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Assessing and understanding the key risks in a PPP power station projects

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Abstract

This research was undertaken to develop a user-friendly, systematic management tool to understand and assess the key risks specific to PPP power station project with the ultimate goal of improving project performance. The study develops a conceptual risk assessment system (RAS) using combined risk map and fuzzy sets theory for assessing PPP projects risks. The proposed system has then been applied to a PPP power station project in Iran in order to demonstrate its effectiveness. The combined risk map and fuzzy sets theory approach is very effective to assess project risks across project, work package and activity levels. According to risk relative importance values, the extreme risk level ranked ones (out of 68 risk items) are assumed as an appropriate way to represent the key risks. In one hand, the conventional project risk assessment frameworks emphasize on managing business risks and often ignore operational risks. On the other hand, the studies that deal with operational risk often do not link them with business risks.

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However, they need to be addressed in an integrated way as there are a few risks that affect only the specific level. Hence, this study bridges the gaps.

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Keywords: Risk assessment, Public private partnerships (PPPs), Risk map, Fuzzy sets theory, knowledge-based fuzzy inference system

1 Introduction

Like most developing countries, up to 2006, most of the generated electricity in Iran had been produced by the government producers, sold to the country's wholesale power market and purchased by the Iran's Grid Management Company (IGMCo). Statistics show that electricity consumption, in 2006 compared with 2005, and has risen to 6.85 percent for each household, 10.68 percent for public sector, 11.78 percent for agriculture, 10.69 percent for industry and mines, 5.47 percent for business and 11.07 percent for street lighting [28]. Thus, Iran's power industry needs large investment annually, to cope with this rising demand and to develop the related infrastructures. In response, Iran's government are tapping the private sector for capital, technology, and expertise to finance, develop, and manage power station projects that called public private partnerships (PPPs) projects. Iran Power Generation, Transmission & Distribution Management Co. (Tavanir) opted that effectiveness of PPP is based on a partnership approach, where the responsibility for the delivery of services is shared between the public and private sectors, both of which bring in their complementary skills to the enterprise. Hence in 2006, from the total of 46,260 MW generated electricity in Iran, approximately 44,510 MW had been produced by the governmental electricity companies and about 1750 MW by the private sector under Energy Conversion Agreements (ECAs). Up to 2010, Tavanir has signed eighteen BOO and BOT power station projects based on ECAs with the private sector [29].

While power station projects under PPPs projects may appear as attractive investments, such projects usually involve elevated levels of risk and uncertainty [17; 11]. Walewski [31] found that 63 percent of 1,778 projects funded by the World Bank between 1974 and 1988 experienced significant cost overruns. Also, Flyvbjerg et al. (2002) examined 258 large infrastructure projects covering 20 countries, and they found that cost overruns occurred in almost 90% of the projects examined, with the highest cost overruns of 86% and 28% on average. Various risk factors influence PPPs projects cost and schedule performance from project conception to completion. Some of these factors are inherent to organizations that are solely responsible for managing them, whereas others are closely related to the political, cultural, economic, and operational environments of the project's location [36]. In practice, project participants tend to be indifferent to risks outside of their control or believe that measures such as forms of contracts and insurance adequately allocate risks between the various parties. Furthermore, many owners and contractors are unaware of the full range of these risks, and few have demonstrated the expertise and knowledge to manage them effectively. As a consequence, poor cost and schedule performance, conflicts, and even business failures are among the consequences for organizations that fail to identify, assess, and manage the risks associated with PPP projects.

PPP projects risk assessment, especially at the early stages of the project, is intricate for both private and public sectors because the nature of risk is usually affected by numerous factors including human errors, the data and available information [13]. In many circumstances, it may be extremely difficult to assess the risks associated with a project due to the great uncertainty involved. However, evidence shows that there is a gap between the existing risk assessment models and their application and use by contractors and owners [2; 31]. Complexity of the situation and the extensive resource commitment necessary to perform good risk assessment are among the reasons that have been put forward to explain why this is the case, and no easy-to-use management tool is currently available that can assess the risks specific to power station projects under PPPs projects. As a result, there is a need to develop such a tool.

In order to improve PPP power station projects performance, it is critical that consideration be given to the portfolio of risks that occur to all participants across the life cycle of a project [26]; and requires a risk assessment [32]. There are mainly three ways to perform a risk assessment: qualitative way, semi quantitative way, and quantitative way. In this paper the semi quantitative approach is taken into account and risk map is used for risk assessment. In traditional approach the risk factors are expressed by crisp categories, and number of categories for each risk factor depends on the analytics. However, in process risk analysis, real situation is often not crisp and deterministic due to number of uncertainties. In such a situation a fuzzy logic can be used. According to Zadeh [34] fuzzy logic or fuzzy set theory can work with uncertainty and imprecision and can solve problems where there are no sharp boundaries and precise values. The concept of a fuzzy set provides mathematical formulations that can characterize the uncertain parameters involved in particular risk analysis method. In such a way all risk components were expressed in terms of fuzzy sets and similarly to crisp risk map the fuzzy risk matrix will develop. Therefore, the primary objectives of this research investigation were to: 1) develop a user friendly, systematic management tool and process to assess the risks specific to power station projects in Iran with the ultimate goal of improving project performance; 2) quantify and prioritize the relative importance of the key identified risks in order to gauge which risks have the highest impact, and to provide guidance when risk impacts are unknown or when uncertainty is high.

The paper is organized as follows: The next section reviews the literature of PPP projects, risk management process by emphasis on risk assessment, and literature related to risk assessment research in the Iran’s’ PPP projects. In section

3, we adopted knowledge-based fuzzy inference approach by risk map to identify the key risk items. In section 4, results and discussion presented. Finally, some conclusions are pointed out at the end of this paper.

2 Literature review

2.1 PPPs projects

Public private partnerships (PPPs) in facilities development involve private companies in the design, financing, construction, ownership and/ or operation of a public sector utility or service (Figure 1) [24; 33]. Such partnerships between the public and private sector are now an accepted alternative to the traditional state provision of public facilities and services. Arguably, the joint approach allows the public sector client and the private sector supplier to blend their special skills and to achieve an outcome, which neither party could achieve alone [24; 25].

