Performance Objectives Selection Model in Public-Private Partnership Projects Based on the Perspective of Stakeholders

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Abstract: Over the years, public-private partnership (PPP) has been acknowledged by many as an innovative approach to the procurement of public projects. The desire for more efficient and effective PPP projects renders the performance management to be increasingly important, in which the influence of the stakeholders must be considered. To implement complete and effective performance management in PPP projects, 15 performance objective attributes are proposed based on the perspectives of different stakeholders. A structured questionnaire survey was conducted to investigate the relative significance of each attribute in four stakeholder groups. According to the survey results, the objective attributes are all important. Integrating all stakeholders' benefits and selecting the appropriate qualitative level of performance objective in the process of decision making are two particularly important problems because of stakeholders' different preferences. To resolve these problems, a fuzzy entropy method and a fuzzy TOPSIS method based on projection distance have been developed to calculate the final decision weights in all stakeholder groups and select appropriate performance objective levels for PPP projects, respectively. The final decision weights are obtained using fuzzy entropy to integrate the experiences and knowledge of all stakeholders. An illustrative case study on the Beijing National Stadium project for the 2008 Olympic Games is used to demonstrate the feasibility and practicability of the proposed model.

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Introduction

Over the years, public-private partnerships (PPPs) have been acknowledged by many as an innovative approach to the procurement of public projects. The function of PPPs is to lower the risks of projects during the life cycle, including cost overruns and delays, while still achieving the best value (Abdul-Malak et al. 2001; Akintoye et al. 2003; Zhang 2005b). Meanwhile, PPPs also provide the opportunity for innovation and establishment of partnerships (Bloomfield 2006; Carrillo et al. 2006; Essig and Batran 2005).

As a public project procurement method, PPP projects must be managed from the process management perspective to control the variables during the execution of project processes and tasks. A significant amount of prior research in PPPs indicates that many failures resulted not only from single factors but also from the interactions of multiple factors during the lifecycle of the projects—including cost, quality, schedule, management ability, and others [Cambridge Economic Policy Associates Ltd. (CEPAL) 2005; Koppenjan 2005; Li et al. 2005b; Zhang 2005a]. To remedy this problem, a performance management method can be introduced to manage PPP projects. Kagioglou et al. (2001) transferred performance management practices from other industries into the construction industry. At the project level, the performance management process tracks how well project performance is in line with its corporate and functional strategies and objectives. The objective of this process is to provide a proactive closed-loop control system, where the corporate and functional strategies are deployed to all processes, activities, and tasks (Bititci et al. 1997). The five key steps of performance management, as concluded by Forslund (2007), are setting objectives and strategies, definition of metrics, measurement, analysis and evaluation, and the improvement process. During the performance management process, the performance objective should be set in the planning stage, which can be viewed as an effective motivational process to manage the projects and a performance measurement baseline based on the goal-setting theory by Locke (1968).

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However, the performance objectives that are expected to be fulfilled in a PPP project, from project planning to operation, can result in related substantial risks because the lifecycle of a PPP project is usually about 30 years and thus prone to potential claims and intractable disputes (Li et al. 2005c; Salman et al. 2007; Wang et al. 2000). The external stakeholders in PPPs and their satisfaction levels often determine the success of these projects. Stakeholder opposition has been reported as the main reason for failure in several major PPP initiatives (El-Gohary et al. 2006). Capturing and addressing stakeholder inputs are therefore crucial to the success of PPP projects. Stakeholder involvement should be considered from different perspectives. Fragmented knowledge (engineering, sociology, psychology, and marketing) in this domain is impeding project operation and successful PPP projects. Prior research on the critical success factors (CSFs) of PPP projects shows that the multiple objectives that benefit stakeholders are very important during the project planning stage (Li et al. 2005a; Qiao et al. 2001; Tiong et al. 1992).

Due to the complexity of PPP projects and different expectations of different stakeholders, a single group of stakeholders often cannot comprehensively consider the whole spectrum of decision problems. As a result, complex decision problems in selection of performance objectives in PPPs have to be conducted by integrating knowledge and experiences of many stakeholder groups.

The practice of multiattribute group decision making can be introduced into the decision process due to its good effectiveness and easy operation. MDGAM has been previously applied in construction projects (Lin et al. 2008). The technique for order preference by similarity to an ideal solution (TOPSIS) is one of the widely used techniques in decision making, and it has been successfully applied to quality control and location analysis (Shih et al. 2007; Lin et al. 2008). TOPSIS may also be combined with multiobjective decision making and group decision making (Lai 1994; Shih et al. 2001). The high flexibility of TOPSIS allows further extension to make better choices in various situations (Shih et al. 2007). Meanwhile, fuzzy set theory (FST) has been used to establish ill-defined multiple criteria decision-making problems. Its efficiency in resolving the ambiguity frequently arising in available information and more accurately accounting for the essential fuzziness in human judgments and preferences (Liang 1999) makes it a more effective method. The value of fuzzy multiple criteria decision-making methods can be improved obviously if human intransitivity (in practice, the term intransitivity is mostly used when speaking of scenarios in which a relation describes the relative preferences between pairs of options, and weighing several options produces a “loop” of preference: A is preferred to B; B is preferred to C; C is preferred to A; intransitivity often occurs in stakeholders’ system of values and preferences, potentially leading to unresolvable conflicts; the public sector for example would consider that the investment from private sectors is more important than technology improvement in public projects, the technology improvement is more important than quality public service, and the quality public service is more important than the investment from private sectors) and dynamic adjustment of preferences can be considered in the decision-making process. One prior application of FST in PPPs was a fuzzy simulation multiple-objective decision model developed by Ng et al. (2007).

As the performance of PPP projects can be influenced by multiple factors (Li et al. 2005a,b; Zhang 2005b), the performance objective actually is an attribute system. This system would contain a set of subobjectives or attributes to reflect the multifaceted requirements of the stakeholders (see Fig. 1). Different attributes would be then set in different levels, which can be defined as objective level. In psychology, the objective level, which is often called objective difficulty in the goal-setting literature (Locke and Latham 1990), refers to the value of an internally represented desired state for a variable (Austin and Vancouver 1996). This value is usually manipulated via differing levels of assigned objectives. It robustly affects performance level (Locke and Latham 1990), which also can be called the objective-level effect, e.g., higher objective levels lead to higher performance (Vancouver et al. 2005). Similarly, the performance objective level in PPP projects can be defined to describe to what extent the performance objective will be achieved. Performance objective levels are determined by the difficulties of those performance objective attributes, the complexity of task for the objective attributes, and the commitments of stakeholders to put effort in the project (Dodd and Anderson 1996). As a result, two key problems related to the attributes and level of performance objective should be resolved during the decision-making process of a PPP project’s performance objectives. The first problem is *how to integrate all stakeholders’ benefits into the process of decision making* (see Fig. 1). Clearly, different groups in PPPs may have different expectations of a PPP project, which makes it difficult to select the proper performance objectives. This means the weight of each performance objective attribute is not the same in different groups. However, the final decision weight of each performance objective attribute should be the only one. Thus, the knowledge and experiences of all stakeholder groups should be put together to solve this complex decision problem. This paper presents a hybrid model to calculate the integrated weights of each performance objective in all stakeholder groups. Furthermore, the integrated weights are also important to resolve the second problem, which is *to select an appropriate performance objective level of a PPP project from a set of available alternate levels that contain multiple attributes* (see Fig. 1). Usually, several representatives of stakeholders will be invited to describe or select their expecta-

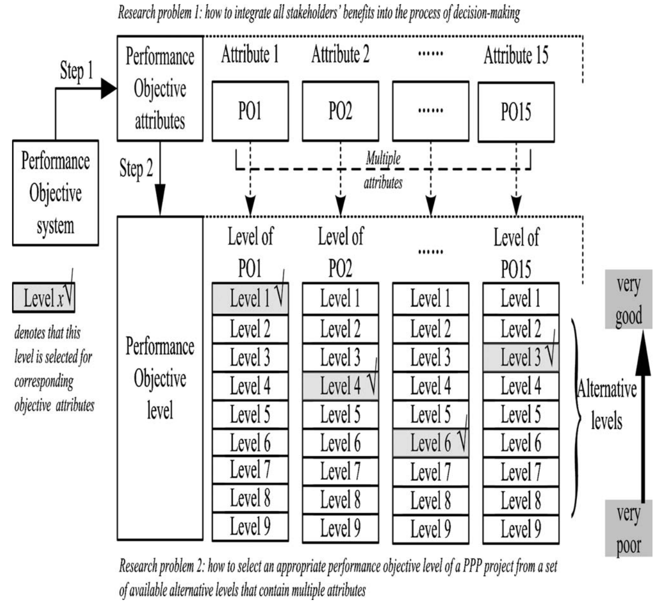

Fig. 1. Research problems and the relationship framework among the performance objective, the attributes of performance objectives, and the level of performance objectives

tions for the PPP project according to their judgments and evaluation of each attribute individually. Then, their expected results and alternatives ranked by their integrated evaluations are aggregated. TOPSIS can rank a finite number of feasible alternatives in order of preference according to the features of each attribute of every alternative and select a suitable alternative that conforms to the decision maker's ideal. The basic concept of TOPSIS is that the selected alternative will have the shortest Euclidean distance from the positive ideal decision (PID) and the farthest Euclidean distance from the negative ideal decision (NID). An improved TOPSIS method to select an appropriate level of performance objective will be developed in this paper by using vertical projection distance to substitute the Euclidean distance, which can adapt the traditional TOPSIS method for ranking potential PPP projects performance objective levels to set an appropriate alternative in a practical PPP application.

