an optimal way to minimize the risks should be developed.

The policy of a company may depend on many factors such as experience of the project manager, resource availability of the company, the number of projects that the company is currently involved, technology that the company uses, the share of the project that the company agrees to accomplish, and so forth.

An important step of risk management is identification of risk management strategies (Flyvbjerg et al. 2003, Xie et al. 2006). Risk management strategies discussed in the literature include eliminating risk (Turner 2005), transferring risk (Bing et al. 2005, Turner 2005), accepting risk (Turner 2005), and creating a contingency (Edaward & Boewn 1998, Turner 2005). Based on the interviews, literature, and experience in several projects by one of the authors, risk management strategies as presented in Table 6 are proposed depending on the nature of the risk and suitability of a risk management strategy.

A risk due to an uncertain event is defined based on the likelihood and impact of the event (Flyvbjerg et al. 2003). As a result, the likelihoods and impacts of risks are considered to develop risk management strategies, to minimize the general risks associated with AP1000 nuclear power plant construction. There are other methods in the literature for indentifying the critical risks such as factor analysis (e.g., Ghosh & Jintanapakanont 2004), hierarchical risk breakdown structure (e.g., Carr & Tah 2001), and heuristic technique (e.g., Madachy 1997).

Table 6 presents different risk management strategies that can be implemented for general risks if they occur. However, from the initial stage of the project, the risk management team should always monitor selected project activities that most likely face identified risks, so that the company can prevent the risk occurring in the first place. For example, the risk management team should coordinate with associated parties in the project for daily monitoring and briefing, and weekly meeting for update. At each step, the risk management team should carefully look into the possible development and take appropriate actions according to the risk management plan.

Table 6 Risk management strategies based on likelihood and impact

Case	Likelihood	Impact	Strategy
1	Low	Low	Acceptance
2	Low	Medium	Acceptance
3	Low	High	Insurance
4	Medium	Low	Minimization
5	Medium	Medium	Transfer
6	Medium	High	Contingency
7	High	Low	Transfer
8	High	Medium	Contingency
9	High	High	Abandonment

The strategies summarized in Table 6 are described as follows.

1. **Acceptance strategy:** Acceptance strategy is where the risk is accepted by a company when undertaking a part of a project. Acceptance strategy does not mean doing nothing. The risks must be documented for future reference and the risks need to be continuously monitored. If the conditions associated with the risk change, the likelihood of occurring and impact of the risk will change. In this case, depending on the status of the likelihood and impact, the corresponding risk management strategy should be implemented. In Table 6, for cases 1 and 2, a company can directly

accept these risks. For example, for the temporary warehouse at a project's site, flooding may be a risk and some equipment used in the project could be damaged by a flood. But it is very expensive to prevent this risk by means of effective preventive measures. Because the likelihood of flooding would be very low, adopting preventive measures is not necessary. Therefore, the risk is just accepted as the best choice. However, if the weather forecast indicates that there will be heavy rain that may cause flooding, then the risk management team should use other preventive measures to minimize the risk.

2. **Minimization Strategy:** Minimization strategy is where a company controls the risk, when the likelihood of occurring of an event is medium and the impact is low. In case 4, even though the risk's impact is low, its regular occurring on a medium basis may create obstacles in the progress of the project. The risk should be minimized by having frequent meetings with involved parties to monitor the situation and progress. This helps take appropriate actions including alternative processes or designs that can minimize the risks.
3. **Insurance strategy:** Insurance strategy is where a company transfers the risk to an insurance company, when undertaking a part of a project. In case 3, the risks, which have a low likelihood of occurring and a high impact, can have catastrophic results for both the project and the company. In this case, the company's best strategy is to buy insurance against the risk. For example, many pieces of expensive equipment required in a project can be damaged while they are being transported to the site. This risk of damage can be protected by insurance.
4. **Transfer Strategy:** Transfer strategy is where a company outsources an activity of a project that is the source of risk to a third party. Although the risk still exists, the risk is transferred to a third party who has the responsibility of handling it. Moreover, the company has an opportunity to improve its performance while outsourcing the risk for a better solution. When the risks have a high likelihood of occurring with lower impact, the company should engage a specialized third party in order to avoid the risks. For example, in AP1000 nuclear power plant construction, there are many modules to be produced, and the whole project schedule will benefit from the parallel construction. For a construction company, based on the available resources and technologies, the company should decide whether to produce those modules in-house or to subcontract them to a third party.
5. **Contingency Strategy:** Contingency strategy is accepting the risk and simultaneously creating a corresponding contingency plan. When the critical event occurs, the company implements the contingency plan to mitigate the impact. A contingency plan strategy generally consists of three parts: emergency response, recovery, and resumption. In cases 6 and 8, the company must deal with the contingency plan. For example, when

