VILNIUS TECH
Vilnius Gediminas Technical University

Journal of Civil Engineering and Management

ISSN 1392-3730 / eISSN 1822-3605

2021 Volume 27 Issue 4: 268–277

https://doi.org/10.3846/jcem.2021.14650

AN ANALYTIC NETWORK PROCESS BASED RISK ASSESSMENT MODEL FOR PPP HYDROPOWER INVESTMENTS

Emre Caner AKCAY *

Department of Civil Engineering, Atılım University, Kızılcasar Mah., 06830 Ankara, Turkey

Received 21 January 2021; accepted 15 March 2021

Abstract. The number of public-private partnership (PPP) projects has gone up especially in developing countries. The risk assessment of PPP projects is essential in ensuring project success. The objective of this study is to develop an Analytic Network Process (ANP) based risk assessment model for hydropower investments, and a tool to facilitate quantification of risk ratings based on this model. The results show that the three most important risk factors that affect the overall risk rating of a PPP hydropower investment are legal risks, contractor/subcontractor risks, and operator risks. In addition, the three most important risk clusters were identified as stakeholders, government requirements, and resources, whereas market was the least important cluster. The tool that measures the risk rating of a PPP of hydropower project was tested on ten real cases, and satisfactory results were obtained in terms of its predictive capability. The contributions of this research include (1) identification of the risk factors and clusters of factors associated with PPP hydropower investments; (2) determination of the priority of each risk factor and cluster; (3) development a tool that guides the investors through the risk assessment of PPP hydropower investments.

Keywords: renewable energy, PPP, hydropower investment, ANP.

Introduction

A Public Private Partnership (PPP) is a long-term cooperation between a public agency and the private sector to provide public services (Liu et al., 2015). It is a project delivery system where a public agency benefits from the private sector's financing opportunities and operations expertise in fulfilling public needs (Mazher et al., 2018; Ashuri et al., 2012). PPP has been widely used in developing countries where governments do not have enough funds to provide better public services (Nguyen et al., 2018). More than 6,000 PPP projects have been performed in developing countries in the past 25 years (Ahmadabadi & Heravi, 2019). PPP projects include a higher degree of risk compared to traditional projects due to its complex nature (Wu et al., 2018). Therefore, the risk assessment of PPP projects should be performed as realistically as possible to ensure project success.

In this study, an ANP-based risk assessment model for PPP hydropower investments was developed for realistic risk assessment and for the prioritization of risk factors associated with hydropower investments. The objective is to develop an Analytic Network Process (ANP) based risk assessment model for PPP hydropower investments, and a tool to facilitate quantification of risk ratings based on this model.

The section following the Introduction provides background research. The subsequent second section describes the methodology of the ANP-based risk assessment model for PPP hydropower investments. In this section, the risk factors and clusters that affect PPP hydropower investments are clarified, general information about ANP is described, the prioritization of risk factors and clusters is performed, the development of a risk assessment tool is introduced. The third section discusses the results of the prioritization process. The fourth section presents the testing of the risk assessment model. Finally, the conclusion and the limitations of this study are reported in the last section.

1. Literature review

The risk assessment of PPP projects drew the attention of many researchers over the last few decades (e.g., Ashuri et al., 2012; Aladağ & Işik, 2018; Wibowo et al., 2012; Nguyen et al., 2018; Mazher et al., 2018; Yu et al., 2018;

*Corresponding author. E-mail: *caner.akcay@atilim.edu.tr*

Kumar et al., 2018; Xu et al., 2009, 2010; Wu et al., 2017). The risk identification process is the initial and most important step in risk assessment (Yu et al., 2018). Several studies solely concentrate on identifying the risk factors for different types of PPP projects in different countries (e.g., Ghorbani et al., 2014; Chan et al., 2011; Wang et al., 2000; Osei-Kyei & Chan, 2015; Thomas et al., 2006; Shao et al., 2016; Yuan et al., 2008; Tang et al., 2015). For instance, Ghorbani et al. (2014) identified risk factors for PPP highway projects in Iran.

Several research studies focus on selecting an appropriate risk assessment method for prioritizing the risk factors. For example, Wu et al. (2018) proposed a three-dimensional risk assessment model that involves probability, losses, and uncontrollability. Kuru and Artan (2020) proposed a canvas model to perform risk assessment and performance evaluation in PPP projects where they prioritized the PPP risk factors by using Analytic Hierarchy Process (AHP). Tah and Carr (2000) developed a model for qualitative risk assessment by using a hierarchical risk breakdown structure. Xu et al. (2010) prepared a fuzzy synthetic evaluation risk assessment model for PPP projects in China. Wu et al. (2017) developed a multi-criteria fuzzy synthetic evaluation framework for public-private partnership straw-based power generation projects. Ameyaw and Chan (2015) assessed the risk level of PPP water supply projects in developing countries using fuzzy synthetic evaluation approach. Li et al. (2017) proposed a fuzzy-grey comprehensive method to perform the risk assessment of China's overseas investments in oil refineries.

A hierarchical risk breakdown structure is constructed and an appropriate multi-criteria decision-making method is used to perform risk assessment in most factor-based studies. Unfortunately, the interrelations between the risk factors are usually ignored in these studies. However, in practice, interrelations do exist between the risk factors. For instance, the demand risk is normally correlated with the risk of economic stability. Therefore, it is obvious that using a network structure is more realistic than a hierarchical structure. The Analytic Network Process (ANP) which allows users to define the interactions among the elements in a network structure is an appropriate choice in developing a PPP risk model.

2. Methodology of ANP-based risk assessment model for PPP hydropower investments

The proposed ANP-based risk assessment model for PPP hydropower investments is presented in Figure 1. It includes four steps: (1) Identifying the risk factors; (2) Defining risk clusters and constructing a network structure; (3) Prioritizing the risk factors/clusters; and (4) Developing a risk assessment tool.