This paper, based on the stakeholders' perspective, provides an insight into a series of achievable performance objective attributes of PPP projects. The remainder of this paper is organized as follows. "Definition of Stakeholders in PPP Projects" gives the definition of stakeholders in PPP projects. "Performance Objectives in PPP Projects" provides an overview of performance objective attributes in PPP projects based on the literature review. A structured questionnaire survey targeting different stakeholders is also presented in this section to seek, analyze, and integrate their perceptions of the PPP projects' performance objective attributes. To resolve the first problem, a fuzzy entropy model to calculate the integrated weight of each performance objective attribute in all stakeholder groups is developed in "Calculating the Integrated Weight of Each Performance Objective Attribute." Based on the findings of "Calculating the Integrated Weight of Each Performance Objective Attribute," the section "Improved TOPSIS Method to Select Performance Objective Level" proposes an improved TOPSIS method to determine the appropriate level of performance objective to resolve the second problem. A case study of PPP project performance objective selection is illustrated in "Case Study of PPP project: the 'Bird's Nest—Beijing National Stadium' for the 2008 Olympic Games" to show the effectiveness of the proposed model. "Summary and Conclusions" provides some concluding remarks.

Definition of Stakeholders in PPP Projects

Prior research discussed the definition and meaning of stakeholders in construction. PMI (2000) states that project stakeholders are individuals and organizations that are actively involved in the project or whose interests may be affected as a result of project execution or project completion. Olander (2007) indicated that a project stakeholder can be defined as a person or group of people who has a vested interest in the success of a project and the environment within which the project operates. Vested interest is defined as having possession of one or more of the stakeholder attributes of power, legitimacy or urgency. There are essentially two categories of stakeholders: internal stakeholders, who are actively involved in project execution; and external stakeholders, who are affected by the project. Newcombe (2003) defined the project stakeholders as groups or individuals who have a stake in, or expectation of, the project's performance. In PPPs, the ultimate success of projects has a close relationship with stakeholders. These stakeholders, who have various interests and influences on the projects, play different roles during the implementation of projects. The stakeholders will therefore affect the performance and success of PPP projects.

Thus, the stakeholders in the PPP context can be divided into four groups based on their role: (1) the public sector, the group of internal stakeholders including governments and public clients, is an important decision maker in the PPP projects; (2) the private sector, the group of internal stakeholders including private contractors, subcontractors, suppliers, designers, and consultants, is the major implementer in the PPP projects. Previous research viewed the project owner, main contractor, subcontractor, and designing company as different stakeholders in the construction context (Wang and Huang 2006). However, these private sector participants are all connected by a concession agreement that needs them to have basically common interests in PPP projects. Hence, they are in the same group. This kind of classification will also simplify the analysis; (3) the general public is a group that includes people who are affected by PPP projects, or the end users of PPP projects. This group typically strongly influences the success of PPP projects. Their urgent needs for quality public facilities and services make public sector adopt PPP methods to deliver corresponding satisfactory projects. Additionally, a successful PPP project relies on the satisfaction of end users, particularly in the operational stage. The last stakeholder, (4) the research group, consisting of external stakeholders, is an observer and provides suggestions related to the PPP projects. The researchers can usually give useful suggestions to the decision makers or implementers based on their academic knowledge and industry experiences. Their expertise is particularly important in the planning stage of the project.

Performance Objectives in PPP Projects

Perception of Performance Objective in PPPs

Performance objectives of a stakeholder group in a PPP project differ due to different expectations. However, the ultimate objective of PPPs, which is the successful implementation of PPP projects, should be accomplished in a real PPP project in spite of the different preferences among the stakeholders. For example, the public sectors in PPPs pursue the maximization of effectiveness in public facilities, the private sectors intend to obtain high profits from PPP projects, and the general public expects the benefits of PPP projects, all of which should depend on the successful completion of the project. As mentioned earlier, to implement complete and effective performance management, the objective identification should be pursued before performance planning. Zhang (2006a) stated that achieving the best value for a public service and product is the ultimate objective for PPPs. The best value is defined as the maximum achievable outcome from the development of an infrastructure project (Gransberg and Ellicott 1997). In PPPs, the best value emphasizes quality, efficiency/effectiveness, value for money, and performance standards (Akintoye et al. 2003). The priority of these value elements depends on the specific and complicated requirements of the integration of stakeholders and the particular attributes of the specific project under consideration, and the achievability of the best-value elements depends on available resources (Zhang 2006a). The best-value objective in a PPP project's delivery of a new built infrastructure project should reflect the public client's overall strategic plan and mission objectives, the private sector's long-term development and payoff strategy (e.g., cost objective, schedule objective, and profit objective), and the general public's require-

Table 1. Attributes of Performance Objectives in the PPP Projects and Their Grades and Rankings in Different Groups (Yuan et al. 2009)

		Academia (A)			Private sector (PI)			Public sector (PII)			General public (PIII)		
Number	Performance objective attribute	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank
PO1	Acceptable quality of project	4.15	0.79	1	4.03	0.95	1	4.17	0.83	1	4.06	1.26	1
PO2	Quality public service	3.98	0.86	2	3.65	1.05	5	3.58	0.90	4	3.73	1.23	2
PO3	Within budget or saving money in construction and operation	3.98	0.8	3	3.71	1.1	3	4.17	0.72	1	3.44	1.09	6
PO4	On-time or earlier project completion	3.87	0.91	4	3.71	1.32	3	3.50	0.80	6	3.52	1.07	5
PO5	Satisfying the need for public facilities	3.67	0.84	5	3.29	1.07	10	3.42	1.08	8	3.54	1.07	4
PO6	Provide timelier and more convenient service for society	3.65	0.92	6	3.45	0.99	7	3.50	1.17	6	3.63	1.14	3
PO7	Solving the problem of public sector budget restraint	3.59	1.11	7	3.23	0.99	12	3.92	0.90	3	3.25	1.18	8
PO8	Life-cycle cost reduction	3.54	1.11	8	3.81	1.08	2	3.42	1.00	8	3.50	1.09	7
PO9	Introducing business and profit generating skills to the public sector	3.30	1.05	9	3.55	1.12	6	3.42	1.08	8	3.13	0.98	9
PO10	Transferring risk to private sector	3.24	1.06	10	2.97	1.05	14	3.58	1.08	4	2.50	1.07	15
PO11	Making profit from public service	3.22	1.21	11	3.45	1.21	7	2.92	1.16	12	2.94	1.04	11
PO12	Promoting local economic development	3.15	1.03	12	3.29	1.04	10	3.17	0.94	11	3.06	0.78	10
PO13	Improving technology level or gaining technology transfer	3.13	0.86	13	3.19	1.08	13	2.67	1.30	14	2.94	0.76	11
PO14	Public sector can acquire additional facilities/service beyond requirement from private sector	2.80	0.98	14	2.90	1.01	15	2.92	1.24	12	2.71	0.92	14
PO15	Private sector can earn government sponsorship, guarantee, and tax reduction	2.74	1.06	15	3.45	1.09	7	2.67	1.07	14	2.88	0.84	13

ments for quality public facilities and service. Project performance may be measured independently against the cost objective, schedule objective, and requirements from stakeholders and products. Therefore, specification toward meeting the requirements from each perspective is the first principle in the performance management system. Requirements-based performance objective states the performance levels that the stakeholders expect the PPP projects to achieve, which can assist the public sector to establish a clear relationship with the private sector, facilitate the development of an innovative PPP method for the private sector, and make both the public and private sectors work in accord with the PPP project's budget, program planning, and performance measures.

Accordingly, the public and private sectors should have a common vision of the project under consideration and work in partnership toward shared objectives (Zhang 2006a). So far, there are few discussions published that examine the performance objectives of PPP projects. According to goal-setting theory (Locke 1968; Locke and Latham 1990), the level of satisfaction can be established by gauging the discrepancies between the objective level (the level that is set) and performance level (the level that is achieved), which will influence project performance (comfortable objective level can improve the performance; otherwise, the performance can be reduced). A value-goal-outcome model is proposed by Leung and Liu (1998) and Liu and Leung (2002), which reveals that values and objectives could be affected by previous experiences and might, subsequently, influence the final outcome. On the basis of psychological value, goal-setting and process satisfaction theories, the value management model of the value-goal-outcome model indicates that value specificity influences project objective-selecting in the decision-making process (e.g., the more specific the value, the more specific the objective). Objective specificity defines the target level for project performance (e.g., project completion within 18 months). The specific value (through specific objectives) guides performance toward a successful project outcome(s). Leung et al. (2004) considered an objective as a cognitive representation of value, while they defined decision making as a process to enable a value to be transformed to an objective.

As a result, the performance objective of PPP projects should be further specified by setting a series of specific subobjectives or attributes among different stakeholders in PPP projects, which should look for the best value and turn it into the objective. As a whole, the objective of a PPP project is to seek the project feasibility and viability, to make the project successful, and to achieve the best value of the project. Thus, the previous experiences can be obtained from related studies in the area of PPP application in literature. The writers have conducted a research to identify the attributes of performance objectives in the PPP projects. After a comparison of different factors that can influence the viability (Salman et al. 2007), success (Li et al. 2005a; Tiong et al. 1992), and the best value of PPPs (Zhang 2006a,b), a series of attributes for the performance objective of the PPP projects have been identified as shown in Table 1 (Yuan et al. 2009).