testing the equipment with a water cooling system, to prevent the damage of the equipment from water leak, the company must come up with a plan to prevent mechanical and electrical equipment from hazardous risks due to unexpected water leak.

6. **Abandonment Strategy:** Abandonment strategy is where a company abandons a project. Although an organization normally does not want to choose the abandonment strategy, it is sometime the most important for the organization to do so. First, a company should systematically analyze its current available resources and the direction of future development of the company. Then, the company should estimate the chance of success of the project, if the company involves in the construction of an AP1000 nuclear power plant. It is clear that when a risk has a high likelihood of occurring and has a high impact on the project, the project should be abandoned. For example, if a company does not have enough manpower, equipment, and expertise in construction of a nuclear power plant, undertaking projects in AP1000 nuclear power plant construction will be unsuccessful and both partners and owners will suffer greatly.

4.1.3 Monitoring General Risks

During the construction of an AP1000 nuclear power plant, it is expected that some risks may disappear after implementing appropriate risk management strategies. Some risks will remain at the same level while other risks change their nature with the project development. With respect to the unchanged risks, the project management team should monitor the risks closely to make sure that they are controllable. With respect to the risk that has changed its nature the project risk management team should prepare different risk management strategies.

4.2 Unique Risks

The risks that can only be encountered in AP1000 nuclear power plant construction are called the unique risks. For example, the top-open construction method is used in AP1000 nuclear power plant construction and is seldom used in other projects. In top-open construction, construction of the building and installation of equipment take place simultaneously. But in other projects, these two activities do not take place simultaneously. Because of novel construction methods and high complexity of an AP1000 nuclear power plant, the risk during construction is much higher than that of other projects. In this section, unique risks in AP1000 nuclear power plant construction are identified and categorized into four groups: technological, political, organizational, and individual personnel. Risk management strategies are proposed.

4.2.1 Technological Risks

An AP1000 nuclear power plant utilizes various new technologies. Therefore, the likelihood of construction problems due to technological risks is higher. For example, in an AP1000 nuclear power plant, the top-open construction as well as modularization approaches are employed to reduce the project duration. Despite the fact that these techniques reduce the amount of time and labor on site, the goal of a shortened project duration may not be achieved unless the Chinese firms master these new technologies. After getting the interview participants' opinions regarding new technologies, the following risks are identified:

1. Modularization: The purpose of modularization is to reduce the number of activities on site. Modularization transfers some of the activities to the manufacturing stage, where the modules are fabricated in factories. Therefore, a company should establish a list of activities that should be done on site and the activities that should be accomplished in the manufacturing stage. Nevertheless, it is impossible to accurately categorize the activities into two groups before the design is completed and finalized. Hence, the risks are likely to arise when the construction starts prior to the completion of the design.
2. Lack of knowledgeable experts: Many new technologies utilized in an AP1000 nuclear power plant require experts who are knowledgeable in several areas such as construction techniques, construction skills, information technology, and so forth. Due to the lack of skilled experts in these areas in China, the companies are exposed to risks.
3. Dispute among external and internal partners: New technologies employed in AP1000 can lead to internal and external conflicts among participating companies due to the uncertainty in the construction processes. Since conflict is a fundamental risk in project management, it is very important to resolve conflicts early.
4. Lack of operational skills: New technologies utilized in AP1000 require trained operators to reduce the errors. For example, one of the features of an AP1000 nuclear power plant is the safety of the reactor. The safety system is used to reduce possibility of human operational errors. For example, the core cooling system in AP1000 is passive relying on gravity and natural recirculation instead of forced circulation using pumps. However, no company in China has prior experience in implementing this new design feature. Therefore, all construction and testing companies should acquire the knowledge to implement this feature in an AP1000 nuclear power plant. Therefore, the lack of operational skills is a potential risk.
5. Related activities versus duration: Duration of a project is directly influenced by several factors such as the construction process and activities related to the project. The activities related to an AP1000 nuclear power plant include specific training programs, arrangements of specific required materials and equipment, and procurement of reactor vessels and steam generators which have a long procurement lead-time. However, it is difficult to be proactive to initiate these related activities, because of inexperience in constructing an AP1000 nuclear power plant. Therefore, there is a potential risk in meeting the promised duration of the overall project.