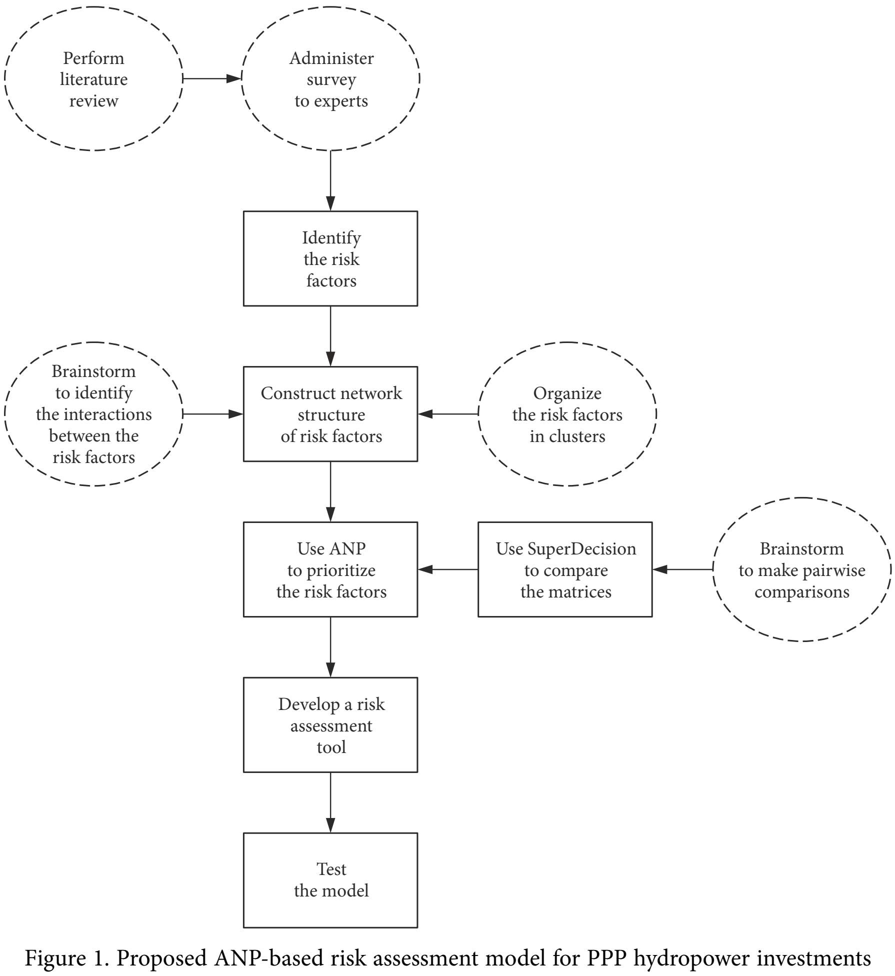

Figure 1. Proposed ANP-based risk assessment model for PPP hydropower investments

2.1. Identifying the risk factors

The first step of identifying the risk factors for PPP hydropower investments was performed in two stages. In the first stage, an extensive literature review was performed and an initial checklist of risk factors for PPP hydropower investments was formed. In the second stage, a questionnaire survey was administered to fourteen experts employed by seven different hydropower investment companies. The demographic information of the respondents is presented in Table 1. The initial checklist of risk factors was made available to the experts who were asked to mark those factors that are applicable to PPP hydropower investments in Turkey and to add any risk factors missing in the checklist. The experts evaluated the risk factors in the questionnaire by mentioning valid (V)/not valid (N). Two rounds of a Delphi process were performed online to minimize the spread of the answers. The final checklist of risk factors, their possible adverse consequences, and the corresponding research papers are presented in Table 2.

2.2. Defining risk clusters and constructing a network structure

The second step involved a brainstorming session with seven experts (a subset of the original fourteen experts; namely experts 1, 2, 4, 5, 7, 9, and 11) employed by seven different hydropower investment companies to develop a risk matrix that shows the relationships between the risk factors. With the help of these seven experts, the factors were organized in eight clusters, namely resources, stakeholders, construction, external environment, market, operation, financing/economic conditions, and government requirements. As seen in Table 2, each cluster is represented by related factors.

Following Saaty's (2003) instructions, the risk clusters were organized into a network structure presented in Figure 2 that shows the interactions between the factors.

2.3. Prioritizing the risk factors using ANP

The third step of the study involved prioritizing the risk factors using ANP. Analytic Network Process (ANP) is the generalized form of the analytic hierarchy process (AHP), which was first introduced by Saaty (1996). It is a flexible and useful multi criteria decision making method that enables decision makers to arrange priorities and to select the best alternative by considering both the tangible and intangible aspects of a problem (Ozorhon et al., 2007; Dikmen et al., 2007). As ANP shows the interactions and interdependencies among the elements, it can allow decision makers to solve more complex problems (Saaty, 1996). ANP has been used in various fields to solve several multi-criteria decision-making problems such as contractor selection (e.g., El-Abbasy et al., 2013; Cheng & Li, 2004; Hasnain et al., 2018), project selection (e.g., Niemira & Saaty, 2004; Shang et al., 2004; Meade & Presley, 2002; Dikmen et al., 2007), construction method selection (Ozcan-Deniz & Zhu, 2015), risk assessment (e.g., Do et al., 2017; Li & Wang, 2019; Valipour et al., 2016, 2015; Bu-Qammaz et al., 2009; Dehdast et al., 2017) and performance assessment (e.g., Zhao et al., 2017; Erdem & Ozorhon, 2015; Zhang et al., 2016; Tohumcu & Karasakal, 2010; Ozorhon et al., 2007). No studies have been reported in the literature about its utilization for risk assessment in PPP hydropower investments. Hydropower investments are large-scale and complex projects (Zhang et al., 2013). They have a long running construction duration, and as a result, they are riskier and more complicated compared to other types of projects (Sharma & Kar, 2018). Based on the research presented in the preceding paragraphs, an ANP-based risk assessment model was used in this study.