As mentioned earlier, three key terms should be clarified in this research, which respectively are performance objective, the subobjectives/attributes of the performance objective, and the level of the performance objective. The framework of relationship among these three terms is presented in Fig. 1. The selection of performance objectives for a PPP project should include setting a set of objective attributes (Step 1 in Fig. 1) because the stakeholders' perceptions of project success are influenced by a range of factors, and may result in each stakeholder group's perception being idiosyncratic (Liu and Leung 2002). In addition, vague objectives (e.g., do your best) of stakeholders should be made more specific. At the same time, the performance objective level is also important for improving the level of project performance. For example, PO1 acceptable quality of project is a performance objective attribute in the performance objective system (Table 1). Its level can be set from Levels 1 to 9 (Step 2 in Fig. 1), which means the expected performance related to this attribute can be ranged from "very good" to "very poor" based on the require-

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ments of stakeholders. For the quality, the defect rate is an important measurement method that is influenced by related quality standard, quality control in the process, and the governance of the public sectors on the quality. The performance objective attribute PO1 reflects the expectations of stakeholders on the outputs of those activities. The level of other attributes can also be set by the similar way. The performance objective level will be positive to the project performance when these objective attributes are set to the appropriate level as presented by Locke and Latham (1990) and Vancouver et al. (2005).

Research Survey and the Significance of Performance Objective Attributes

The identified objective attributes do not target a single group but integrate stakeholders' opinions. For different groups, the significance of these attributes may be different. The different significance of these attributes in different stakeholders will not only reflect the opinions of stakeholders but also influence the stakeholders' efforts on different performance aspects to affect the project performance. The relative significance of the 15 performance objective attributes have been examined by a structured questionnaire survey of the opinions of different stakeholders in PPPs by Yuan et al. (2009). The survey targets were limited to the available information listing those with PPP experience or expressed interest in PPP and the people who were related to the PPP projects. The questionnaire was pilot tested to ensure that it was practical. The initial draft was presented to a group of international research professionals from the University of Maryland, College Park, Maryland, United States, Nanyang Technological University of Singapore, and International Finance Corporation of Washington, D.C., United States.

The structure of the final questionnaire is provided by Yuan et al. (2009), and the questionnaire is also attached in Appendix I. This paper reports the identification of the performance objectives of PPP projects, which reflects the expectations of different stakeholders. Likert-style rating questions, using a five-point scale, were used to elicit respondents' opinions of the importance of each of the nominated objective attributes. The scale intervals are interpreted as follows: (1) can be ignored or not important; (2) maybe important; (3) important; (4) very important; and (5) most important. A total of 1,083 questionnaires were sent out and 141 respondents returned complete questionnaires (Yuan et al. 2009). They are from different organizations/institutions in a number of countries and regions. The survey respondents' roles and experiences can be given by Yuan et al. (2009). The effective return rate was 13.02%, which was deemed adequate for the purposes of data analysis (Yuan et al. 2009).

The respondents are classified into four groups in this research based on the aforementioned definition of stakeholders. The first group, from academia (A), was composed of those who have taken part in related research of PPPs; the second group, from private sector (PI), was composed of those who have rich experience in PPP projects; the third group, from public sector (PII), was composed of those who have participated in real PPP projects; the last group came from general public (PIII), including the people who are generally interested in PPPs or affected by PPPs but do not belong to any of the previous groups.

The score of each performance objective attribute for each group is shown in Table 4. The survey rankings of respondents' opinions of the performance objective attributes of PPPs are listed in Table 1. For the 15 attributes offered to respondents, the mean response rating values (for all respondents) range from 4.17 (acceptable quality in group PII) down to 2.5 (transferring risk to private sector in group PIII). No attribute mean value scores fell into the "extremely important" (>4.50) and "not important" (<1.5) categories. However, the differences among the different group are very significant, which can be reflected by the score and rank in different group. For example, the score of "*achieving budget or saving money*" is more important in group PII (4.17) than in the other three groups (A, 3.98; PI, 3.71; PIII, 3.44). The similar phenomena can be found in PO_7 and PO_8, which are especially important in group PII and PI, respectively. On the other hand, the rank of "*transferring risk to the private sector*" in group PI (14) is lower than in Group A (10) and group PII (5), which reflects different attitudes toward risk. The rank of "satisfying the need of more public facility" is in group PIII (4), higher than in group PI (10) and group PII (8). The detailed presentation and analysis of the survey results can be supplied by Yuan et al. (2009).

Calculating the Integrated Weight of Each Performance Objective Attribute

Although the specific attributes of performance objective based on the experience and knowledge in the questionnaire are clear to the project stakeholders, their judgments about the relative significances of these attributes are usually vague and imprecise because of the application of linguistic variables in the survey. Meanwhile, these objective attributes are multifaceted and strongly project related. Thus, different stakeholders would have different perceptions about these attributes, which means that they need to be comprehensively understood and that each should have only one decision weight across the entire group in the decision-making process. To obtain the appropriate weight for each attribute of the performance objective, the FST pioneered by Zadeh (1965) is used here to address the problems involving fuzzy phenomena. FST is specifically designed to mathematically represent uncertainty and vagueness and to provide formalized tools for dealing with the imprecision intrinsic to many problems (Zhang and Zou 2007). The fuzzy information entropy approach will be employed to tackle the weight of each attribute involved in the selection of performance objectives. The proposed approach includes three steps: (1) setting up the fuzzy matrix of the attributes; (2) determining the weight vector of stakeholder groups; and (3) determining the final decision weight of each attributes in all the groups, as presented in the following.

Step 1: Setting up the Fuzzy Matrix

As mentioned earlier, four groups of stakeholders were asked to determine the relative significance of prospective performance objective attributes of PPP projects based on their own judgments and preferences. These attributes are defined qualitatively and assessed in linguistic terms represented by scale intervals. As a result, the raw matrix PO_{ijt} can be obtained by returned questionnaire ($i=1, 2,\ldots, 15$; $j=1, 2, 3, 4$; $t=1, 2, \ldots, n$; i means the ith objective attribute, j means the jth group, t means the tth stakeholder in the jth group). As it is very difficult for conventional quantification to reasonably express those situations that are overtly complex or hard to define, the notion of a linguistic variable is necessary in such situation (Zadeh 1965). Therefore, we use linguistic variables to compare the significance of the attributes by five basic linguistic terms as mentioned earlier with respect to a fuzzy five level scale by using trapezoidal fuzzy

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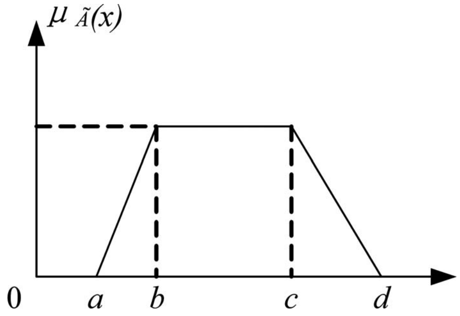

Fig. 2. Trapezoidal fuzzy number $\widetilde{A}$

Table 3. Linguistic Measurements of Performance Objectives and Fuzzy Numbers for the Significance Weight

Objective description	Fuzzy number
Very poor (EP)	(0,0,0,20)
Between very poor and poor (EP/P)	(0,0,20,40)
Poor (P)	(0,20,20,40)
Between poor and fair (P/F)	(0,20,50,70)
Fair (F)	(30,50,50,70)
Between fair and good (F/G)	(30,50,80,100)
Good (G)	(60,80,80,100)
Between good and very good (G/EG)	(60,80,100,100)
Very good (EG)	(80,100,100,100)

numbers. Determining the number of conversion scales is generally intuitive: while too few conversion scales reduce analytical discrimination capability, too many conversion scales make the system overly complex and impractical. Therefore, a scale of 1–5 is used for significance weight in this paper. The detail description of trapezoidal fuzzy numbers can be found in Chou et al. (2008). As illustrated in Fig. 2, the trapezoidal fuzzy number can be denoted by (a,b,c,d). The x in interval $[b,c]$ gives the maximal grade of $\mu_{\tilde{A}}(x)$, i.e., $\mu_{\tilde{A}}(x)=1$; it is the most probable value of the evaluation data. Constants c and d are the lower and upper bounds of the available area for the evaluation data. These constants reflect the fuzziness of the evaluation data (Liang 1999).

Given the fuzzy nature of the performance objectives selection problem, significance weights of individual attributes and ratings of alternatives versus various subjective attributes are used as linguistic variables in the questionnaire survey. Table 2 lists significance weights of individual attributes. Here each membership function (scale of fuzzy number) is defined by four parameters of the symmetric trapezoidal fuzzy number. The linguistic effect values of performance objective attributes found in this study are primarily used to assess the linguistic ratings given by the stakeholders.

Thus, the linguistic weighting variables of each stakeholder can be converted to fuzzy numbers based on Table 2. The raw matrix PO_{ijt} can be converted to a new fuzzy matrix $W_{ijt}=(a_{ijt},b_{ijt},c_{ijt},d_{ijt})$, where i denotes the ith objective attribute, j denotes the jth stakeholder group, and t denotes the tth respondent in the jth group.

Furthermore, linguistic variables are also used as a way to measure the expected level of performance objectives in PPPs for each criterion from very poor to very good as shown in Table 3, which can indicate the membership functions of the expression values.