4.2.2 Political Risks

AP1000 nuclear power plants are a high-tech project that brings technologies into China.

Therefore any changes in China's import and export policies could have a major impact on the project. For example, a delay in the delivery of essential equipment, which is imported, could prolong the entire project. Political risks related to AP1000 nuclear power plant construction in China are identified from the interview participants' opinions as follows.

1. Equipment procurement: Prototype reactor, used in the first AP1000 nuclear power plant in China, is the first design in the world. Therefore, many unforeseen problems may emerge from the reactor. To reduce these risks, at the beginning, SNPTC should import only one reactor. Actually, SNPTC imports four reactors simultaneously. Therefore, the cost overrun is a potential risk.
2. Technology import and indigenization: The Chinese government's policy is to use the AP1000 advanced design and technologies as a basis to make improvements in the Chinese large-size advanced nuclear power plants (Xiaoliang 2007, Zhang 2007a). Based on the agreement between Westinghouse and SNPTC, Westinghouse provides the general blueprint design, while Chinese designers complete the detail design (Zhang 2007b). Because this process provides opportunities for Chinese designers to learn so that they can contribute to the development of large-size advanced nuclear power plants in China in the near future. However, this process would expose risks related to the design such as unclear scope of work, inadequate specification, document conflict, and frequent modifications.
3. Project implementation: As a high-tech project and prototype, Chinese designers need more time to gain knowledge and experience to design the nuclear power plants. This brings obstacles to the current requirement towards completion of the project in three years. Therefore, designers will have less time to design and communicate, as they have to implement the project according to the required timeline established by the government. This not only will lead to increase in the cost of design modifications, but also would increase the possibility of not completing the project on schedule.

4.2.3 Organizational Risks

As a complex and high-tech project, during the construction period of an AP1000 nuclear power plant, many partners will be involved. When they work together, conflicts are likely to emerge due to different work styles and internal cultures. In addition, if a project employs a company that has an improper work style for that project, the project is likely to be unsuccessful. Risks that may emerge in AP1000 nuclear power plant construction due to organizational policies and processes are identified as follows.

1. Operations strategy: An organization's operations strategy must be flexible to meet the requirements of AP1000 nuclear power plant construction projects. For a company to participate in AP1000 nuclear power plant construction, it has to be able to spontaneously adjust its operations strategy. For example, AP1000 nuclear power plant design requires top-open construction.

Therefore an organization involved in AP1000 must be able to change its operations strategy to meet this requirement. This change is necessary since the top-open construction method has never been implemented in China.

2. Bidding strategy: Construction of AP1000 nuclear power plants is one of the highly competitive projects in the construction industry in China. Some of the participating construction companies in AP1000 nuclear power plant construction do not have adequate experience and knowledge. To increase the chance of getting involved in AP1000 projects, some companies may use illusive data for unfair competition. Therefore, these companies have higher risks. For example, when the owner of an AP1000 project does not have an effective process to evaluate the bidders, some companies will have a chance to provide illusive data to take part in the project despite lack of resources. As a result, the project will be unlikely to be successful.
3. Attitude towards risk: Some companies, which have a good reputation for troubleshooting problems, are unwilling to change their risk management strategies. Although risk management planning is beneficial, these companies are often used to deal with any risk when it arises. When a company has this kind of tendentious attitude, the project will simply fail due to the lack of actively managing certain risks.
4. Management authority: Some managers ignore participations or inputs of employees in goal setting. Instead, they prefer to make optimistic decisions by themselves. For example, when a manager requests employees to finish a task in 22 months instead of 32 months, the probability of the project to be successful will decrease. This optimistic judgment of the manager does not include the opinion or capacity of employees.