ANP requires that pairwise comparisons of the factors in each cluster be made (Saaty, 2003, 2004). For this purpose, another brainstorming session was organized with the same seven experts who participated to the first brainstorming session. A total of 31 pairwise comparisons

Table 1. Demographic information of experts

ID	Sector	Profession	Position	Experience in PPP Hydropower Projects (in years)
Expert 1	Private	Civil Engineer	Owner	20
Expert 2	Private	Civil Engineer	Project Manager	25
Expert 3	Private	Mechanical Engineer	Project Manager	18
Expert 4	Private	Civil Engineer	Senior Manager	17
Expert 5	Private	Civil Engineer	Project Manager	26
Expert 6	Private	Electrical Engineer	Project Manager	17
Expert 7	Private	Architect	Project Manager	21
Expert 8	Private	Architect	Owner	25
Expert 9	Private	Civil Engineer	Project Manager	19
Expert 10	Private	Civil Engineer	Project Manager	17
Expert 11	Private	Civil Engineer	Project Manager	22
Expert 12	Private	Mechanical Engineer	Senior Manager	25
Expert 13	Private	Civil Engineer	Project Manager	24
Expert 14	Private	Civil Engineer	Project Manager	28

were made by the experts by using the fundamental scale specified by Saaty (2008) in Table 3. An example of a comparison matrix for the "construction" cluster is presented in Table 4. The consistency of the responses was calculated for each cluster. This ratio has to be smaller than 0.1 for a 2-factor cluster, 0.05 for a 3-factor cluster, and 0.08 for a 4-factor cluster for consistency (Saaty, 1994). The consistency ratios of all clusters satisfied the requirements.

Table 2. Risk factors of PPP hydropower investments

			References																		
			Nguyen et al. (2018)	Mazher et al. (2018)	Yu et al. (2018)	Kumar et al. (2018)	Ahmadabadi and Heravi (2019)	Palaco et al. (2019)	Keers and Fenema (2018)	Wu et al. (2018)	Xu et al. (2010)	Ameyaw and Chan (2015)	Wu et al. (2017)	Thomas et al. (2006)	Li et al. (2017)	Ke et al. (2010)	Xu et al. (2009)	Karim (2011)	Bing et al. (2005)	Ibrahim et al. (2006)	Chan et al. (2011)
Cluster name	**Risk factor**	**Possible adverse consequences**																			
Resources	Material	Unavailability, poor quality, delay, low productivity	*	*				*			*				*	*	*	*	*	*	*
	Labour	Unavailability, poor quality, delay, low productivity	*	*	*		*	*	*		*				*	*	*	*	*	*	*
	Equipment	Unavailability, poor quality, delay, low productivity		*			*	*							*	*	*	*	*		*
Stakeholders	Contractor/ subcontractor	Poor performance, insolvency, lack of experience, unavailability	*	*	*		*		*	*	*	*	*		*		*	*	*	*	*
	Designer	Poor performance, insolvency, lack of experience, unavailability	*	*	*		*		*	*	*		*		*		*		*	*	
	Operator	Poor performance, insolvency, lack of experience, unavailability	*	*	*		*		*	*	*	*	*			*	*	*	*		
Construction	Scope/design	Vagueness, change, poor quality, delay	*	*	*	*		*					*		*	*	*	*	*	*	*
	Quality	Vagueness, change, poor quality, delay		*	*	*	*	*			*				*	*	*		*		
	Productivity	Vagueness, change, poor aquality, delay		*	*	*	*	*	*		*	*	*		*	*	*	*			
	Safety	Vagueness, change, poor quality, delay			*	*		*				*			*				*	*	*
External environment	Weather	Unpredictability, unfavorability		*				*			*	*	*			*		*	*	*	
	Geotechnical	Unpredictability, unfavorability		*	*						*		*			*		*	*		
	Natural disasters	Unpredictability, unfavorability	*	*	*			*			*	*	*	*		*	*		*	*	*
Market	Demand	Change, vagueness	*		*	*		*			*	*	*	*	*	*	*	*	*		
	Competition	Change, vagueness	*		*			*			*				*	*		*	*		
	Tariff rate	Change, vagueness	*		*	*		*			*					*					
Operation	Safety	Poor			*	*						*			*			*	*		*
	Productivity/ Performance	Poor	*		*	*						*		*		*	*	*	*	*	*
Financing/ Economic conditions	Exchange rate	Change	*	*		*	*	*		*	*	*	*	*	*	*	*	*	*	*	*
	Inflation	Change	*	*		*	*	*		*	*	*	*	*	*	*	*	*	*	*	*
	Interest rate	Change	*	*		*	*	*		*	*	*	*	*	*	*	*	*	*	*	*
Government requirements	Approval/ Permits	Adverse impact, delay, change	*	*	*		*	*		*	*	*	*	*	*	*	*	*	*	*	*
	Expropriation	Adverse impact, delay, change		*				*		*	*			*	*	*	*	*		*	*
	Laws/ Regulations	Adverse impact, delay, change	*	*	*		*	*		*	*	*	*	*	*	*	*	*	*	*	*