Table 2. Linguistic Variables and Fuzzy Numbers for the Significance Weight

Linguistic variables	Score in the questionnaire	Fuzzy numbers
Can be ignored or not important	1	(0,0,0,3)
Maybe important	2	(0,3,3,5)
Important	3	(2,5,5,8)
Very important	4	(5,7,7,10)
Most important	5	(7,10,10,10)

Step 2: Determining the Weight Vector of Stakeholder Groups

If the significance weight of each attribute is equal, then the stakeholder groups are deemed to be a homogeneous group. Otherwise, the groups are deemed to be a heterogeneous (nonhomogeneous) group, which means the weight of each stakeholder group is different. In this research, the weight of each group is calculated by three objectives including "*satisfying the need for public facilities* (PO_5)," "*solving the problem of public sector budget restraint* (PO_7)" and "*making profit from public service* (PO_{11})." These three attributes are designed to investigate the initial desires of each stakeholder group when developing PPPs, which can objectively evaluate the final decision weight of each group in PPPs at the time of selecting the performance objectives. Meanwhile, the weight of the academia group is supposed to be the mean weight of the other three groups because its academic perspective can be viewed as no preference, which means that $I_{j=1}=(1/3)\Sigma_{j=2}^{4}I_j=I/4=0.25$. The weights of the other three groups can be calculated by the signed distance of trapezoidal fuzzy number of the academia group $(j=1)$.

The signed distance of trapezoidal fuzzy number $\widetilde{A}=(a,b,c,d)$ can be defined as $d(\widetilde{A})=(a+b+c+d)/4$. The discussion on the superiority of signed distance can be found in Yao and Chiang (2003). In our research, fuzzy numbers represent aggregated fuzzy weights and total fuzzy scores. To identify the optimal alternative, fuzzy numbers should be transformed into crisp real numbers to rank alternatives. Hence, the weights of the other three groups can be calculated as follows:

$$I_j = 0.75 \times \frac{d(\widetilde{w}_{i1})}{\sum_{i=5,7,11} d(\widetilde{w}_{i1})} \tag{1}$$

where $I_{j=2}=I_{i1}$, $i=11$; $I_{j=3}=I_{i1}$, $i=7$; and $I_4=I_{i1}$, $i=5$.

$$d(\widetilde{w}_{i1}) = \frac{1}{4}\left(\sum_{t=1}^{46} a_{i1t} + \sum_{t=1}^{46} b_{i1t} + \sum_{t=1}^{46} c_{i1t} + \sum_{t=1}^{46} d_{i1t}\right), \quad i = 5,7,11$$

Therefore, the weight of stakeholder groups can be calculated by Eq. (1), which is $I_j=[0.25,0.27,0.26,0.22]$ $(j=1,2,3,4)$. The results indicate that the private sector members are the most important stakeholders in the decision process. The public sector constituents are also very important in decision making. Additionally, the opinions of general public cannot be ignored.

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Table 4. Final Decision Weights of Performance Objectives by the Method of Fuzzy Entropy

Performance objective attributes	Defuzzyfied significance in each group $[d'(\tilde{w}_{ij})]$				Weighted defuzzyfied significance	Weighted linear weights			Final decision weights
	A $[d'(\tilde{w}_{i1})]$	PI $[d'(\tilde{w}_{i2})]$	PII $[d'(\tilde{w}_{i3})]$	PIII $[d'(\tilde{w}_{i4})]$	$[\Sigma_{j=1}^{4}=I'_j\times d'(\tilde{w}_{ij})]$	(w_i)	$\ln w_i$	$-w_i \ln w_i$	(I_i)
PO1	7.1359	6.4032	6.2708	6.5625	6.5857	0.0750	−2.5904	−0.1943	0.0720
PO2	7.5054	7.2419	7.5218	7.2813	7.3920	0.0842	−2.4749	−0.2083	0.0772
PO3	7.1359	6.5403	7.5417	5.9375	6.8270	0.0777	−2.5544	−0.1986	0.0736
PO4	6.8859	6.5161	6.0833	6.1198	6.4045	0.0729	−2.6183	−0.1909	0.0707
PO5	6.5272	5.6129	5.6875	6.1667	5.9835	0.0681	−2.6863	−0.1830	0.0678
PO6	6.4239	5.9758	6.0605	6.3438	6.1917	0.0705	−2.6521	−0.1870	0.0693
PO7	6.2663	5.5081	7.0000	5.5365	6.1067	0.0695	−2.6659	−0.1854	0.0687
PO8	6.1630	6.7339	5.8958	6.0833	6.2218	0.0708	−2.6472	−0.1875	0.0695
PO9	5.6630	6.1855	5.8958	5.2813	5.7777	0.0658	−2.7213	−0.1790	0.0663
PO10	5.5761	4.9516	6.2917	3.9271	5.2442	0.0597	−2.8182	−0.1683	0.0623
PO11	5.3261	5.9758	4.8125	4.8646	5.2548	0.0598	−2.8162	−0.1685	0.0624
PO12	5.3424	5.6290	5.3542	5.1354	5.3746	0.0612	−2.7936	−0.1710	0.0633
PO13	5.2880	5.4194	4.2708	4.8594	4.9532	0.0564	−2.8753	−0.1622	0.0601
PO14	4.5652	4.7903	4.7917	4.3698	4.6419	0.0529	−2.9402	−0.1554	0.0576
PO15	4.4239	5.9919	4.2917	4.7240	4.8619	0.0554	−2.8939	−0.1602	0.0593

Step 3: Determining the Weight of Each Attribute in All Groups

Shannon (1948) developed the concept of entropy as a tool to measure information uncertainty. In physics, the word entropy has important physical implications as the amount of "disorder" of a system. According to Shannon, the uncertainty of a system decreases as we receive more information about the possible outcomes of the systems. From this perspective, entropy can be regarded as a general modeling framework of the different information of stakeholders, which allows deriving relevant general conclusions from uncertain information. Mathematically, entropy is defined as

$$H = -\sum_{i=1}^{N} P_i \times \log P_i \qquad (2)$$

where P_i=probability of occurrence of the event E and H=level of entropy. In the performance objective selection process, the decisions of stakeholders are full of uncertainty because of the complexity and diversity of the problem. In this case, the measurement of uncertainty of each stakeholder's expectations can be regarded as a tool to avoid the inability to accurately determine the performance objectives of a PPP project. Therefore, the level of entropy of entire performance objective attributes can be shown as follows (Shannon 1948; Asllani and Ettkin 2007):

$$H_{PO} = \sum_{i=1}^{15} H_{POi} = \sum_{i=1}^{15} (-w_i \times \ln w_i) \qquad (3)$$

$$w_i = \frac{\sum_{j=1}^{4} I_j \times d'(\tilde{w}_{ij})}{\sum_{i=1}^{15}\sum_{j=1}^{4} I_j \times d'(\tilde{w}_{ij})} \qquad (4)$$

The defuzzification of $\tilde{w}_{ijt}$, denoted as $d(\tilde{w}_{ijt})$, is therefore given by $d(\tilde{w}_{ijt})=(a_{ijt}+b_{ijt}+c_{ijt}+d_{ijt})/4$. Thus, $d'(\tilde{w}_{ij})$ is the mean significance of each objective in each group, $d'(\tilde{w}_{ij}) = \Sigma_{t=1}^{n} d(\tilde{w}_{ijt})/n$. H_{PO} in Eq. (3) is the weighted aggregate entropy (uncertainty) of the entire performance objective system, which is composed of the entropy of each single performance objective attribute as expressed by Eq. (2). The entropy of each performance objective attribute $(-w_i \ln w_i)$ is shown in Table 4 on the basis of a coefficient (w_i) that represents the linear weights of the attribute calculated by Eq. (4). Eq. (4) integrates the group weights [see Eq. (1)] into the linear weights, which considers the different preference of each stakeholder group and makes the final decision weights more appropriate. Simultaneously, entropy is a measurement that characterizes the degree to which information of each attribute contributes to the aggregate process. The final decision weights based on the entropy of each attribute are displayed by Eq. (5)

$$I_i = \frac{H_{POi}}{\sum_{i=1}^{15} H_{POi}} \qquad (5)$$

Discussion on the Final Decision Weights of Performance Objectives

As presented by Eq. (1), the private sector is the most important stakeholder group in the PPP decision-making process. In the early stage of traditional infrastructure projects, the impact of private sectors, including potential contractors in the project, is rather weak (Olander 2007). However, the private sector in PPPs in addition to construction is also typically responsible for the design, operation, and maintenance, of the project which makes it an imperative for this sector to be involved in the decision-making process to ensure the project success for the public end user (Li et al. 2005a). Furthermore, the private sector bears more risks than the public sector, particularly those related to unforeseen increase of construction/operation cost, project duration and completion date, changing market prices for construction materials, and unexpected ongoing service delivery costs (Li et al. 2005b). The involvement of the private sector in the decision-making process is helpful for reducing these risks and earning profitable return. For example, the economic foreign exchange exposure is an important risk factor in PPP projects, which should