4.2.4 Individual Personnel Risks

AP1000 nuclear power plant construction utilizes individuals with different skills and professions. The following risks related to individual personnel are identified.

1. Human errors: In principle, risks arising from people are the most common and dynamic of all sources of risks. Almost all project failures can be traced back to human errors. As an international collaborative project, AP1000 has people coming from different regions to work together. These employees have different cultural backgrounds, lifestyles, methods of working, and mindsets. When they work together, there would be misunderstandings and conflicts, which could be destructive to the progress of the project.
2. Concealing new design: Chinese designers do not want to share their tasks for designing an AP1000 nuclear power plant with designers from other countries. Therefore, Chinese designers will try their best to provide a complete and controllable design. As a result, an external design will appear to increase the cost, difficulty of constructing, and conflict among designers, owners, and contractors. This may cause various delays.
3. Cultural and political influence: if a

manager could not achieve success during a short executive period, the company would replace the manager based on political and cultural pressure. Therefore, whenever different managers are responsible for a project, they would introduce new strategies and processes. This would definitely affect the progress of the project.

4. Habitual relationships: The habitual or cultural relationships among people in East Asia encourage mutual help at workplaces. This sometimes makes it difficult to pinpoint the origin of a risk. For example, in a team, if one of the members does not play his or her role, other members are unwilling to disclose the fact, causing risks during a project.

4.2.5 Proposed Risk Management Strategies for Unique Risks

It is not only important to identify the unique risks, but also crucial to propose effective risk management strategies to deal with the unique risks. In order to effectively manage the unique risks, potential risks under each category of unique risk are identified in Table 7. A pilot project can be used to collect data and develop appropriate risk management strategies that can be applied in a full-scale implementation of the program in the future (Turner 2005). The main purpose of this study is to identify risks and propose risk management strategies, so that companies involved in the pilot projects of the Chinese AP1000 nuclear power program, currently being under construction, can take the initial step to manage risks. As addressed in this research, there are many unique risks including shortage of experts, resources, and manpower in a third generation AP1000 project. Several risk management strategies for megaprojects have been identified in the literature (e.g., Flyvbjerg et al. 2003). Based on the interviews, literature, and experience in several projects by one of the authors, several risk management strategies as given in Table 7 are proposed for managing the unique risks considering the nature of the risks.

The strategies summarized in Table 7 are described as follows.

1. **Research Strategy:** Research strategy is defined as the systematic gathering, recording, and analyzing of data related to a risk. As a high-tech project, there are many technical related risks. Many of these problems are related to inadequate information available in the project. If more knowledge or information could be gathered before implementing, many uncertainties could be resolved effectively. In addition, if a problem is unavoidable, research can provide alternative methods for solving the problem. For example, when a project team faces a problem, the first step is to decompose the problem into a finite number of sub-problems. For each sub-problem, the team should identify familiar and unfamiliar issues, and then the team should concentrate on the unfamiliar issues and solve them effectively.

   Although there are many risks associated with new technologies and novel processes, research can reduce the possibility of failure. It is the immanent nature of human beings for breaking through traditions to develop new skills. Some of the team members in the project will find that learning new technologies is their best interest, and therefore they would engage in research. As a result, members will gain adequate knowledge by self-education during the progress of the project

2. **Negotiation Strategy:** The lack of understanding is one of the common aspects of failure in effective risk management. Therefore, communication can enhance interpersonal understanding, which could increase the probability of success for a project. Negotiation is the most important method of communication that is used by companies involved in a project. Negotiation can be used for different purposes such as strengthening relationships among team members to prevent disputes, and clarifying problems in order to avoid failure. Therefore, negotiation strategy could remarkably reduce the risks that arise because of cultural or personal reasons. By negotiation, a better way could be established in the initialization phase of the project to build suitable team members for the project.