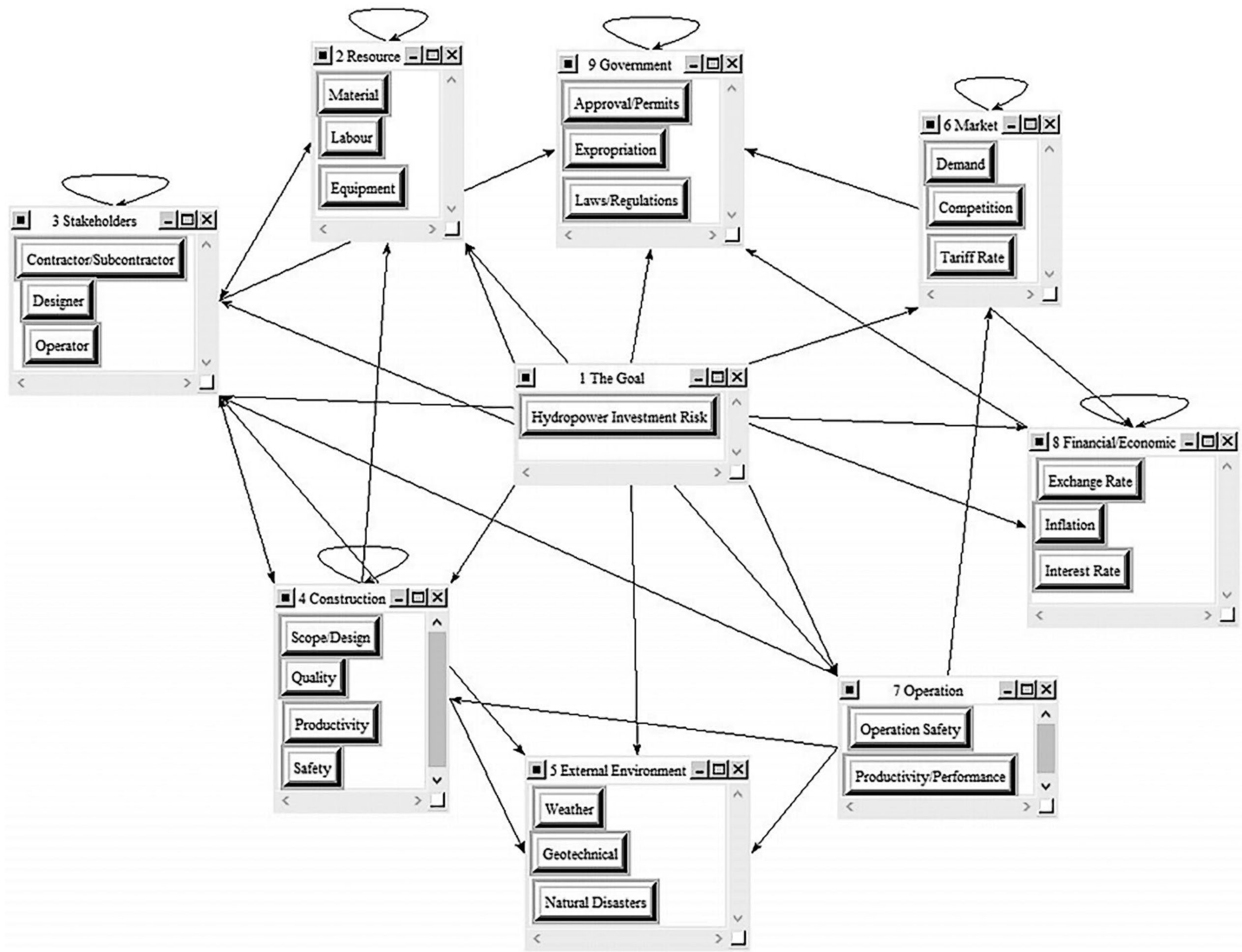

Figure 2. The network structure of the model

Table 3. Fundamental scale of absolute numbers (Saaty, 2008)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very strong plus	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Table 4. An example of comparison matrix for "construction" cluster

	Scope/design	Quality	Productivity	Safety
Scope/design	1	1/3	1/2	1/3
Quality	3	1	1/5	7
Productivity	2	5	1	2
Safety	3	1/7	1/2	1

ANP was performed by a software named "SuperDecisions" which was developed by Saaty (1996). The pairwise comparisons were input to SuperDecisions which calculated a super matrix in three steps. First, it constructed an unweighted super matrix using the local priorities derived from the pairwise comparisons; second, it calculated a weighted super matrix by multiplying the values of the unweighted super matrix with their related cluster weights; and in the last step, it derived a limiting super matrix by raising the weighted super matrix to higher powers until all the columns have stable values. The priority or importance weight of each risk factor and each cluster were thus obtained by examining the limiting super matrix. The results are presented in Table 5 and Table 6, respectively.

Table 5. Priority of risk factors

Risk factor	Importance weight	Rank
Laws/Regulations	0.212300	1
Contractor/Subcontractor	0.097839	2
Operator	0.096380	3
Labor	0.086907	4
Operation Productivity	0.081464	5
Equipment	0.060932	6
Material	0.059685	7
Designer	0.057509	8
Construction Quality	0.040821	9
Operation Safety	0.032592	10
Exchange Rate	0.026649	11
Interest Rate	0.026649	12
Weather	0.024751	13
Scope/Design	0.020066	14
Inflation	0.015694	15
Market Demand	0.011975	16
Competition in Market	0.010094	17
Approval/Permits	0.007363	18
Tariff Rate	0.007314	19
Construction Safety	0.006260	20
Natural Disasters	0.005178	21
Construction Productivity	0.004954	22
Expropriation	0.004214	23
Geotechnical Conditions	0.002412	24

Table 6. Priority of risk clusters

Risk cluster	Importance weight	Rank
Stakeholders	0.25173	1
Government requirements	0.22388	2
Resources	0.20752	3
Operation	0.11406	4
Construction	0.07210	5
Financing/economic conditions	0.06899	6
External environment	0.03234	7
Market	0.02938	8

2.4. Developing a risk assessment tool

The last step of the study involved developing a risk assessment tool for PPP hydropower investors. The total risk rating (TRR) was calculated by considering the priority of each risk factor in Eqn (1):

$$TRR = \sum_{i=1}^{24} P_i \times R_i, \tag{1}$$

where: TRR is the total risk rating; P_i is the priority of the i^{th} risk factor and R_i is the risk rating of the i^{th} risk factor.

By entering the risk rating of each risk factor using a 1–5 Likert scale where 1 means no risk and 5 extreme risk, a potential PPP hydropower investor can easily see the total risk rating of the project using a scale of 0–100. The tool's user-friendly interface is presented in Figure 3.

3. Discussion of results

According to Table 5, the most important risk factor in a PPP hydropower investment in Turkey is legal risks. The Turkish government provided a legal framework for PPP renewable energy investors in 2005, but the policies have not yet been finalized. There have been several modifications in energy policies for the design, construction and operation phases of PPP hydropower investments between 2005 and 2020. Because Turkey is a developing country, the existing energy policies are mostly ambiguous. As a result, it is almost impossible to predict legal risks. Consequently, investors seriously hesitate to commit to a PPP