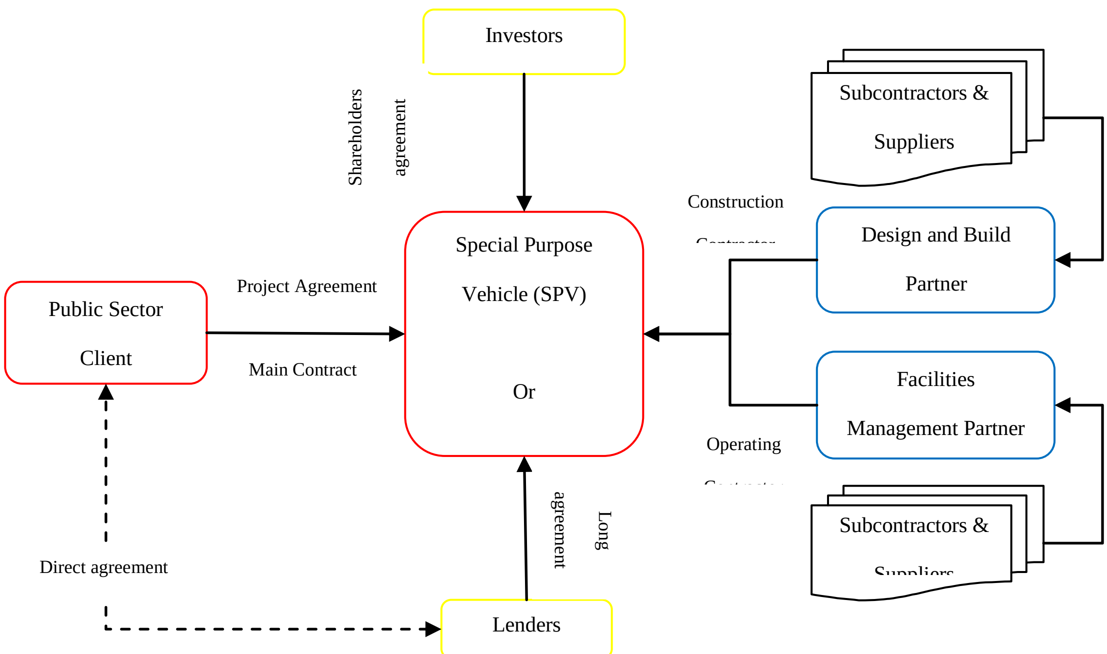

Figure 1: Contractual relationship and agreement between key parties in PPP

PPP projects are characterised by five distinct phases of preliminary stage, identification and appraisal, planning and design development, construction, and service delivery and operation [13; 26]. There are number of distinct activities associated with each phase. By far, the most complicated phases are planning and design development associated with detailed assessment of the public sector or client's needs to justify the project and to choose a preferred bidder and the operation and service delivery phase to ensure that the public sector achieves value for money (VFM). From the public sector client perspective, the operation and maintenance phase is the most crucial to ensure that value for money is achieved in delivering services [15]. Each phase is associated with specific steps or stages to achieve the objectives of the PPP project.

However, it is widely recognized that an effective PPP policy and a strategic framework are required where the public sector is able to identify specific development needs, and engage the private sector to address them using their knowledge, innovation, technology, finance, technical and management skills [33, 11].

2.2 Risk management process

Every risk evolves through three main phases [1]: the potential risk, the actual occurrence, and the impact. Risk should be perceived and treated early since risk will be probably developed to the last phase of its potential loss or harm. This research considers that the management of risk is not only proactive but it can be the reactive approach to manage risk when it is already occurred. Moreover, the risk management can be viewed as not only problem preventing tool but also problem solving tool [7]. Increased concerns about project risk have given rise to various attempts to develop risk management process (RMP) methodologies. Generally, the RMP is described as a systematic approach to deal with risk. The RMP should establish an appropriate context; set goals and objectives; identify and analyze risks; and review risk responses [32]. Various studies have proposed the process of project risk management for project success [6; 23; 30]. Though some studies used a detailed process for specific application [16], or a modified process for evaluating the risk ranking of various projects [3], the general project risk management process consisted of four phases: risk classification and identification (Risk allocation), risk assessment, risk analysis, and risk control [18].

Risk assessment is the vital link between systematic identification of risks and rational management of the significant risks. The risk assessment aims to evaluate the consequences associated with risks and to assess the impact of risk by using risk analysis and measurement techniques [14]. In this paper the semi quantitative approach is taken into account and risk map is used for the risk assessment. The semi quantitative method applies to the categorization of those components and final risk score is achieved using different methods. Risk assessment is an evaluation of probability (likelihood) that each risk will occur, as well as its related consequences (impact), does indeed occur [7]. Some risks can have serious ramifications, whereas others may never occur or if they do happen will have little impact on the project [20].

2.3 Risk assessment research in the Iran PPPs projects

In the recent years, little study was committed to systematically identify and manage risks in the Iran PPP power station projects industry and hence the PPP activities in Iran are exposed to many risks [27; 9; 19]. For example, Sobhiyah et al. [27] conducted case study to increasing VFM in PPP power station projects. They focused only on market and revenue risks; while case study agreement could answer Iranian government's urgent need for electricity demand in short-term, due to poor market and revenue risks allocation, it cannot contribute to competitive market conditions and thus, cannot achieve VFM in long-term by contracting such agreement.

These studies have not been systematically studied risks associated with construction activities and managing strategies have not been systematically established in the PPP power station projects industry yet.

3 Research Methodology

This paper is the second stage of a funded Ph.D. thesis, which aims to design a knowledge-based risk management system for PPPs projects related to power station projects in Iran. At the first stage, we used the grounded theory and