3. **Monitoring Strategy:** Risk monitoring is significantly important to analyze information and to make an effective decision. In the initialization phase of a project, the monitoring system is employed to inform the risk management group about the problematic areas before the risks become threatening or catastrophic. For example, some risks may have a low likelihood of occurring, but have high impact for the project. In addition, an advance and effective monitoring system could also influence: (1) the impact of a potential risk on the project, (2) the probability of the risk occurring, and (3) the information for the project team to execute proper mitigation actions at the right time.

4. **Controlling Strategy:** In a stable environment, a company with a strong internal control strategy has less exposure to risks than a company with a weak internal control strategy. A key controlling strategy includes an effective execution plan of a project, which reduces the number of uncertainties related to the project, and assists the project staff implementing the procedures according to the plan. To minimize risks, the execution plan should be made from the beginning of the project. Moreover, controlling actions should be implemented to minimize risks that are identified based on the ongoing monitoring and evaluation of potential risks, as well as the schedule of contingency plans. An effective execution plan can reduce the probability of risks occurring and increase the likelihood of the successful completion of the project. Therefore, defining the project activities, creating a well defined list of related activities, and effectively planning the project are major concerns of the project team. Nowadays, almost all the project teams use the work breakdown strategies to develop a detailed project plan. The project team can use the plan to control the potential risks.

Table 7 Risk management strategies for unique risks

Category	Potential Risk	Management Strategy
Technological	Unclear requirements, conflict of design	Research
	Vague problems, inadequate design	Negotiation
Political	Deliveries from foreign countries, contractor failures	Monitoring
Organizational	Financial failures of contractors, changeable project management, changeable business environment, inadequate resources, tendered prices, subcontractor delays, productivities of companies	Controlling or Negotiation
Individual personnel	Delays in solving exposed risks	Monitoring or Controlling
	Uncooperative activities, unwillingness to change	Negotiation

Control of over-optimistic schedules is another issue that should be taken into consideration during the planning stage of a project. That is, most people tend to judge the project events more optimistically than pessimistically. According to Flyvbjerg (2006), in order to create a more accurate project plan, a project team should focus on:

(a) The internal view - on project itself. This is concerned with unfamiliar novel techniques, using the team members' experience and knowledge to judge the activities and their related events.

(b) The external view - by employing experts who are unfamiliar with the special project and ignoring the details of the project, create a rough project plan by using the experiences of similar projects.

The project team should combine the external and internal views to create a more accurate project plan. The external rough plan can be used as a framework and the internal plan can be utilized as a detailed supplement regarding the special activities to reduce the probability of risks occurring. During the implementation phase, the project team should insist on identifying and monitoring the risks, because risks may change as the situation varies. As a result, unforeseen risks can be incorporated into the project plan. To control these types of risks, the project team can use general methods such as kick-off meeting, milestone planning, and top-down estimation.

5. Conclusions

AP1000 nuclear power reactors are a new, Generation III+, design by Westinghouse. Up to now, there are no AP1000 nuclear power plants in operation anywhere in the world. This research identified a number of sources of risk by using the knowledge elicitation process of semi-structured interviews, conducted with 16 experts who are involved in the AP1000 nuclear power plant construction in China. The semi-structured interview technique was selected based on the study objectives and required cognitive aspects. Based on the results, the risks faced by firms participating in constructing AP1000 nuclear power plants in China are categorized into two groups: general and unique risks. The unique risks are further divided into four types: technological, political, organizational, and individual personnel risks. The risk management strategy for a general risk is proposed based on the likelihood and impact of the risk, while the risk management strategy for a unique risk is proposed based on the nature of the risk; and those risk management strategies are discussed. This study would be useful for Chinese firms that are embarking on the journey of constructing AP1000 nuclear power plants in China to mitigate the risks associated with the projects.