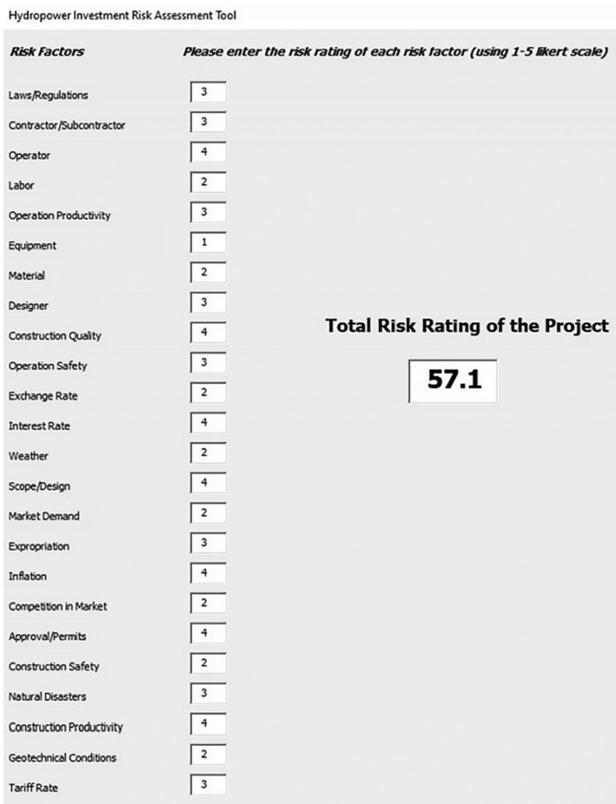

Figure 3. The risk assessment tool

investment. It would be safe to say that if this research had been conducted in an industrialized country with fully established energy policies, legal risks would not have had such importance.

The second most important risk factor is contractor/subcontractor risk. It is one of the most typical risk factors for PPP projects not only in Turkey but also in other countries (Nguyen et al., 2018; Mazher et al., 2018; Chou & Pramudawardhani, 2015; Hwang et al., 2013; Yu et al., 2018; Ahmadabadi & Heravi, 2019). As Choma (2008) stated, a company must take preventative action against contractor/subcontractor risk to prevent incurring significant losses rather than planned profits. Any contractor or subcontractor failure can cause significant delay in the construction phase of the PPP project, which leads to a shorter operation phase, which in turn directly affects the cash flow of the investment. In addition, poor construction quality also increases the potential risks in the operation phase (Yu et al., 2018). Compared to legal risks over which the investor has no control, the contractor/subcontractor risk is much more controllable and transferable. Indeed, the investor can mitigate this risk by paying extra attention to contractor selection (experience of contractor in similar type of projects, company structure, references, etc.), specifying contract conditions clearly (Aladağ & Işik, 2019; Choma, 2008), and by transferring this risk to a third party through bonding and insurance. Furthermore, as Yu et al. (2018) pointed out, the probability of project success can be dramatically increased by mitigating the contractor/subcontractor risk properly.

The third most important risk factor is operator risk. Operating revenue is one of the most important cash flow parameters in PPP investments (Nguyen et al., 2018), and has a direct impact on the Net Present Value (NPV) of the investment. Like picking the right contractor, the selection of the right operator (experience in similar type of projects, competence, references) is vital in successful PPP projects. The experts who participated in the surveys and brainstorming sessions mentioned that as hydropower plants are complex systems that involve advanced technology and equipment. Inexperienced and incompetent operators may not be able to operate in this environment, causing frequent interruptions in the operation of the power plant to perform costly maintenance and significant drops in revenue caused by the deactivation of the power plant.

According to Table 6, the three most important risk clusters are "stakeholders", "government requirements", and "resources", whereas "market" is the least important cluster.

- That "stakeholders" is the most important cluster is an expected result because two elements of the "stakeholder" cluster (contractor/subcontractor risk and operator risk) are three of the most important risk factors in PPP hydropower investments.
- "Government requirements" is the second most important risk cluster. This is not a surprise as one of the elements of this cluster (legal risk) is the most important risk factor of PPP hydropower investments. According to Mazher et al. (2018), the legal risks involved in PPP projects cause more problems in developing countries compared to more industrialized countries.
- The third most important risk cluster, "resources" that involves labor, material and equipment related risks also makes sense because according to Zayed et al. (2008), the quality and availability of the right material, labor and equipment are the key elements in achieving project success.
- The elements of the "market" cluster include demand risk, competition risk, and tariff rate risk. "Market" is the least important risk cluster because governments typically provide guarantees to buy the energy produced at a rate agreed upon in the contract, hence by and large minimizing the risk of fluctuating demand, the risk of aggressive competition from other investors, and the risk of changes in the rates.

The results were discussed with the fourteen experts who participated in the surveys and the brainstorming sessions. The experts were unanimous in their opinion that the ANP-based risk assessment model that identifies the priority of each risk factor/cluster is realistic as the method considers the interdependencies between the risk factors.

4. Testing the performance of the risk assessment model

Ten real PPP hydropower investments made in different regions of Turkey were chosen as case studies to test the performance of the proposed model in terms of its predictive capability. These projects were undertaken by the seven companies that supported this research by providing the participants of the survey and of the brainstorming sessions. The capacity of each of the hydropower stations is larger than 10 MW, considered to be large size projects. An expert team was formed of 10 project managers who were directly involved in all stages of the investments. In the first step, the experts were asked to rate the risk of each factor by using a Likert scale (1–5 scale), taking into consideration the characteristics of the projects. The overall risk rating of each project was calculated out of 100 by using the risk assessment tool. In the second step, the experts were asked to assign an overall risk rating to each of the 10 case study projects out of 100 by using their subjective judgments. The reliability of the model is determined by calculating the percentage error between the calculated risk rating and the risk rating assigned by an expert. As seen in Table 7, the percentage error of each case study ranges between 0.29% and 9.11% with an average of 3.56% for the 10 cases, which indicates that the proposed model generates results that are consistent with expert judgements. Therefore, the proposed model is of value to inexperienced decision-makers who can use this tool for risk assessment without expert involvement.