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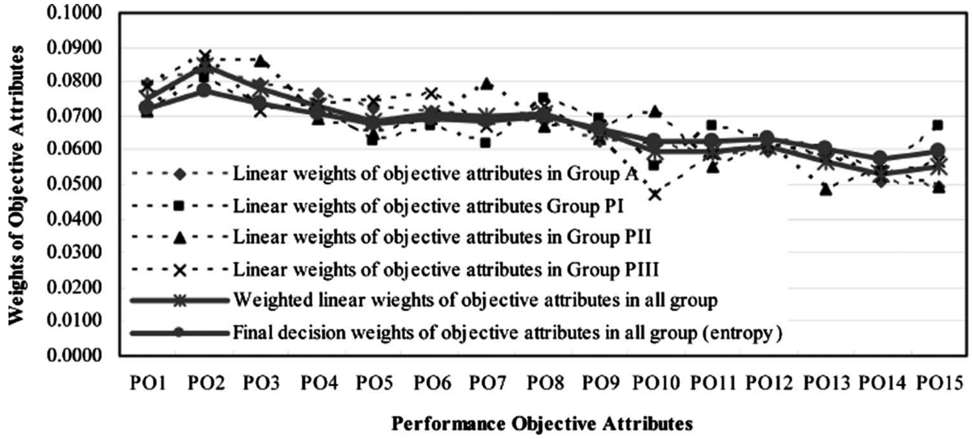

Fig. 3. Comparison of different significances by different methods

be carefully analyzed in the financing planning by the private sector to improve the feasibility of project (Ehrlich and Tiong 2009). Based on the theory of stakeholder impact on the construction projects (Olander 2007; Newcombe 2003), the private sector's power toward the project and interests level are greatly strengthened in PPPs. For this reason, the role and influence of the private sector is vital for the success of PPP projects. In the investigation about CSF of PPP projects, Li et al. (2005a) demonstrated that a strong private consortium is the most important factor in a successful PPP project, which suggests that sponsors should pay strategic attention to private participant consortia and to how they might best be encouraged in the planning and development stages of PPP projects. In much of other prior research, the influence of the private sector is also an important CSF (Qiao et al. 2001; Tiong et al. 1992).

As shown in Table 4, the attribute "*acceptable quality of project*" has the largest entropy value among all attributes, which means that the largest uncertainty in this regard should be considered. Therefore, this objective attribute is the most important for all groups in the decision process. Likewise, the attribute "*public sector can acquire additional facilities/service beyond requirement from private sector*" is the least important attribute. The reminder of the top five important attributes are "*within budget or saving money in construction and operation*," "*quality public service*," "*on-time or earlier project completion*," and "*life-cycle cost reduction*." As in the case of traditional construction activity, cost, time, and quality are similarly important. However, *quality* in a PPP project is especially important, which implies that the requirements of stakeholders focus on long-term sustainable development of PPP projects. Evidence exists that the cost reduction in the PPP projects is not only emphasized in the stage of construction and operation but also extended to the life cycle of built facilities. Concurrently, providing quality service is very important for every stakeholder group, which is also a distinguishable characteristic of PPPs.

Fig. 3 compares the linear weights of attributes within each stakeholder group (I'_{ij}), weighted linear weights (w_i) of attributes for all stakeholders, and final decision weights (I_i). The linear weights of attributes within each stakeholder group can be calculated as shown in Eq. (6)

$$I'_{ij} = \frac{d'(\tilde{w}_{ij})}{\sum_{i=1}^{15} d'(\tilde{w}_{ij})} \tag{6}$$

where $i=1,2,\ldots,15$ and $j=1,2,3,4$.

I'_{ij} reflects the opinions of each stakeholder group, which just represents the stakeholders' preference within their own group. Compared to I'_{ij}, w_i integrates the benefits of all stakeholders, which would make the decision process more thorough and complete. As there is some uncertainty associated with the value of w_i, I_i reduces the uncertainty due to the data collection with the use of the entropy method. Fig. 3 shows that I_i cannot only integrate the stakeholders' benefits, but also eliminates the uncertainty, illustrating the significance of each objective attribute of all stakeholders in a PPP projects.

Improved TOPSIS Method to Select Performance Objective Level

Locke and Latham (1990) demonstrated that a comfortable objective level can improve performance of the project with respect to the given objective. Otherwise, the performance can be diminished. The relationship between the objective level and the performance level studied by Locke et al. (1988) and by Dodd and Anderson (1996) indicates that difficult and complex objectives can lead to high levels of performance (conversely, an easy objective will likely result in low levels of performance). However, the performance level can drop when the difficulty of the objective and task complexity are too high for the stakeholder, i.e., over and above their capabilities and past experiences. Therefore, a comfortable objective level of PPP projects discussed in our research can be defined as the achievable level that can make stakeholders exert their best efforts to achieve high levels of performance. For example, the level of PO1 acceptable quality usually is set in a relatively high level in a PPP project because the quality will strongly influence many activities, e.g., cost control and project operation. However, zero quality defect rate is usually hard to achieve for construction activities because of many uncertainties. Thus, the requirements of stakeholders for the quality should be high and achievable. Otherwise, too high level would dampen the enthusiasm of contractors. Decision weights of attributes in PPPs in Table 4 are intended as a practical guideline to help decision makers select a comfortable performance objective level from a set of available alternative levels when facing multiple attributes of performance objectives. Usually, a couple of professionals from stakeholder groups will participate in this decision-making process to select the performance level based on their capabilities and past experiences, including both quantitative

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and qualitative criteria (Shih et al. 2007). In our research presented here, we focus on the qualitative criteria.

A comfortable performance objective level consists of a series of feasible objective attributes and their associated values. As shown in Table 3, performance objective attributes can range from very poor to very good, which reflects the imprecise or vague nature of the linguistic assessment. Conventional approaches tend to be less effective. Under these circumstances, the values of the qualitative attributes are often imprecisely defined for the decision makers. To resolve this problem, we propose an improved TOPSIS method by using FST and a vertical projection distance to select an appropriate qualitative performance objective. The detailed traditional TOPSIS solution can be found in (Lai 1994; Shih et al. 2007).

The presented improved TOPSIS method then can be implemented with three steps: (1) establishing the weighted normalized decision matrix; (2) determining the positive ideal and negative ideal objectives; and (3) calculating the separation measures. Suppose there are m stakeholders so that the raw decision matrix can be defined as $D=x_{ki}$ $(i=1,2,\ldots,15;\ k=1,2,\ldots,m)$. Here x_{ki} denotes the evaluations of the kth decision maker with respect to the ith attribute.

Step 1: Establishing the Weighted Normalized Decision Matrix

The raw decision matrix D should be converted to the fuzzy number matrix $D'=(e_{ki},f_{ki},g_{ki},h_{ki})$, then it can be further defuzzified by signed distance to matrix D'. The defuzzification of D' can be expressed as $D''=d_{ki}(D')$, where $d_{ki}(D')=(e_{ki}+f_{ki}+g_{ki}+h_{ki})/4$. As all the attributes are the larger-the-better in the matrix D'', d_{ki} can be normalized by a linear transformation function to $r_{ki}=d_{ki}/\max(d_{ki})$. Thus, the weighted normalized value of r_{ki}, v_{ki} can be calculated by

$$v_{ki}=I_i r_{ki} \tag{7}$$

where I_i = weight of the ith objective as mentioned earlier.

Step 2: Determining the Positive Ideal and Negative Ideal Objectives

PID is a hypothetical decision in which all attributes correspond to the best level of performance objective. On the contrary, the NID alternative is also a decision in which all objective attributes correspond to the worst level. We can denote the positive ideal alternative, S_i^+, and the negative ideal alternative, S_i^-, as

$$S_i^+=\{(\max_k v_{ki}|i\in J)k\in n\}=[v_1^+,v_2^+,\ldots,v_m^+] \tag{8}$$

and

$$S_i^-=\{(\min_k v_{ki}|i\in J)k\in n\}=[v_1^-,v_2^-,\ldots,v_m^-] \tag{9}$$

where J = attribute sets of the larger-the-better type.

Step 3: Calculating the Separation Measures

Traditional Method

Traditionally, the m-dimensional Euclidean distance was used in TOPSIS as shown in the following:

$$d_k^+=\left[\sum_{i=1}^{15}(v_{ki}-v_i^+)^2\right]^{1/2} \tag{10}$$

$$d_k^-=\left[\sum_{i=1}^{15}(v_{ki}-v_i^-)^2\right]^{1/2} \tag{11}$$

where d_k^+ = distance from the positive ideal level to decision "k" and d_k^- = distance from the negative ideal level to decision k.

Then the relative closeness to the positive ideal objective level can be obtained by

$$C_k^+=\frac{d_k^-}{d_k^+ + d_k^-},\quad C_j^+\in[0,1] \tag{12}$$

Thus, the decision with the largest C_k^+ is the best objective level for the PPP projects in question.

Improved Method

To simplify the calculation, the origin of a coordinates in Euclidean space can be translated to the point of positive ideal objective level. The positive ideal solution S_i^+ will be changed to $S_i^{*+}=\{0,0,\ldots,0\}$. The weighted normalized decision matrix v_{ki} will be changed to a new matrix $T=t_{ki}$ as shown in Eq. (13)

$$t_{ki}=v_{ki}-\max_k v_{ki} \tag{13}$$

Therefore, the negative ideal solution S_i^- will be changed to $S_i^{*-}=t_{k'I}$, as shown in Eq. (14), where $t_{k'i}$ should satisfy the following condition: $|t_{k'i}|\geqslant t_{ki}$, $1\leqslant k'\leqslant m$

$$S_i^{*-}=\{(\min_k t_{ki}|i\in J)k\in n\}=[t_1^-,t_2^-,\ldots,t_m^-] \tag{14}$$

Finally, the simplified closeness is equivalent to P_k that can be calculated as

$$P_k=|S_i^{*-}\cdot T_k|=\sum_{i=1}^{15} S_i^{*-}\times t_{ki} \tag{15}$$

where T_k = kth row vector in the matrix T. A smaller P_k means a better solution. The objective level with the smallest P_k would be the best solution. Detailed calculation of the simplified closeness P_k is presented in Appendix II.