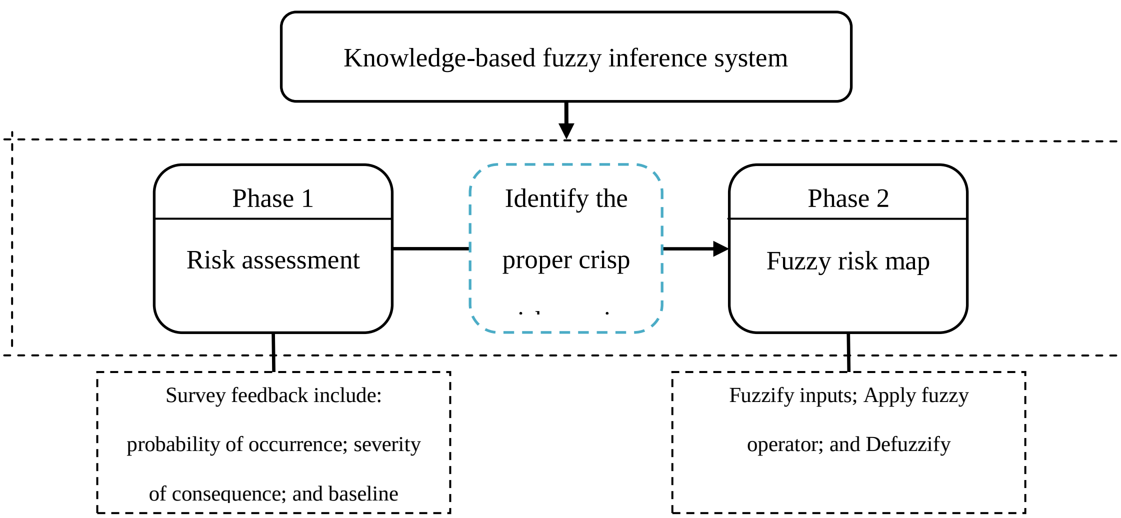

Figure 2: Knowledge-based risk assessment model

member checking to reorganize and analyze the risks influencing PPP projects in the past literatures and classified them into three risks meta-level and nine category groups. The members included the PPPs projects staff in SPV and the risk management personnel large-scale project-based enterprises. The researcher identified 68 knew the risks influencing PPPs projects identified in power station projects.

At the second stage (means this paper), aims to understand the key risks associated with power station projects in the Iran PPPs projects industry. A risk assessment model based on fuzzy reasoning is proposed as shown in Figure 2. The model consists of two steps: questionnaire survey step for understanding the proper risk map and then fuzzy inference step for understanding the key risks based on risk map approach. The details are described in the following sections.

3.1 Risk assessment map approach

Risk map is a tool to conduct subjective risk assessment for use in different process hazard analysis (PHA) including the layer of protection analysis (LOPA). The bases for risk map are the definition of risk as a combination of probability of occurrence and severity of the consequences. In order to build risk map the following steps need to be undertaken: 1) Categorization and scaling of the probability of occurrence and severity of consequences; 2) Categorization of output risk index; 3) Knowledge acquisition to build-up rule-based risk assessment; 4) Representation knowledge to generate of the risk map [7; 37].

The categorization of the probability and severity depends on the type of activity or specifics of the processes involved. In this paper, risk map were celled 5×5—meaning that there are 5 different levels of probabilities and 5 different levels of severity of consequences. This matrix has 25 risk cells. Also, we have applied four risk categories: Extreme risk (E) – occurrence would prevent achievement of objectives, causing unacceptable cost overruns, schedule slippage, or project failure; High risk (H) – could substantially delay the project schedule or significantly affect technical performance or costs, and requires a plan to handle; Medium risk (M) – requires identification and control of all contributing factors by monitoring conditions and reassessment at project milestones; Low risk (L) – normal control and monitoring measures are sufficient [35]. The relation between probability, severity and risk categories is described by the knowledge-based risk rules. This is presented by the classical logic implication as follows:

IF probability of occurrence is "p"' category AND severity of consequences is "s" category THEN risk is "r" category.

The above risk rules are obvious for the boundary categories of the probability and severity, e.g. IF probability of occurrence is "low" and severity of consequence is "negligible" THEN the risk category may be assessed as a "low risk" only. The situation is more difficult for intermediate categories of probability and severity. In such cases an expert opinion is applied with the application of an interpolation scheme.

The categorization of all parameters and the risk rules provide a risk tolerance zoning and constitutes the risk map. To apply of risk map, after assessment of the probability and severity categories the risk category as one out of four categories is specified using risk map. This is a basis for further risk control measures. Note that procedures, which use qualitative verbal descriptors, e.g. low, high, or possible, are quite vague and imprecise, however risk analysts frequently use them. Uses of such value judgments introduce uncertainty that is a result of fuzziness, not randomness [22; 8; 21]. The selection of proper risk map is an important management task that is included into safety policy that based on PPP power station projects industry we selected the “hard” map that represents the high cost map however is safer. There would be a benefit if baseline risk value could be determined for each element. This baseline guidance value of risk probability and severity would be of assistance to project participants when the risk is unknown, and would also provide the framework to select a proper risk map. On the other hand, the best way to quickly develop reasonable and credible relative impact values for each element was to rely on the knowledge and experience from a broad range of PPP power station projects industry experts.

3.1.1 Questionnaire survey

The questionnaire was designed to understand the proper risk map for PPPs power station projects in Iran, so the interviews are collected from public and private sectors among this industry. The questionnaire designed for this research consisted of three parts, including: (1) the first section explained the purpose of the research, definition of some key terms, and critical rules to achieve the proper’s knowledge of experts; (2) The second carried a total of 68 risks associated with PPPs power station projects and asked respondents to review and indicate the probability of occurrence of these risks on each PPPs project life cycle step (program decision, pre-project planning, engineering & design, construction, and operations) and the severity of consequence on each project objective (time, cost, quality, safety and environmental sustainability), measured on a five-point Likert scale, for each risk item. Also each participants must to determine the baseline relative value to guidance of each risk level based on four risk categories the mentioned in last section; (3) The third section was intended to gather information about the respondents’ profile, including: industry sector, hierarchical level, employment of respondents, and PPP experience of respondents.

A pilot study was then completed, involving participants with PPP projects experience. The results of the pilot were analysed, and prompted refinement of the research instrument before it was applied to the target audience in the selected companies. A total of 120 questionnaires, including 69 valid questionnaires with a return rate of 57% during the period of 2011, were used for this study, which is acceptable according to Moser and Kalton’s assertion.

3.1.2 Data analysis

The survey feedback includes three groups of data, the probability of occurrence (P) of each risk items as '1 = very low probability and occurs in only exceptional circumstances (<10% chance), 2 = low chance and unlikely to occur in most circumstances (10% chance <35%), 3 = medium chance and will occur in most circumstances (35% chance <65%), 4 = high chance and will probably occur in most circumstances (65% chance <90%), 5 = very high chance and almost certain and expected to occur (90% or greater chance of occurrence); the severity of consequence (S) on project objectives that would result in as '1 = negligible and routine procedures sufficient to deal with the consequences, 2 = minor and would threaten an element of the function, 3 = moderate and would necessitate significant adjustment to the overall function, 4 = significant and would threaten goals and objectives; requires close management, 5 = extreme and would stop achievement of functional goals and objectives [29,30]; and baseline relative value based on the main four category of risk level. The recommended baseline is for the risk level that gets more than 50% of the votes for each risk level. If a risk did not have a level with more than 50% of the votes, it is labelled ''undecided''.