Table 7. Test results

Project name	Calculated risk ratings	Risk ratings assigned by experts	Percentage error (%)
Project 1	57.1	55	3.82
Project 2	45.4	45	0.89
Project 3	68.3	70	2.43
Project 4	74.3	75	0.93
Project 5	30.9	30	3.00
Project 6	35.1	35	0.29
Project 7	40.9	45	9.11
Project 8	42.1	40	5.25
Project 9	32.4	35	7.43
Project 10	48.6	50	2.80

Conclusions

This paper presents an ANP-based risk assessment model that can be used to quantify the total risk rating of a PPP hydropower investment by considering the risk factors associated with PPP hydropower investments. Using the proposed model, one should be able to obtain the total risk rating and the relative importance of each risk factor. In this study, first, the risk factors associated with PPP hydropower investments were identified by means of an extensive literature review, and a checklist survey of risk factors was administered to 14 experts. Second, the risk factors were grouped into 8 clusters named resources, stakeholders, construction, external environment, market, operation, financing/economic conditions, and government requirements. Third, a brainstorming session was arranged to identify the interactions between these risk factors and a network structure of risk factors was constructed. A second brainstorming session was organized to make pairwise comparisons of the factors. By using the "SuperDecisions" software, the weighted, unweighted, and limited super matrices were calculated and the priorities of each risk factor and cluster were identified with the help of the limited super matrix. The results presented in Table 5 and Table 6 indicate that the most important risk factor is "legal risk", and the most important risk cluster is "stakeholders". Fourth, a risk assessment tool was created to calculate the total risk rating of a PPP hydropower investment.

To test the performance of the model, ten real PPP hydropower investments were chosen as test cases. The average percentage error between the calculated (by the model) and estimated (by an expert) total risk ratings for the ten test cases was found to be 3.56%. The tool can be used by decision-makers who have only limited experience with PPP hydropower projects to estimate the risk level and to formulate response strategies. The contributions of this research include: (1) identifying the risk factors associated with PPP hydropower investments in Turkey, which may be similar to the risk factors in most developing countries; (2) determining the relative importance of each risk factor and cluster; (3) creating a tool that can inform and guide investors with limited experience in PPP hydropower investments. Although this model was proposed for PPP hydropower investments in Turkey, it can also be used in different countries by duplicating the four steps in the proposed model. The proposed model can also be used to perform the risk assessment of other PPP investments such as renewable energy investments, using a different set of risk factors, and a different risk network relevant for the investment.

It should be noted that the limitation of the proposed model involves the subjectivity of risk ratings. Indeed, it is difficult to reach consensus when the pairwise comparisons are made by multiple experts. Also, as the number of relationships between the risk factors increases, the number and complexity of the pairwise comparisons of risk factors increases, endangering the consistency of the ratings. Further research could focus on ways to minimize the subjectivity and enhance the consistency of the ratings calculated by ANP models.

Disclosure statement

I don't have any competing financial, professional, or personal interests from other parties.

References

Ahmadabadi, A. A., & Heravi, G. (2019). The effect of critical success factors on project success in public-private partnership projects: A case study of highway projects in Iran. *Transport Policy*, *73*, 152–161. https://doi.org/10.1016/j.tranpol.2018.07.004

Aladağ, H., & Işik, Z. (2018). The effect of stakeholder-associated risks in mega-engineering projects: A case study of a PPP airport project. *IEEE Transactions on Engineering Management*, *67*(1), 174–186. https://doi.org/10.1109/TEM.2018.2866269

Aladağ, H., & Işik, Z. (2019). Design and construction risks in BOT type mega transportation projects. *Engineering, Construction and Architectural Management*, *26*(10), 2223–2242. https://doi.org/10.1108/ECAM-08-2018-0351

Ameyaw, E. E., & Chan, A. P. C. (2015). Evaluation and ranking of risk factors in public-private partnership water supply projects in developing countries using fuzzy synthetic evaluation approach. *Expert Systems with Applications*, *42*(12), 5102–5116. https://doi.org/10.1016/j.eswa.2015.02.041

Ashuri, B., Kashani, H., Molenaar, K. R., Lee, S., & Lu, J. (2012). Risk-neutral pricing approach for evaluating BOT highway projects with government minimum revenue guarantee options. *Journal of Construction Engineering and Management*, *138*(4), 545–557. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000447

Bing, L., Akintoye, A., Edwards, P. J., & Hardcastle, C. (2005). The allocation of risk in PPP/PFI construction projects in the UK. *International Journal of Project Management*, *23*(1), 25–35. https://doi.org/10.1016/j.ijproman.2004.04.006

Bu-Qammaz, A. S., Dikmen, I., & Birgonul, M. T. (2009). Risk assessment of international construction projects using the analytic network process. *Canadian Journal of Civil Engineering*, *36*(7), 1170–1181. https://doi.org/10.1139/L09-061

Chan, A. P. C., Yeung, J. F. Y., Yu, C. C. P., Wang, S. Q., & Ke, Y. (2011). Empirical study of risk assessment and allocation of public-private partnership projects in China. *Journal of Management in Engineering*, *27*(3), 136–148. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000049

Cheng, E., & Li, H. (2004). Contractor selection using the analytic network process. *Construction Management and Economics*, *22*(10), 1021–1032. https://doi.org/10.1080/0144619042000202852

Choma, A. A. (2008). How to reduce risks in contractors' management. In *PMI® Global Congress 2008*, North America, Denver, CO. Project Management Institute, Newtown Square, PA.

Chou, J., & Pramudawardhani, D. (2015). Cross-country comparisons of key drivers, critical success factors and risk allocation for public-private partnership projects. *International Journal of Project Management*, *33*, 1136–1150. https://doi.org/10.1016/j.ijproman.2014.12.003

Dehdast, G., Zin, R. M., Ferwati, M. S., Abdullahi, M. M., Keyvanfar, A., & McCaffer, R. (2017). DEMATEL-ANP risk assessment in oil and gas construction projects. *Sustainability*, *9*, 1420. https://doi.org/10.3390/su9081420

Dikmen, I., Birgonul, M. T., & Ozorhon, B. (2007). Project appraisal and selection using the analytic network process. *Canadian Journal of Civil Engineering*, *34*(7), 786–792. https://doi.org/10.1139/l07-006

Do, S. T., Likhitruangsilp, V., Kiet, T. T., & Nguyen, P. T. (2017). Risk assessment for international construction joint ventures in Vietnam. *International Journal of Advanced and Applied Sciences*, *4*(6), 104–114. https://doi.org/10.21833/ijaas.2017.06.015