The information for this research was obtained from interviews with 16 experts from China who have years of experience in building traditional nuclear power plants and relatively short experience in constructing AP1000 nuclear power plants. Since no AP1000 nuclear power plant is in operations anywhere in the world and currently only two are being built in China: Sanmen in the Province of Zhejiang and Haiyang in the Province of Shandong, as pilot projects under the National Economic Plan of China, the information obtained from a small number of experts, who are all from China, makes it difficult to generalize the findings to other countries, in particular the unique risks, because some of the unique risks are more related to China. However, this is an initial investigation of the construction risks arisen from China's large AP1000 nuclear power plant program that should not be overlooked. In the future, research should be conducted to update, validate and generalize the findings by obtaining data from the current projects as they progress and from new projects as well as by applying risk assessment techniques.

Table 8 Nuclear power plants to be constructed in China

Plants	Province	Possible type	Net capacity (MWe)
Fangjiashan (Qinshan 5)	Zhejiang	CNP-1000	2×1000
Bailong	Guangxi	CPR-1000	2×1080
Tianwan 2	Jiangsu	AES-91	2×1060
Wuhu 1 (Bamaoshan)	Anhui	CPR-1000	2×1080
Lianyungang 2	Jiangsu	CPR-1000	2×1080
Hongshiding 1 Rushan	Shandong	-	2×1000
Fuqing 1/Hui'an 1	Fujian	-	2×1000
Tianwei/Shanwei Lufeng	Guangdong	CPR-1000	2×1080

Table 9 Proposed nuclear power plants in China

Plants	Province	Possible type	Net capacity (MWe)
Heyuan	Guangdong	-	4×1000
Tianwan 3	Jiangsu	AES-91	4×1060
Hongyanhe 2	Liaoning	CPR-1000	2×1000
Rongcheng, Shidaowan	Shandong	CPR-1000	4×1000
Haiyang 2	Shandong	AP1000	4×1100
Tianwei 2, Lufeng	Guangdong	-	4×1000
Bailong 2	Guangxi	-	4×1000
Yangjiang 2	Guangdong	-	2×1000/1500
Sanmen 2	Zhejiang	AP1000	4×1100
Haijia	Guangdong	-	2×1000
Jinzhouwan	Liaoning	-	2×1000
-	Jiangsu	-	2×300
-	Hainan	-	2×300
Taohuajiang, Yueyang	Hunan	-	2×600
Taohua, Lishanhe Yiyang	Hunan	-	4×1000
Fuling	Chongqing	-	2×900
Bamaoshan, Wuhu	Anhui	CPR-1000	4×1000
Baishan	Jilin	-	4×1000
Gaokeng	Hubei	-	4×1000
Guidong	Guangxi	-	4×1000

Appendix A. Future Nuclear Power Plants in China

In China, in addition to nuclear power plants that are in operation or under construction, a number of nuclear power plants have been planned under the 11th Five-Year National Economic Plan (2006-2010) to be constructed as shown in Table 8. Moreover, several nuclear power plants have been proposed to be constructed in the near future, as given in Table 9 (World Nuclear Association 2007).

Appendix B. Questions Used in Semi-structured Interviews

The interviews were conducted in Chinese. The questions used during the second session are translated into English as follows:

1) Please comment on the current nuclear power stations in China and their impact on AP1000.
2) What types of risk do you expect to be

faced with in the AP1000 project?
3) What types of risk did you meet in your recent projects? Please explain how you dealt with the risks?
4) Are there any other effective risk management strategies in nuclear power projects?
5) Are there significant attributes on the site such as extreme weather or shortage of infrastructure that may impact on project performance?
6) What types of risk do you think that the owner may have?
7) Are there significant constraints for the project schedule?
8) For a project team, what capabilities are you concerned about? What actions should Chinese firms take to reduce risks?
9) What type of risk is most likely to come from the design?
10) What is the main problem in your company for the upcoming AP1000 project?
11) What do you think is the best way to deal with the risk of relationship with a third party?
12) What are your opinions if you intend to build new plants in China?
13) Are skilled construction workers easily available in China?
14) In your latest project, had risks been identified by the project team prior to the research?
15) Why do some risks tend not to be identified or managed?
16) Are there significant environmental, regulatory considerations that may constrain the project?
17) What are the attributes of the various types of projects undertaken by your company?
18) Do available routes and lifting paths allow using of modules with the dimensions set by truck, rail, or barge shipment?

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