Relative importance (*RI*) for each risk assessed by each respondent can be calculated through Eq. (1), which is presented in detail by Zou et al [37]:

$$RI_{ij} = p_{ij} s_{ij} \tag{1}$$

where RI_{ij} = relative importance score assessed by respondent j for the relative importance of risk i; i = ordinal number of risk, $i \in (1, m)$; m = total number of risks; j = ordinal number of valid feedback to risk i, $j \in (1, n)$; n = total number of valid feedbacks to risk i; p_{ij} = probability occurrence of risk i, assessed by respondent j; s_{ij} = level of severity of consequence of risk i on project objectives that assessed by respondent j. The average score for each risk considering its significance can be calculated through Eq. (2). This average score is called the risk relative importance (RRI) index score and can be used to rank among all risks:

$$RRI_i = \frac{\sum_{j=1}^{n} RI_{ij}}{n} = \frac{1}{n} \sum_{j=1}^{n} p_{ij} s_{ij} \tag{2}$$

Where RRI_i = risk relative importance index score for risk i. Risks are ranked in accordance with risk relative importance (RRI_i) index.

The data collected from the current questionnaire survey was analyzed using the mean score method, within different groups as categorized according to the primary roles of the respondents. RI_{ij} Described previously was used to calculate the mean score for each risk, which was then used to determine their RRI_i. These results made it possible to cross-compare the relative importance index of the risks to the respondents with and without public affiliation by using the independent two-sample t-test [10].

3.2 Fuzzy risk map development

Phase 2 aims to to overcome uncertainties and imprecision connected with the risk map (matrix), the fuzzy logic (FL) was employed. FL can work with uncertainty and imprecision and can solve problems where there are no sharp boundaries and precise values [4]. In fuzzy logic, the equivalent to traditional independent variables, fuzzy sets are defined for specific linguistic variables, i.e. probability, severity of the consequences and risk category. The selected categories of each variable constitute the fuzzy sets. A fuzzy set defined on a universe of discourse (U) is characterized by a membership function, $\mu(x)$, which takes on values from the interval [0, 1]. A membership function provides a measure of the degree of similarity of an element in U to the fuzzy subset. Fuzzy risk map development requires an application of the fuzzy logic system (FIS), which is shown in Figure 3. The FIS consists of the following elements [35; 8]:

- The fuzzifier maps crisp input into fuzzy sets. It means that during fuzzification for each risk matrix component (frequency, severity and risk) appropriate fuzzy sets are formed according to fuzzy set principles using knowledge base.

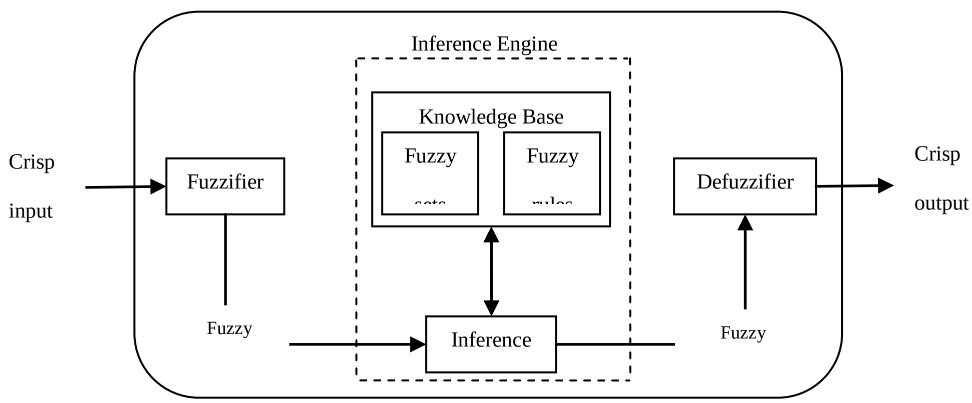

Figure 3: The structure of a typical FLS

- The inference engine of the FLS maps input fuzzy sets, by means of a set of rules, into fuzzy output sets. In handles the way in which rules are combined.

These set of rules are generated from engineering knowledge by means of the collection of IF-THEN statements. It allows for fuzzy risk assessment.

- Defuzzification is the process of weighting and averaging the outputs from all of the individual fuzzy rules into one single output value. This output decision, concerning risk index is a precise, defuzzified, and has crisp value.

4 Results and discussion

4.1 Understanding the proper risk map

4.1.1 Descriptive statistic

The questionnaire survey forms were distributed to project risk management professionals associated with the Iran PPPs power station projects industry. The completed responses were collected either personally, or received through regular postal mails, e-mails, and faxes. Out of 120 distributed questionnaires, 73 were returned. 69 out of 73 questionnaires were complete and used in the analysis. Table 1 summarizes the respondents' profile.

Table 1: Survey's profile (N=69)

respondent's profile	(%)	respondent's profile	(%)
Affiliation type		*Hierarchical level*	
Public sector	35.8	Managing director	8.5
Private sector	28.3	Executive	13.8
Lenders	8.2	Project manager	27.3
Consultants	15.7	Special Experts	39.1
Academic organizations	9.4	Academic position	9.4
Others	2.6	Others	1.9
Employment of respondents		*PPP experience of respondents*	
Less than 5 years	30.4	Never	21.8
Between 5 to 10 years	28.2	Less than 3 years	19.3
Between 10 to 20 years	22.1	Between 3-7 years	32.4
More than 20 years	19.3	More than 7 years	26.5

Seventy percent of the respondents had more than 5 years of experience. 60 % of the respondents have experience in PPPs projects as a project manager, special experts, consultants, etc.

4.1.2 Survey results

All risks observed in the questionnaire can happen to any PPP power station project. The purpose of this investigation is not only to generate a list of risks but also to identify the proper risk map that can significantly influence the delivery of PPP power station projects. Based on the survey results, the risk relative importance (RRI) index was calculated for each risk based on probability and severity. Also, these risks were determined to their baseline risk level category. The results are presented in Table 2. It presents the category of risks in the Iran PPP power station projects industry based on baseline risk level and risk relative importance index for comparing to each other and select the best risk map (matrix) that is a basis for further risk control measures. According to risk relative importance values, the extreme risk level ranked ones (out of 68 risk items) are assumed as an appropriate way to represent the key risks. After calculation, the results showed that there are 26 risk items with values equal to extreme risk level category (40 %), 24 risk items with values equal to high risk level category (35%), and 17 risk items with values equal to Medium risk level category (25%); and we can focus on extreme risk level category for the more controls.