Discussion on the Proposed Improved TOPSIS Method

During the decision-making process, there is no need for evaluation to make a decision if the ideal decision is exactly the one comprised of the feasible attributes. However, this situation is rarely seen in the real world of PPP projects. The evaluations of each decision are often found to include higher values of some attributes and lower with respect to other attribute. For example, the private sector entity may have better construction quality, but its operational service level may be low. Thus, the ultimate decision should consider carefully all the attributes to select a comfortable level based on a reasonable compromise.

TOPSIS can help decision makers organize the problems which to be solved and analyzed, and help carry out comparisons and rankings of the alternatives. Accordingly, the selection of a suitable alternative(s) will be made. The basic idea of TOPSIS is rather straightforward. The ranking of alternatives is based on the shortest distance from PID and the farthest from NID. Traditional TOPSIS simultaneously considers the distances to both PID and NID, and a preference order is ranked according to their relative closeness by using m-dimensional Euclidean distance, which is a combination of these two distance measures. Compared to the traditional method, the superiority of the method presented in this paper can be concluded from two perspectives: (1) the traditional

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method cannot deal with fuzziness in the decision problem. When the performance objective level is set by linguistic assessments, the improved method can transform such assessments to crisp integer number for ranking alternative levels; (2) when a decision is selected as the best decision according to the traditional method, it probably has a shorter distance with PID as well as has a shorter distance with NID: suppose that two decisions have the same distance with PID, thus the decision with shorter distance to NID should be better based on the Eq. (12). In this case, the ranking results of decisions based on the *m*-dimensional Euclidean distance cannot exactly reflect the superiority and inferiority between the decisions. The presented method moves the origin of the coordinate system to the point of positive ideal objective level. The problem in the *m*-dimension space is then transformed to one dimension. The ranking results will therefore be clearer and easily understood.

Case Study of PPP Project: "Bird's Nest—Beijing National Stadium" for the 2008 Olympic Games

Introduction

The \$560 million Beijing National Stadium is a stunning landmark building for staggering 2008 Olympic Games. The initial seating capacity was 91,000, which was later reduced to 80,000 when the Olympics was finished. The stadium is 333 m long from north to south, 294 m wide from east to west, and 69.2 m tall. The China International Trust and Investment Corporation (CITIC) consortium, which raised 42% of the finances for the project in return for a 35-year tender after the Olympics were finished, comprises the CITIC Group, the Beijing Urban Construction Group, the Golden State Holding Group of the United States, and the CITIC Group affiliate Guoan Elstrong. The remaining 58% has been funded by the Beijing municipal government and this portion of the project was entrusted to the Beijing state-owned Assets Management Co Ltd. as the government's representative. This stadium was the first PPP project applied in the construction of Chinese sports venues.

However, there were many problems encountered during the project execution. These problems led to the reduction of project performance. The construction of competition venues for the Beijing Olympic Games, in which new technologies, new materials, and innovative design were extensively adopted, was a vast and complex undertaking. Precise time deadlines for competition functions were required in this complex program and, consequently, exposed the venue's construction to high risks. These risks would potentially cause a negative impact on the project performance (Sun et al. 2008). For example, the construction work began on the stadium with earthworks and foundations in late 2003 and the main construction work started in March 2004. By August 2004 construction work had been halted due to the perceived high construction costs. The designers were asked by major stakeholders of the project (e.g., government officials) to change the design to save money.

In this case, the objectives of cost, schedule, quality, and new technology were interactive. Sun et al. (2008) indicated that safety performance is also the highest priority among the objectives of the Olympic venue construction. All of stated objectives influence each other. However, all these objectives in the project were difficult to achieve at the same time. Therefore, a careful decision on comfortable level of performance objective should be made before the commencement of projects, thus decreasing the risks resulting from the likely conflicts caused by imprecisely expressed expectations of different stakeholders. Also, the comfortable objective level can inspire both of the public and private sectors to put forth efforts to develop the projects.

Table 5. Performance Objectives Selection Matrix Based on Input from Professional Experts

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8
L1	G/EG	EG	G	G/EG	F/G	EG	F	F
L2	G/EG	G	G	G	G	G/EG	G	EG
L3	EG	G	G/EG	G	F/G	G	F/G	G

	PO9	PO10	PO11	PO12	PO13	PO14	PO15
L1	G	G	F	F/G	G	P	EP/P
L2	F/G	F	G	G	P	F/G	P/G
L3	F	F/G	F/G	F	P/G	F	P/G

Illustrative Example to Select the Appropriate Objective Level for Beijing National Stadium

The analysis described herein was performed after the completion of construction activities, allowing for insights for further operation of the project. As shown in Table 5, three experts in PPP projects were selected: each of them is from the public sector, the private sector and from academia. Expert 1, who has participated in several PPP projects (e.g., Water Treatment Plant No. 10 in Beijing and Pudong Water Treatment Plant in Shanghai), was an employee of the municipal government of Beijing, China. Expert 2 was a professional consultant in concession agreements employed by a publicly owned Chinese consulting firm. He had been involved with such PPP projects in China as the M6 Metro Line and Zifen Highway in Shanghai and the Olympic Central in Shenzhen. Expert 3 was an academic at Southeast University, a leading PPP research center in China, who specializes in PPP risk management. They specified expected values of each objective attribute based on their professional judgments to allow the project achieve low cost, short duration, the implementation of advanced technologies, and other desirable outcomes. The expectations of these experts were regarded as the target levels of performance objectives, L1, L2, and L3, respectively. Hence, the optimal decision, to be adopted by a decision maker can be determined by integrating the opinions of the experts. The optimal decision should allow selecting the comfortable performance objective levels L1, L2, and L3 to ensure that the best performance level will be achieved on behalf of all project stakeholders.

Based on Tables 3 and 5, the raw matrix can be converted to matrix D'. Then the matrix D'' can be obtained by using signed distance. According to Eq. (7) and Table 4, the weighted normalized defuzzified decision matrix v can be obtained as shown in Table 6, where the final decision weights I_j can be obtained from Eq. (5).

Based on Table 6, PID (S_i^+) values are {0.0866, 0.0608, 0.0634, 0.0601, 0.0867, 0.0701, 0.0596, 0.0625, 0.0668, 0.0648, 0.0717, 0.0588, 0.0664, 0.0752, 0.0666}. NID (S_i^-) values are {0.0775, 0.0512, 0.0597, 0.0566, 0.0705, 0.0590, 0.0350, 0.0329, 0.0418, 0.0405, 0.0448, 0.0368, 0.0208, 0.0231, 0.0380}. The traditional *m*-dimensional Euclidean distance method and improved projection distance method will be compared as follows.

Traditional Method

Based on the Eqs. (10) and (11), d_k^+ and d_k^- can be calculated respectively as follows:

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Table 6. Weighted Normalized Defuzzified Decision Matrix v

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8
L1	0.0775	0.0608	0.0597	0.0601	0.0705	0.0701	0.0350	0.0329
L2	0.0775	0.0512	0.0597	0.0566	0.0867	0.0627	0.0596	0.0625
L3	0.0866	0.0512	0.0634	0.0566	0.0705	0.0590	0.0596	0.0526

	PO9	PO10	PO11	PO12	PO13	PO14	PO15
L1	0.0668	0.0648	0.0448	0.0478	0.0664	0.0231	0.0380
L2	0.0543	0.0405	0.0717	0.0588	0.0208	0.0752	0.0666
L3	0.0418	0.0527	0.0583	0.0368	0.0291	0.0578	0.0666

$$d_1^+ = \left[\sum_{i=1}^{15} (v_{1i} - v_i^+)^2\right]^{1/2} = 0.0788$$

$$d_1^- = \left[\sum_{i=1}^{15} (v_{1i} - v_i^-)^2\right]^{1/2} = 0.2602$$

In the same way, the value of d_2^+, d_2^-, d_3^+, and d_3^- can be further obtained, which are 0.0555, 0.4324, 0.02997, and 0.2997, respectively. Thus the relative closeness values to the positive ideal objective level can be obtained by Eq. (12), which are 0.7674, 0.8862, and 0.8309 for C_1^+, C_2^+, and, C_3^+, respectively. Based on the results, the priority of alternative objective levels is $L2 \succ L3 \succ L1$, where the symbol "$\succ$" means "superior to." Therefore, L2 will be the appropriate objective level calculated by the traditional method.

Improved Method

Matrix $T=(t_{ki})_{\text{mxn}}$ can be obtained by Eq. (13) as shown in Table 7. Thus, the negative ideal solution is S_i^{*-}, {−0.0091, −0.0096, −0.0037, −0.0162, −0.0111, −0.0246, −0.0296, −0.0250, −0.0243, −0.0269, −0.0.0220, −0.0456, −0.0521, −0.0286}. Then the values of P_k according to Eq. (15) are finally obtained, which are

$$P_1 = \sum_{i=1}^{15} S_i^{*-} \times t_{1i} = 0.0063$$

In the same way, P_2 and P_3 values can be further obtained, which are 0.0033 and 0.0052, respectively. Based on the results, the priority of alternative objective levels is $L2 \succ L3 \succ L1$. Therefore, L2 will be the appropriate objective level by the projection distance method.