El-Abbasy, M. S., Zayed, T., Ahmed, M., Alzraiee, H., & Abouhamad, M. (2013). Contractor selection model for highway projects using integrated simulation and analytic network process. *Journal of Construction Engineering and Management*, *139*(7), 755–767. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000647

Erdem, D., & Ozorhon, B. (2015). Assessing real estate project success using an Analytic Network Process. *Journal of Management in Engineering*, *31*(4), 04014065. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000281

Ghorbani, A., Ravanshadnia, M., & Nobakht, M. B. (2014). A survey of risks in public private partnership highway projects in Iran. In *2014 International Conference on Construction and Real Estate Management*, Kunming, China. https://doi.org/10.1061/9780784413777.058

Hasnain, M., Thaheem, M. J., & Ullah, F. (2018). Best value contractor selection in road construction projects: ANP-based decision support system. *International Journal of Civil Engineering*, *16*, 695–714. https://doi.org/10.1007/s40999-017-0199-2

Hwang, B., Zhao, X., & Gay, M. J. S. (2013). Public private partnership projects in Singapore: Factors, critical risks and preferred risk allocation from the perspective of contractors. *International Journal of Project Management*, *31*, 424–433. https://doi.org/10.1016/j.ijproman.2012.08.003

Ibrahim, A. D., Price, A. D. F., & Dainty, A. R. J. (2006). The analysis and allocation of risks in public private partnerships in infrastructure projects in Nigeria. *Journal of Financial Management of Property and Construction*, *11*(3), 149–163. https://doi.org/10.1108/13664380680001086

Karim, N. A. A. (2011). Risk allocation in Public-Private Partnership (PPP) project: A review on risk factors. *International Journal of Sustainable Construction Engineering* & *Technology*, *2*(2), 8–16.

Keers, B. B. M., & Fenema, P. C. V. (2018). Managing risks in public-private partnership formation projects. *International Journal of Project Management*, *36*, 861–875. https://doi.org/10.1016/j.ijproman.2018.05.001

Ke, Y., Wang, S., Chan, A. P. C., & Lam, P. T. I. (2010). Preferred risk allocation in China's Public Private Partnership (PPP) projects. *Journal of Project Management*, *28*, 482–492. https://doi.org/10.1016/j.ijproman.2009.08.007

Kumar, L., Jindal, A., & Velaga, N. R. (2018). Financial risk assessment and modelling of PPP based Indian highway infrastructure projects. *Transport Policy*, *62*, 2–11. https://doi.org/10.1016/j.tranpol.2017.03.010

Kuru, K., & Artan, D. (2020). A canvas model for risk assessment and performance estimation in public-private partnerships. *International Journal of Construction Management*, *20*(6), 704–719. https://doi.org/10.1080/15623599.2020.1763898

Li, H., Dong, K., Jiang, H., Sun, R., Guo, X., & Fan, Y. (2017). Risk assessment of China's overseas oil refining investment using a fuzzy-grey comprehensive evaluation method. *Sustainability*, *9*, 696. https://doi.org/10.3390/su9050696

Li, Y., & Wang, X. (2019). Using fuzzy analytic network process and ISM methods for risk assessment of public-private partnership: A China perspective. *Journal of Civil Engineering and Management*, 25(2), 168–183. https://doi.org/10.3846/jcem.2019.8655

Liu, J., Love, P. E. D., Smith, J., Regan, M., & Davis, P. R. (2015). Life cycle critical success factors for public-private partnership infrastructure projects. *Journal of Management in Engineering*, *31*(5), 04014073. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000307

Mazher, K. M., Chan, A. P. C., Zahoor, H., Khan, M. I., & Ameyaw, E. E. (2018). Fuzzy integral-based risk-assessment approach for public-private partnership infrastructure projects. *Journal of Construction Engineering and Management*, *144*(12), 04018111. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001573

Meade, L. M., & Presley, A. (2002). R&D project selection using the analytic network process. *IEEE Transactions on Engineering Management*, *49*(1), 59–66. https://doi.org/10.1109/17.985748

Nguyen, A., Mollik, A., & Chih, Y. (2018). Managing critical risks affecting the financial viability of public-private partnership projects: Case study of toll road projects in Vietnam. *Journal of Construction Engineering and Management*, *144*(12), 05018014. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001571

Niemira, M. P., & Saaty, T. L. (2004). An analytical network process model for financial-crisis forecasting. *International Journal of Forecasting*, *20*(4), 573–587. https://doi.org/10.1016/j.ijforecast.2003.09.013

Osei-Kyei, R., & Chan, A. (2015). Review of studies on the critical success factors for public–private partnership (PPP) projects from 1990 to 2013. *International Journal of Project Management*, *33*(6), 1335–1346. https://doi.org/10.1016/j.ijproman.2015.02.008

Ozcan-Deniz, G., & Zhu, Y. (2015). A multi-objective decision-support model for selecting environmentally conscious highway construction methods. *Journal of Civil Engineering and Management*, *21*(6), 733–747. https://doi.org/10.3846/13923730.2014.893915

Ozorhon, B., Dikmen, I., & Birgonul, M. T. (2007). Using analytic network process to predict the performance of international construction joint ventures. *Journal of Management in Engineering*, *23*(3), 156–163. https://doi.org/10.1061/(ASCE)0742-597X(2007)23:3(156)

Palaco, I., Park, M. J., Kim, S. K., & Rho, J. J. (2019). Public–private partnerships for e-government in developing countries:

An early stage assessment framework. *Evaluation and Program Planning*, *72*, 205–218. https://doi.org/10.1016/j.evalprogplan.2018.10.015

Saaty, T. L. (1994). How to make a decision: The analytic hierarchy process. *Interfaces*, *24*(6), 19–43. https://doi.org/10.1287/inte.24.6.19

Saaty, T. L. (1996). *Decision making with dependence and feedback: The analytic network process*. Pittsburgh: RWS Publications.