The data collected from the current questionnaire survey was analyzed using the independent samples T-test [10]. The T-test is used to compare the values of the means from two samples and test whether it is likely that the samples are from populations having different mean values. In this research, the independent samples T-test compare the mean scores of two groups, means public affiliation type respondents group and non-public affiliation type respondents group on a given variable means the risk relative importance of the risks to the parties in PPPs projects. If the T- test is significant (the value under "Sig." is less than .05), the two means are significantly different. If it is not significant (Sig. is greater than .05), the two means are not significantly different; that is, the two means are approximately equal.

To properly evaluate PPP power station projects risks, one must consider both the probability of occurrence and the severity of consequences on project objectives once the risk event occurs. Some authors contend that multiplying the probability and severity values might be misleading [17; 6]. This is achieved best by plotting the risk probability – severity matrix (Figure 4). In the matrix, the x-axis represents the severity value while the y-axis represents the probability value. Both scales are 1–5 (one being very low to 5 being very high) and baseline risk level compare with RRI to generate the best risk map.

Table 2: Risk relative importance index and baseline risk level for understanding the proper risk map

Risk	Description	Probability of occurrence (P)		Severity of consequence (S)		Risk Relative Importance (RRI)		T- test		Baseline
		Mean	Std.	Mean	Std.	Mean	Std.	t	Sig.	
1	Termination of concession by Government	1.79	.73	4.33	.47	7.79	3.38	.378	.708	High
2	public / political opposition	2.56	.68	3.38	.54	8.61	2.47	- 1.74	.089	High
3	Tax regulation changes	4.41	.67	4.07	.70	18.00	4.35	.455	.652	Extreme
4	Political Force majeure	4.33	.66	4.23	.66	18.41	4.32	- .670	.507	Extreme
5	Expropriation and nationalization	2.05	.88	3.02	.81	6.38	3.73	.766	.448	Medium
6	Change in law	4.53	.60	4.43	.59	20.15	3.87	- .439	.663	Extreme
7	Unstable government	4.58	.54	4.64	.53	21.35	3.78	- .438	.664	Extreme
8	Adverse government action or inaction	4.74	.49	4.64	.58	22.05	3.79	- .149	.882	Extreme
9	Inflation risk	4.20	.76	4.07	.70	17.17	4.41	.943	.352	Extreme
10	Economic disaster	2.38	.71	3.53	.71	8.58	3.43	- .506	.616	High
11	Interest rate risk	4.05	.72	3.89	.78	15.71	3.97	.916	.365	Extreme
12	Foreign currency risk (exchange rate fluctuation/ convertibility)	4.23	.66	4.12	.73	17.53	4.39	- 1.675	.102	Extreme
13	Insufficient financial audit	2.38	.71	2.82	.75	6.74	2.71	1.059	.296	Medium
14	Availability of finance	4.38	.63	4.17	.72	18.28	3.95	1.371	.179	Extreme
15	Contractual risk	3.15	.70	3.71	.79	11.82	3.89	- 1.523	.136	High
16	Third party tort liability	2.82	.88	3.74	.81	10.74	4.30	- .804	.427	High
17	Un-inform risk	2.05	.72	3.46	.85	7.15	3.18	- .746	.461	High
18	Immature juristic system	4.10	.75	4.20	.73	17.10	3.88	1.820	.077	Extreme
19	Consortium inability	2.76	.87	3.46	.85	9.58	4.10	.220	.827	High
20	Breach of financing documents	2.41	.75	3.15	.81	7.66	3.32	1. 072	.291	High
21	insufficient income	4.38	.74	3.82	.79	16.76	4.38	.545	.589	Extreme
22	Competition (exclusive right)	4.12	.73	4.28	.68	17.56	3.88	.434	.667	Extreme
23	Tariff change	4.17	.75	4.23	.74	17.69	4.53	1.364	.181	Extreme
24	Fluctuating demand of power generated	4.61	4.5	4.12	.69	19.07	3.98	.827	.414	Extreme
25	Fluctuating supply of power generated	3.07	.73	3.30	.69	10.20	3.39	.895	.377	High
26	Delay payment on contract	4.82	.38	4.64	.53	22.38	3.24	- .242	.810	Extreme
27	Transmission failure risk	3.12	.80	3.82	.85	11.94	4.02	- .682	.500	High
28	Problem in bill collection risk	2.02	.70	2.79	.61	5.66	2.46	.357	.723	Medium
29	Power theft risk	2.58	.78	2.64	.74	6.92	3.11	- .203	.840	Medium
30	Fluctuation of cost and availability of fuel / coal	4.20	.73	4.66	.52	19.53	3.75	- .223	.825	Extreme
31	Investment insurance	2.12	.76	2.46	.78	5.05	2.11	- 1.39	.172	Medium
32	Get loans on time	4.38	.67	4.23	.66	18.53	3.99	- .292	.772	Extreme
33	Private investor change	2.58	.75	2.61	.71	6.87	2.94	.425	.673	Medium