Discussion

Although the two methods presented earlier draw the same conclusion after the calculations, two obvious problems can be identified in the traditional procedure of TOPSIS method when being compared to the improved projection method: (1) according to Table 6, we can find that the interval ranges of evaluations of L3 are larger: i.e., the information risk from L3 is higher. However, the traditional method cannot express this phenomenon, which results in that the relative closeness of L3 is very close to the one of L1. Obviously, the improved method has better discriminability. (2) The operation of the traditional method is more complicated than the improved method, which translates the origin of coordinate in Euclidean space to the point of positive ideal objective level so that just the one-dimensional Euclidean distance is calculated.

As a representative of the government, Expert 1 has very high expectations with respect to PO1, PO2, PO3, PO4, and PO6. He also hopes to transfer more risks to the private sectors (PO10) and improve the technology level (PO13). However, this solution ignores the driving factors for the private sectors with low expectations in PO15. This selection will probably damage the partnership between public and private sectors and reduce the project performance. As the representative of private sector, L3 has high expectations with respect to PO1, PO2, PO3, and PO4. However, this solution ignores the driving factors for the public sectors with low expectations in PO9 and PO14. L2 is a representative of public client. Compared to L1 and L3, L2 pays more attention to the benefits of private and public sectors (PO5, PO7, PO8, PO14, PO15), and attempts to share the project risks between the private and public sectors. Meanwhile, the expected levels of project quality, cost, and service are still kept at a high level. Notwithstanding the expected level of technology improvement/innovation is relatively low, a mature, proven technology is more appropriate for this high risky project. Therefore, L2 is indeed the optimal objective level in the presented example.

Stressing project quality and cost reduction was a priority of Beijing Organizing Committee for the 28th Olympic Games. Therefore, the problems related to the economical viability of the sports venues during the process of construction have drawn widespread attention from different stakeholders. The construction of "Bird Nest" was shutdown from July 30, 2004 to December 28, 2004, during which the integrated reassessment of safety, quality, function, schedule, and cost took place and resulted in a newly streamlined strategy. Accordingly, the designer was asked to further optimize the stadium design to reduce the overall cost, enhance functionality, and improve environmental sustainability. Hence, the initial design of a retractable roof was altered, and the opening of the roof was enlarged. Structural steel consumption was reduced by 22.3%, and the membrane material consumption was reduced by 13%. As a result, the total construction and operational costs were significantly reduced. These actions taken to deal with the problems agree with the calculation results obtained from the illustrative example presented earlier. If these performance objective levels were set comfortably before construction,

Table 7. Matrix $T=(t_{ki})_{\text{mxn}}$ in the Improved Method

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8
L1	−0.0091	0.0000	−0.0037	0.0000	−0.0162	0.0000	−0.0246	−0.0296
L2	−0.0091	−0.0096	−0.0037	−0.0035	0.0000	−0.0074	0.0000	0.0000
L3	0.0000	−0.0096	0.0000	−0.0035	−0.0162	−0.0111	0.0000	−0.0099

	PO9	PO10	PO11	PO12	PO13	PO14	PO15
L1	0.0000	0.0000	−0.0269	−0.0110	0.0000	−0.0521	−0.0286
L2	−0.0125	−0.0243	0.0000	0.0000	−0.0456	0.0000	0.0000
L3	−0.0250	−0.0121	−0.0134	−0.0220	−0.0373	−0.0174	0.0000

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the possibility of shutdown could have been significantly reduced because high construction cost would be avoided and the architectural and structural design of the stadium project would not have been significantly altered. Consequently, the total duration of the construction phase of the project would have been shortened. Furthermore, the value of L2 provides suggestions for the operation phase of the Bird Nest Stadium project. To maintain a high performance level of this unique facility, the operational and maintenance costs should be reduced and the quality service should be provided to meet with satisfaction of all stakeholders and earn the required profit. For this reason, this stadium should continue to regularly host various sporting events after the Olympics. A shopping mall and a hotel, with rooms overlooking the field, will be developed to help increase the use of the Stadium after the Olympics. For example, one year after the Olympics, the stadium was scheduled to host the 2009 Italian Super Cup final, a traditional curtain raiser for the Italian soccer league season, on 8 August 2009 (Pasternack 2008). These types of high profile follow-up uses are consistent with the stated aim of government for the stadium to become one of the most important public spaces in Beijing.

Based on the case study, the method proposed in this paper can assist the decision maker to identify the requirements of stakeholders and measure the stakeholders' expectations by using linguistic assessments. The stakeholders should put their efforts to make the PPP project to achieve the expected level of each performance objective attribute during the lifecycle. Additionally, the proposed method can be further improved. The quantification of those linguistic ratings probably would introduce the errors into decision process because the performance objectives are convoluted and comprehensive concepts. Each of objective attribute would contain multiple aspects, thus the detail performance indicators should be developed on the basis of the performance objective. The performance indicators can describe the project performance effectively. It is "how good" a system is, in objectively measurable terms. These indicators valued by stakeholders are always capable of being specified quantitatively and along a definable scale of measure (Solomon and Young 2007). Thus, the errors will hopefully be avoided. Meanwhile, the level of those attributes is useful for the benchmarking in the project performance measurement.

Summary and Conclusions

There is an ever increasing popularity of PPP applications in worldwide infrastructure development. While this brings a good opportunity for efficient and quality public service and management, large risks often arise due to different cultural, political, economic, and environmental problems presented in the project environment. Diverse stakeholders in PPPs can also bring about conflicts that will hinder the projects. Previous studies have explored and evaluated the negative influence of these factors and stakeholders in PPPs. In regard to the influencing factors during the lifecycle of PPP projects, this paper offers a set of performance objective attributes from the perspective of stakeholders on the basis of goal-setting theory. A structured questionnaire survey has shown that the 15 performance objective attributes were all important for all groups of stakeholders.

However, the problems with decision making have also been exposed in the survey results. How to integrate all stakeholders' benefits into the process of decision making and how to select the appropriate qualitative level of performance objectives are the two main problems in the decision process. Unlike in typical decision problems with only one group of decision makers, this paper deals with four stakeholder groups involved in the PPP projects. To resolve these two problems, a fuzzy entropy method and a fuzzy TOPSIS method were introduced to calculate the final decision weight in all four stakeholder groups and to select appropriate performance objective levels for PPP projects.

Decision making by project stakeholders plays an important role in the PPP project management. The decision-making problems described in this paper are framed as a collaborative effort among different stakeholders. Therefore, an effective group decision model aggregating knowledge and judgments of diverse experts is necessary. An important finding in this paper is that the private sector stakeholders are the most important decision makers in the project because of their unique responsibilities in PPPs to deliver quality projects and the resulting products. Due to increasing complexity of decisions related to PPPs, the uncertainty of evaluations will also be increasing. Hence, effectively dealing with uncertain information is an important topic for group decision making. In this study, the proposed fuzzy entropy method uses fuzzy numbers to describe the imprecise linguistic expressions and entropy to overcome the uncertainty within and among the stakeholder groups. An integrated decision weight vector considering different stakeholders' preferences is obtained based on the proposed method. It can be used for finding the significance level of each performance objective attribute in all stakeholder groups and for further decision making. Based on the weights calculated by the aforementioned fuzzy entropy method combined with the implementation of the traditional TOPSIS method, an improved TOPSIS method using fuzzy number and projection distance is adopted to select comfortable qualitative levels of performance objective in the study. The projection distance method is more convenient and precise than the traditional method in the solution to this problem.

This paper also featured an illustrative case study of PPP project performance objective-level selection for the Beijing National Stadium (the so-called Bird's Nest) project for the 2008 Olympic Games. Aiming at resolving the problems presented in the project for the sake of similar projects in the future, the case study shows how to select the appropriate level of performance objective. The results show that the group decision model presented in the paper can effectively deal with the uncertain information and does not cause undue computational burden. The group decision model is not only efficient and robust, but also realistic and reasonable for real-world applications.

The proposed performance objective attributes, the associated decision weights, and the performance objective-level selection method can be readily applied in other PPP projects. However, the proposed method is used qualitatively to express the requirements and expectations of stakeholders and provide useful information for decision-making process by linguistic assessments. Therefore, the potential errors might be included into decision process because there are numerous activities are related to those performance objectives and their levels (e.g., good quality control, the application of high technology, and effective interface management may help project achieve high quality). Hence, further work on the specified performance indicators should be developed and be quantitatively measured to avoid the weakness.

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Appendix I. Survey Questionnaire

UNIVERSITY OF MARYLAND
GLENN L. MARTIN INSTITUTE OF TECHNOLOGY
A. JAMES CLARK SCHOOL OF ENGINEERING
Department of Civil and Environmental Engineering
Project Management Program

e-Construction Group

Dear Sir / Madam,

The e-Construction Group of the Project Management Program in the Department of Civil and Environment Engineering at the University of Maryland, College Park, USA is currently carrying out research on **"Key Performance Indicators (KPIs) Selection for Public Private Partnerships (PPPs) to Achieve the Best Value for Money"**. This research aims to evaluate the input and output of PPPs, determine the best process management practice for implementing PPPs, and establish the best framework for performance management in PPP projects. It is anticipated that this effort will help project owners engaged in PPPs to ensure better rates of success in their projects.

We are collecting data for this research via a brief questionnaire. The findings collected through this survey will help us to analyze the influence of risk-based performance management methods in PPPs. Furthermore, constructive suggestions are expected to be gained from this survey to improve integrated performance management in PPPs.