Saaty, T. L. (2003). Decision-making with the AHP: Why is the principal eigenvector necessary? *European Journal of Operational Research*, *145*(1), 86–91. https://doi.org/10.1016/S0377-2217(02)00227-8

Saaty, T. L. (2004). Fundamentals of the analytical network process-dependence and feedback in decision-making with a single network. *Journal of Systems Science and Systems Engineering*, *13*(2), 129–157. https://doi.org/10.1007/s11518-006-0158-y

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83–98. https://doi.org/10.1504/IJSSCI.2008.017590

Shang, J. S., Tjader, Y., & Ding, Y. (2004). A unified framework for multicriteria evaluation of transportation projects. *IEEE Transactions on Engineering Management*, *51*(3), 300–313. https://doi.org/10.1109/TEM.2004.830848

Shao, Y., Yuan, J., & Li, Q. (2016). Identification of the residual value risk factors for road PPP projects in China: Questionnaire survey and analysis. *Proceedings of the 20th International Symposium on Advancement of Construction Management and Real Estate*, 379–389. https://doi.org/10.1007/978-981-10-0855-9_33

Sharma, S., & Kar, S. (2018). Risk management and analysis in hydro-electric projects in India. *SSRG International Journal of Civil Engineering*, *5*(3), 1–7. https://doi.org/10.14445/23488352/IJCE-V5I3P101

Tah, J. H. M., & Carr, V. (2000). A proposal for construction project risk assessment using fuzzy logic. *Construction Management and Economics*, *18*(4), 491–500. https://doi.org/10.1080/01446190050024905

Tang, L., Shen, G., Skitmore, M., & Wang, H. (2015). Procurement-related critical factors for briefing in public-private partnership projects: Case of Hong Kong. *Journal of Management in Engineering*, *31*(6), 04014096. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000352

Thomas, A., Kalidindi, S. N., & Ganesh, L. (2006). Modelling and assessment of critical risks in BOT road projects. *Construction Management and* Economics, *24*(4), 407–424. https://doi.org/10.1080/01446190500435275

Tohumcu, Z., & Karasakal, E. (2010). R&D project performance evaluation with multiple and interdependent criteria. *IEEE Transactions on Engineering Management*, *57*(4), 620–633. https://doi.org/10.1109/TEM.2009.2036159

Valipour, A., Yahaya, N., Md Noor, N., Kildienė, S., Sarvari, H., & Mardani, A. (2015). A fuzzy analytic network process method for risk prioritization in freeway PPP projects: an Iranian case study. *Journal of Civil Engineering and Management*, *21*(7), 933–947. https://doi.org/10.3846/13923730.2015.1051104

Valipour, A., Yahaya, N., Md Noor, N., Mardani, A., & Antucheviciene, J. (2016). A new hybrid fuzzy cybernetic analytic network process model to identify shared risks in PPP Projects. *International Journal of Strategic Property Management*, *20*(4), 409–426. https://doi.org/10.3846/1648715X.2016.1210547

Wang, S. Q., Tiong, R. L. K., Ting, S. K., & Ashley, D. (2000). Evaluation and management of foreign exchange and revenue risks in China's BOT projects. *Construction Management and Economics*, *18*, 197–207. https://doi.org/10.1080/014461900370825

Wibowo, A., Permana, A., Kochendörfer, B., Kiong, R. T. L., Jacob, D., & Neunzehn, D. (2012). Modeling contingent liabilities arising from government guarantees in Indonesian BOT/PPP toll roads. *Journal of Construction Engineering and Management*, *138*(12), 1403–1410. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000555

Wu, Y., Li, L., Xu, R., Chen, K., & Hu, Y. (2017). Risk assessment in straw-based power generation public-private partnership projects in China: A fuzzy synthetic evaluation analysis. *Journal of Cleaner Production*, *161*, 977–990. https://doi.org/10.1016/j.jclepro.2017.06.008

Wu, Y., Song, Z., Li, L., & Xu, R. (2018). Risk management of public-private partnership charging infrastructure projects in China based on a three-dimension framework. *Energy*, *165*, 1089–1101. https://doi.org/10.1016/j.energy.2018.09.092

Xu, Y., Hu, C., & Chan, A. P. C. (2009). Risk factors for running public private partnerships (PPP) – An empirical comparison between government and private sector. In *International Conference on Management and Service Science* (*MASS'09*), Wuhan, China. https://doi.org/10.1109/ICMSS.2009.5301324

Xu, Y., Yeung, J. F. Y., Chan, A. P. C., Chan, D. W. M., Wang, S. Q., & Ke, Y. (2010). Developing a risk assessment model for PPP projects in China—A fuzzy synthetic evaluation approach. *Automation in Construction*, *19*(7), 929–943. https://doi.org/10.1016/j.autcon.2010.06.006

Yu, Y., Darko, A., Chan, A. P. C., Chen, C., & Bao, F. (2018). Evaluation and ranking of risk factors in transnational public-private partnerships projects: Case study based on the intuitionistic fuzzy analytic hierarchy process. *Journal of Infrastructure* Systems, *24*(4), 04018028. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000448

Yuan, J. F., Deng, X. P., & Li, Q. M. (2008). Critical risks identification of public private partnerships in China and the analysis on questionnaire survey. In *the 4th International Conference on Wireless Communications*, *Networking and Mobile Computing*, Dalian, China. https://doi.org/10.1109/WiCom.2008.2453

Zayed, T., Amer, M., & Pan, J. (2008). Assessing risk and uncertainty inherent in Chinese highway projects using AHP. *International Journal of Project Management*, *26* (4), 408–419. https://doi.org/10.1016/j.ijproman.2007.05.012

Zhang, C., Liu, X., Jin, J., & Liu, Y. (2016). A stochastic ANP-GCE approach for vulnerability assessment in the water supply system with uncertainties. *IEEE Transactions on Engineering Management*, *63*(1), 78–90. https://doi.org/10.1109/TEM.2015.2501651

Zhang, S., Sun, B., Yan, L., & Wang, C. (2013). Risk identification on hydropower project using the IAHP and extension of TOPSIS methods under interval-valued fuzzy environment. *Natural Hazards*, *65*, 359–373. https://doi.org/10.1007/s11069-012-0367-2

Zhao, Z. Y., Tang, C., Zhang, X. L., & Skitmore, M. (2017). Agglomeration and competitive position of contractors in the international construction sector. *Journal of Construction Engineering and Management*, *143*(6), 04017004. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001284