34	high cost of investment	4.23	.66	4.07	.70	17.17	3.78	.042	.966	Extreme
35	Design change	2.53	.78	2.58	.75	6.46	2.75	- .295	.770	Medium
36	project control risk	2.84	.67	2.48	.75	6.97	2.41	.049	.961	Medium
37	unproven engineering techniques	2.23	.74	2.35	.81	5.53	3.24	.973	.337	Medium
38	Insolvency of subcontractors	2.25	.67	2.76	.80	6.30	2.87	1.49	.143	Medium
39	Availability of labor/materials	2.05	.60	2.74	.71	5.61	2.17	- .860	.395	Medium
40	Financial failure of contractor	2.10	.59	3.41	.84	7.30	3.20	- .652	.518	High
41	Ground conditions	2.53	.71	3.87	.80	9.84	3.46	.015	.988	High
42	Site availability	2.41	.67	3.38	.78	8.20	3.01	- 1.209	.234	High
43	Import risk of equipment/ materials	4.00	.79	4.17	.64	16.76	4.46	.989	.329	Extreme
44	Time and quality risk	2.46	.68	2.92	.77	7.20	3.01	1.478	.148	High
45	Construction changes	2.28	.68	2.97	.66	6.82	2.55	1.117	.271	Medium
46	Environmental protection	3.00	.72	3.12	.69	9.56	3.66	.009	.993	High
47	natural force majeure	4.02	.70	4.10	.71	16.25	2.94	.046	.964	Extreme
48	Construction cost overrun	4.12	.73	4.38	.67	18.00	3.95	.418	.679	Extreme
49	Construction completion	3.00	.72	3.07	.70	9.25	3.17	- .794	.432	High
50	Supporting utilities risk	4.51	.64	4.35	.66	19.58	3.93	.997	.325	Extreme
51	Protection of geological and historical objects	2.15	.70	2.38	.71	5.12	2.34	- 1.725	.093	Medium
52	Operation cost overrun	4.23	.70	4.46	.64	18.84	4.10	2.234	.032	Extreme
53	Operator inability	2.64	.70	3.46	.64	9.23	3.19	1.57	.124	High
54	Condition of maintenance facility	2.76	.74	2.71	.75	7.64	3.11	.533	.597	High
55	Technology risk	2.20	.73	3.10	.68	6.79	2.54	- .276	.784	Medium
56	Fuel supply risk	2.89	.64	3.05	.68	8.97	3.01	- 1.070	.291	High
57	Quality of operation	2.43	.68	2.56	.59	6.20	2.23	- .276	.784	Medium
58	Termination of concession by concession company	2.35	.70	3.51	.68	8.28	2.76	.849	.401	High
59	Environmental damage-ongoing	2.53	.55	3.17	.68	8.02	2.42	- .874	.388	High
60	Force majeure event	4.02	.70	4.10	.71	16.25	2.94	.046	.964	Extreme
61	Residual risk	3.41	.78	3.35	.81	11.48	4.16	1.393	.172	High
62	Corruption	4.48	.60	4.48	.60	20.12	3.86	1.420	.164	Extreme
63	Uncompetitive tender	2.30	.61	2.56	.55	6.00	2.18	- .301	.765	Medium
64	Organization and coordination	4.53	.50	4.69	.52	21.23	2.98	.980	.334	Extreme
65	Subjective evaluation	2.23	.66	3.20	.65	7.05	2.36	.319	.752	High
66	Tendered price risk	3.02	.70	3.33	.77	10.15	3.63	- .195	.846	High
67	Change order negotiation	3.12	.76	3.05	.68	6.20	2.23	- .276	.784	Medium
68	delay in solving contractual issues	4.28	.72	4.56	.50	19.46	3.58	- 1.068	.293	Extreme

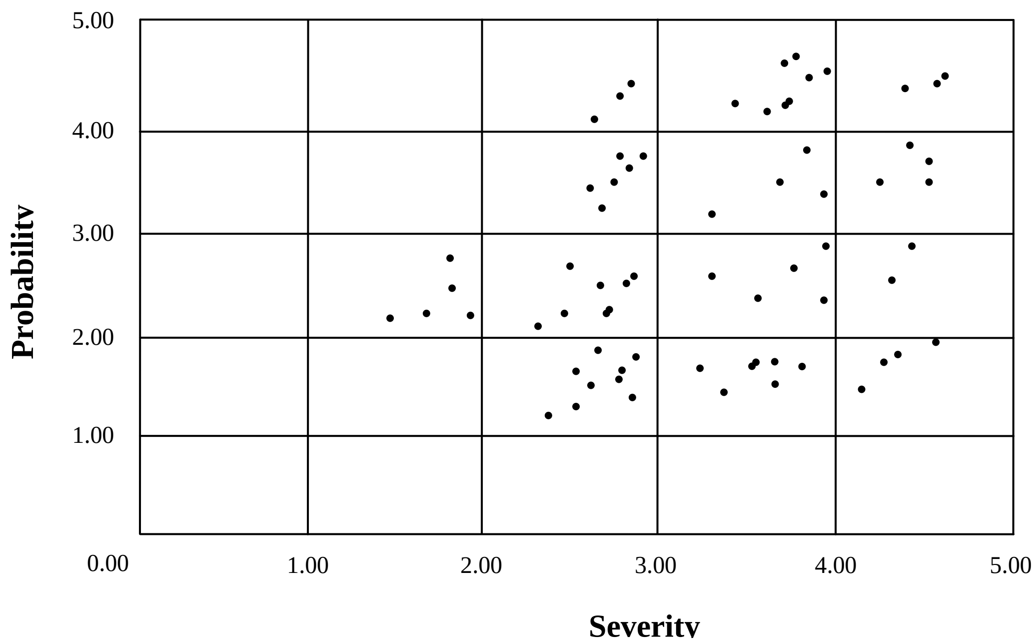

Figure 4: Probability- severity scatter matrix

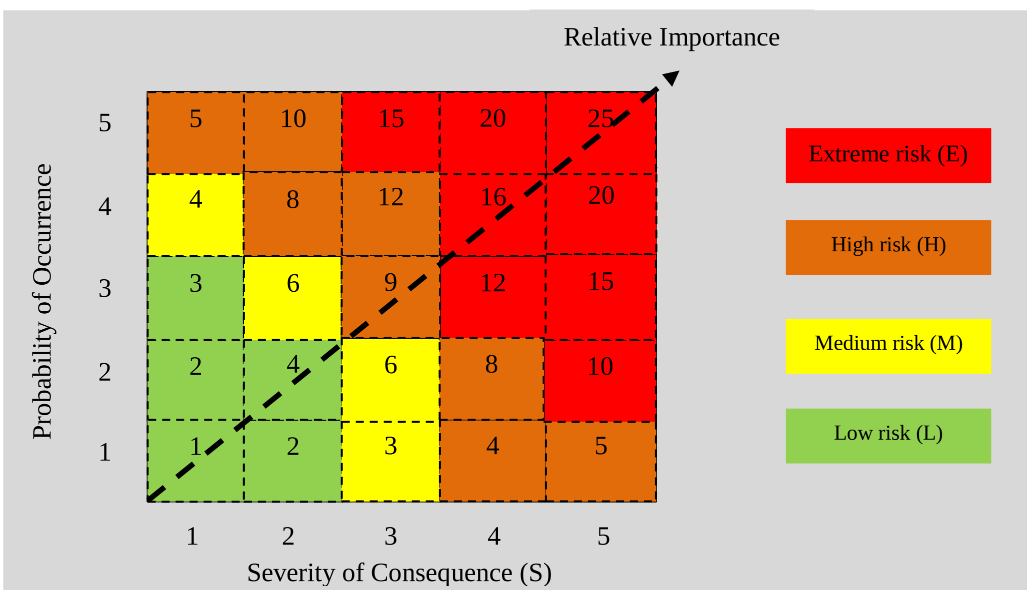

Figure 5: Risk map

Based on the Figure 4, the proper risk map (risk matrix) presented in Figure 5 that is the “hard” matrix which It presents the high cost matrix however safer. It shows the converted numerical values and the calculation of the relative importance (RI). The risk matrix includes a legend of risk level that would be of assistance to project participants when the risk is unknown, and would also provide the framework to rank order risk elements by severity for subsequent mitigation: Extreme risk (E) – occurrence would prevent achievement of objectives, causing unacceptable cost overruns, schedule slippage, or project failure; High risk (H) – could substantially delay the project schedule or significantly affect technical performance or costs, and requires a plan to handle; Medium risk (M) – requires identification and control of all contributing factors by monitoring conditions and reassessment at project milestones; Low risk (L) – normal control and monitoring measures are sufficient.

4.2 Risk map fuzzy inference system

4.2.1 Fuzzy risk map sets definition (*fuzzification*)

To develop fuzzy risk assessment matrix, relevant and available input variables must be selected and their domain is partitioned in a number of fuzzy sets. Crisp risk map provides data for the number of sets as well as for their range. The ranges of frequencies and severities of the consequences were reconverted from the look-up table provided by LOPA book [6]. Different forms of a membership function can be used depending on the type of the characteristics of input and output variables. In this research the Gaussian type of membership function was selected as the most natural and popular choice for these systems. Fig. 5 presents the fuzzy sets and its membership function for each variable used in the fuzzy risk assessment matrix.

4.2.2 Fuzzy inference system

A fuzzy inference system applies risk rules-based knowledge in mapping of fuzzy input sets (probability and severity) into fuzzy output risk set. It is performed by fuzzy IF-THEN rules. The structure of fuzzy rules for the fuzzy risk map can be presented as follows: IF probability is $\overline{p}_n$ AND severity of consequences is $\overline{s}_m$ THEN risk is $\overline{r}_z$, where $\overline{p}_n$, $\overline{s}_m$, $\overline{r}_z$ are the fuzzy sets for probability $\overline{P}$, severity $\overline{S}$ and risk $\overline{R}$ defined on the universes of discourse, respectively.

Fuzzy rules are provided by crisp risk map (Figure 5). A combination of 5 categories of probability and 5 categories of severity (called antecedents), according to the assumed structure of risk map, generates 25 rules providing 25 conclusions, which represent risk categories. In order to transfer the qualitative rules into quantitative result a Mamdani fuzzy inference algorithm is applied [35; 8]. The Mamdani model applies min operator for AND method and implication of the output set. After the rules have been evaluated, the output fuzzy set for each rule was aggregated. The aggregating output membership function of a resultant output fuzzy risk category is expressed as:

$$\mu_{\tilde{R}}(r) = \max_k \{\min \mu_{\tilde{P}}^k(p_n),\ \mu_{\tilde{C}}^k(c_m),\ \mu_{\tilde{R}}^k(r_z),\} \quad (3)$$

where k is the number of rules, n the number of fuzzy frequency sets, m the number of fuzzy severity sets, and z is the number of fuzzy risk sets.

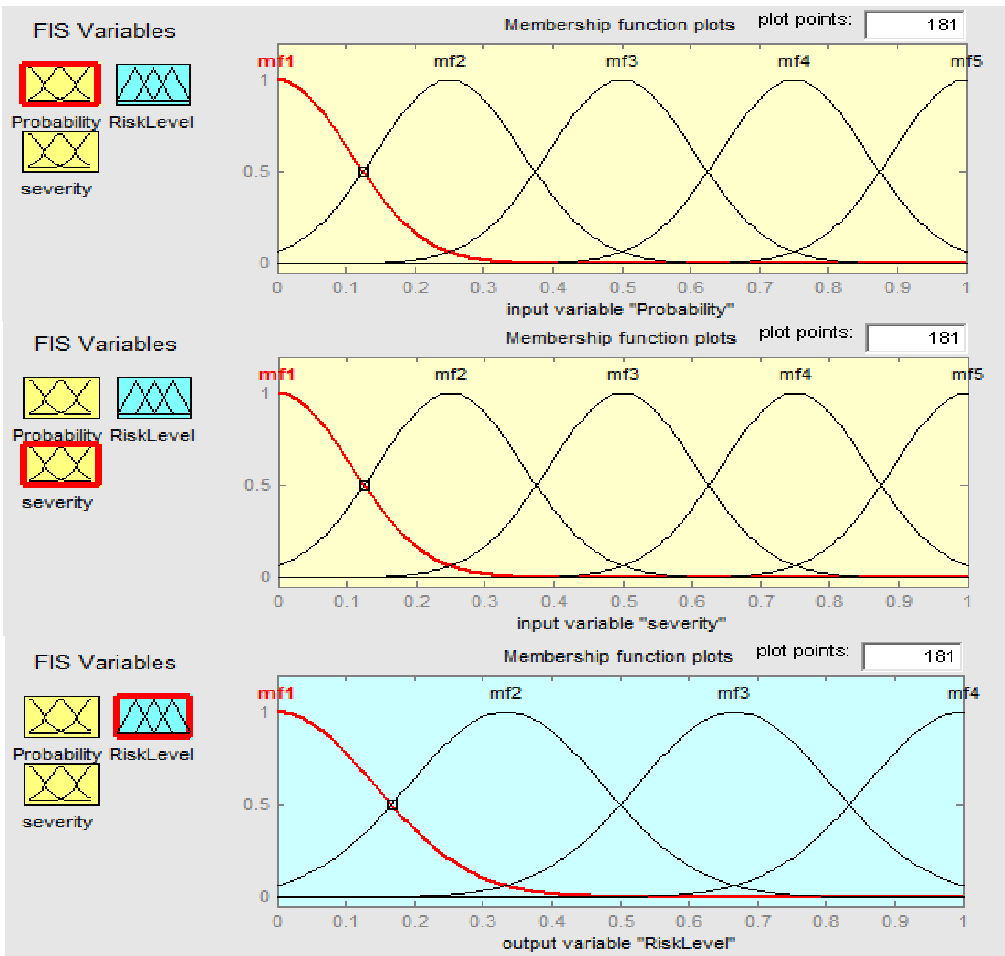

Figure 6: Membership functions for fuzzy risk assessment

4.2.3 Defuzification and fuzzy risk surface

The conversion of final combined fuzzy conclusion into a crisp (nonfuzzy) form is called the defuzzification. There are numbers of available defuzzification techniques. In this work we have applied the centre of area (COA) or the centroid method. The COA calculates the weighted average of a fuzzy set. The result of applying COA defuzzification for risk index can be expressed by the formula:

$$r = \frac{\int \mu_{\bar{R}}(r) r dr}{\int \mu_{\bar{R}}(r) dr} \quad (4)$$

The relationship between probability, severity and risk can be illustrated by three-dimensional plot that represents the mapping from two inputs (probability and severity) to one output (risk). This is s risk surface. Figure 7 shows such a surface for “hard” risk map (matrix).

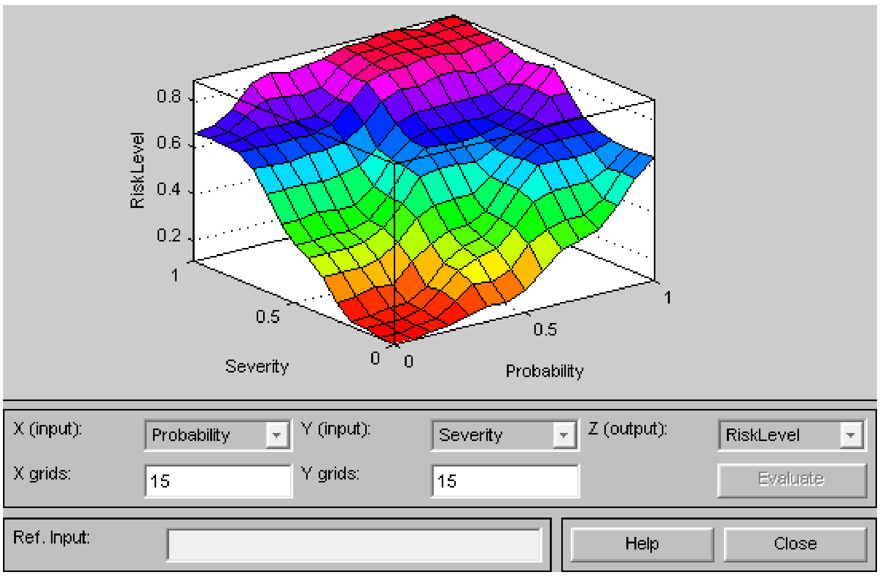

Figure 7: Fuzzy risk map

The risk surfaces present different the regions of risk depending on input parameters and can be used for risk assessment. The characteristic mean risk index for “hard” matrix is equal 2.75.

5 Conclusion

This paper details the research and development of the fuzzy risk map, a project assessment tool that allows for the assessment and understanding of the key risk specific to PPP power station projects for both owners and contractors. As mentioned in paper, a variety of data collection activities were performed and input was provided by 69 different industry experts in developing and testing the fuzzy risk map. As detailed in this paper, the collected data was analyzed using standard statistical and qualitative analysis techniques. The fundamental conclusions of this paper:

1) A comparison of the results using different risk matrixes (crisp risk map and fuzzy risk map) with different risk zoning design is analysed. Comparing the crisp data on risk category received by the crisp risk map and fuzzy risk indexes by the fuzzy risk map it can be stated that the results are more precise and describe in detail the possible contribution of each fuzzy set in a final result. This may be of help in a more accurate design of the risk control measures or the layers of protection. The risk index increase with the level of riskiness, which means that in order to meet at least risk tolerance criteria in the case of hard matrix we will need to spend more (but with a better protection) than in the case of the easy matrix. The collective results from this research shows that the fuzzy risk map tool is a comprehensive and sound method to assess and understand the relative impact of the majority of risk issues encountered on power station capital facilities.

2) The fuzzy risk map tool helps the project team to identify the key risk factors of highest importance to the project team. In this research, each of the 68 elements was ranked in order of importance using a fuzzy risk relative importance index. According to fuzzy risk relative importance values, the extreme risk level ranked ones (out of 68 risk items) are assumed as an appropriate way to represent the key risks and more protection (Table 3).

This paper was an exploratory effort and it expands the body of knowledge and research regarding PPP power station project risk management. This is the first investigation to develop a systematic risk assessment and understanding the key risks method for PPP power station projects that considers the full project life cycle and the portfolio of risks encountered by owners and contractors. Other efforts to date within the PPP industry are fragmented and tend to focus on risk categories, country-specific issues, or concerns unique to another infrastructure. For example, Ebrahimnejad et al. [12] focused on improving risk assessments for build-operate-transfer projects, Azari et al. [2] analyzed the construction industry to selection of model for risk assessment, Zou et al. [37] understudied the key risks in construction projects in China and Ghosh and Jintanapakanont (2004) indentified and assessed the critical risk factors in an underground rail project in Thailand by a factor analysis approach.

Also unique to this effort is the development of fuzzy risk relative importance index for individual risk elements based on data collected from industry experts reporting on recently completed projects. Because few organizations collect and track information related to the risk severity and risk probability, the Baseline values fill a knowledge gap and can provide some guidance when risk impacts are unknown or when uncertainty is high. This is especially critical during the business and pre-project planning phases because failure to identify risks early in the project life cycle can result in serious ramifications. Because the structured risk assessment process can be used to determine the relative importance ranking of a project’s risk, this work also contributes an additional analytical method as a precursor to detailed analysis, quantification, and modelling of risk issues that are difficult to measure.

Table 3: the key risk factors and key risk groups

Risk meta level	Key risk group	Key risk factors
1. Macro level	1.1. Political risks	1.1.1. Tax regulation changes 1.1.2. Political Force majeure 1.1.3. Change in law 1.1.4. Unstable government 1.1.5. Adverse government action or inaction
	1.2. Financial and economic risks	1.2.1. Inflation risk 1.2.2. Interest rate risk 1.2.3. Foreign currency risk 1.2.4. Availability of finance
	1.3. Legal risks	1.3.1. Immature juristic system
	1.4. Market and revenue risks	1.4.1. Insufficient income 1.4.2. Competition (exclusive right) 1.4.3. Tariff change 1.4.4. Fluctuating demand of power generated 1.4.5. Delay payment on contract 1.4.6. Fluctuation of cost and availability of fuel / coal
2. Mezzo risks	2.1. Investment risks	2.1.1. Get loans on time 2.1.2. High cost of investment
	2.2. Construction risks	2.2.1. Import risk of equipment/ materials 2.2.2. Natural force majeure 2.2.3. Construction cost overrun
	2.3. Operating risks	2.3.1. Supporting utilities risk 2.3.2. Operation cost overrun
3. Micro level	3.1. Relations risks	3.1.1. Corruption 3.1.2. Organization and coordination 3.1.3. Delay in solving contractual issues

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