Attached to this letter is a MS Word-formatted version of the questionnaire which we would like for you to complete. If at all possible, we also appreciate input from your colleagues. Alternatively, the questionnaire can also be completed on-line and it is available from this address: http://www.my3q.com/home2/192/seu_umd_yuan_jingfeng/97007.phtml

Our survey will be utilized for research purposes only. Your expert opinions are most valuable for the success of this study. We greatly appreciate your participation kindly request that the completed questionnaires be returned to us by e-mail at jyuan@umd.edu or filled in online by 18 February 2008.

Please feel free to contact Mr. Jingfeng Yuan at (+1) 240-645-8030 or by e-mail to jyuan@umd.edu if you have any questions.

We will be most grateful for your contribution to this important effort. Best wishes for a happy, healthy and prosperous New Year.

Jingfeng Yuan
Ph.D. Candidate

Miroslaw J. Skibniewski
Ph.D., A.J. Clark Chair Professor of Construction Engineering & Management

A. About the Respondent

1. Name of your organization: ______________________
2. Your position in the organization: ______________________
3. Your Country: ______________________
4. Please indicate your primary role in your organization:

☐ Researcher ☐ Public sector (official or public agent) ☐ Designer/contractor/operator
☐ Financier (e.g. bank) ☐ Other, please specify: ______________________

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5. How many years of construction industrial-related experience do you have?

☐ 5 years or less ☐ 6-10 years ☐ 11-15 years ☐ 16-20 years ☐ 21 years or more

6. How many years have you been involved in PPP projects?

☐ 5 years or less ☐ 6-10 years ☐ 11-15 years ☐ 16-20 years ☐ 21 years or more

7. What type of PPP projects have you been involved with (you may select more than one answer)?

☐Hospital ☐Transportation ☐Water and Sanitation ☐Power and Energy
☐IT & Communication ☐Housing & Office ☐Defense & Naval ☐Police & Prison
☐School & Education ☐Others (please specify): ______________________

Note:
In the following form, please select the significance of each criteria based on the following scale:
Therein,
1-can be ignored or not important;
2-maybe important;
3-important;
4-very important;
5-most important.

B. Selection of performance objectives

The following 15 objectives represent independent aims from PPP projects' stakeholders including public sector, private sector and involved citizens. Please select the significance of each indicator based on your experience and judgment:

Performance objectives	Significance				
	1	2	3	4	5
1. On-time or earlier project completion	☐	☐	☐	☐	☐
2. Within or under budget	☐	☐	☐	☐	☐
3. Acceptable quality	☐	☐	☐	☐	☐
4. High level and quality of public service	☐	☐	☐	☐	☐
5. Provide timelier and more convenience service for society	☐	☐	☐	☐	☐
6. Satisfy the need for more public facilities	☐	☐	☐	☐	☐
7. Solve the problem of public sector budget restraint	☐	☐	☐	☐	☐
8. Transfer risk to private sector	☐	☐	☐	☐	☐
9. Promote local economic development	☐	☐	☐	☐	☐
10. Improve technology level or get technology transfer	☐	☐	☐	☐	☐
11. Earn a profit from public service	☐	☐	☐	☐	☐
12. Private sector can get government sponsorship, guarantee and tax reduction	☐	☐	☐	☐	☐
13. Public sector can obtain additional facilities/service beyond requirement from private sector	☐	☐	☐	☐	☐
14. Life-cycle cost reduction	☐	☐	☐	☐	☐
15. Introduce business and profit generating skill in the public sector	☐	☐	☐	☐	☐

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C. Selection of KPIs

The following 17 indicators are closely related with the performance of PPP projects, which are determined before construction begins and which usually do not change during the whole lifecycle of a project. Please select the significance of each indicator based on your experience and judgment:

Performance indicators	Significance				
	1	2	3	4	5
1. Type of construction	☐	☐	☐	☐	☐
2. Different outputs of different type of construction	☐	☐	☐	☐	☐
3. Level of design complexity	☐	☐	☐	☐	☐
4. Level of construction complexity	☐	☐	☐	☐	☐
5. Level of technological advancement	☐	☐	☐	☐	☐
6. Concessionaire's knowledge of PPP	☐	☐	☐	☐	☐
7. Government's knowledge of PPP	☐	☐	☐	☐	☐
8. Competitive tender procedure	☐	☐	☐	☐	☐
9. Standard PPP contract	☐	☐	☐	☐	☐
10. Flexibility in the contracts (e.g. necessary if the user needs change, exit position for private sector)	☐	☐	☐	☐	☐
11. General public support	☐	☐	☐	☐	☐
12. Stable and favorable macro-economic condition	☐	☐	☐	☐	☐
13. Stable and favorable legal environment	☐	☐	☐	☐	☐
14. Stable and favorable political environment	☐	☐	☐	☐	☐
15. Commitment and responsibility between public and private sectors	☐	☐	☐	☐	☐
16. Project technical feasibility, constructability	☐	☐	☐	☐	☐
17. Project maintainability	☐	☐	☐	☐	☐
18. Appropriate risk allocation, risk sharing and risk transfer	☐	☐	☐	☐	☐

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The following indicators relate to financing and market. Please select the significance of each indicator:

Performance indicators	Significance				
	1	2	3	4	5
1. Sound financial analysis and operation	☐	☐	☐	☐	☐
2. Sustainable profitability	☐	☐	☐	☐	☐
3. Financial ability of contractor and investors	☐	☐	☐	☐	☐
4. Increased marketability	☐	☐	☐	☐	☐
5. Perfect tariff/tolls or price adjustment mechanism for the project	☐	☐	☐	☐	☐
6. Low financing cost	☐	☐	☐	☐	☐
7. Realistic schedule of investment, revenue	☐	☐	☐	☐	☐
8. Insurance coverage	☐	☐	☐	☐	☐
9. Construction and concession period	☐	☐	☐	☐	☐
10. Construction cost	☐	☐	☐	☐	☐
11. Operational cost	☐	☐	☐	☐	☐

The following indicators relate to innovation and learning. Please select the significance of each indicator:

Performance indicators	Significance				
	1	2	3	4	5
1. Investment in research and development of new technology	☐	☐	☐	☐	☐
2. Establishment of learning organization	☐	☐	☐	☐	☐
3. Employee Training	☐	☐	☐	☐	☐
4. Technology innovation (e.g. designing, construction, planning, etc.)	☐	☐	☐	☐	☐
5. Technology transfer	☐	☐	☐	☐	☐
6. Financial innovation (e.g. creative financial package)	☐	☐	☐	☐	☐

The following indictors relate to project stakeholders. Please select the significance of each indicator:

Performance indicators	Significance				
	1	2	3	4	5
1. The satisfaction from public client or government	☐	☐	☐	☐	☐
2. General public/social satisfaction	☐	☐	☐	☐	☐
3. Good relationship among the concessionaire, subcontractors, and suppliers	☐	☐	☐	☐	☐
4. Good relationship among project team members (special purpose vehicle, SPV)	☐	☐	☐	☐	☐

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The following indicators relate to the process of lifecycle including planning, design, construction, operation, maintenance, transfer, and post-transfer. Please select the significance of each indicator:

Performance indicators	Significance 1	2	3	4	5
1. High quality control (e.g. low number of major quality accidents, effectiveness of applying quality management methods)	☐	☐	☐	☐	☐
2. Safety management	☐	☐	☐	☐	☐
3. Health control (e.g. reduce disease, physical check-up, food management, etc.)	☐	☐	☐	☐	☐
4. Environmental protection	☐	☐	☐	☐	☐
5. Effective risk management system	☐	☐	☐	☐	☐
6. Facility management	☐	☐	☐	☐	☐
7. Stress or conflicts management	☐	☐	☐	☐	☐
8. Resource utilization (material and equipment)	☐	☐	☐	☐	☐
9. Good work environment	☐	☐	☐	☐	☐
10. Prominent technical management and skill	☐	☐	☐	☐	☐
11. Interface management between organizations and stages	☐	☐	☐	☐	☐
12. Cost management	☐	☐	☐	☐	☐
13. Time management	☐	☐	☐	☐	☐
14. Contractual management	☐	☐	☐	☐	☐
15. Effective benefits and Penalties mechanism	☐	☐	☐	☐	☐
16. Good governance in the process of the PPP projects	☐	☐	☐	☐	☐

We appreciate your kind participation!

Please state your suggestions and comments about our questionnaire and about other factors that may be missing at this time but are also important for the performance and success of PPP projects:

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Returning Questionnaire:

Kindly return the completed questionnaire by e-mail to jyuan@umd.edu

Further Information:

Please provide your e-mail address if you are interested in assisting in our further research and in receiving a report when this research is completed: ____________________

Appendix II. Calculation of Simplified Closeness

As shown in Fig. 4, B and C are the PID and NID, respectively. X is on the plane $L_1L_2L_3L_4$, whose normal vector is in the line BC. Y is on the plane $M_1M_2M_3M_4$ whose normal vector is also in the line BC. The vertical projection distance between X and Y means the distance between plane $L_1L_2L_3L_4$ and plane $M_1M_2M_3M_4$, which is the one-dimensional Euclidean distance between O (the projective point of X in line BC) and U (the projective point of Y in line BC).

Suppose that the corresponding vectors of the point B,C,X,Y are b,c,x,y, respectively, the vertical projection distance between X and Y can be obtained by

$$DI = \frac{|(b-c)\cdot(x-y)|}{\|b-c\|} \tag{16}$$

where $\cdot$ =dot product of the vectors; $|\ |$=absolute value; $\|\ \|$=norm; and $\|b-c\|$ means the distance from B to C.

As shown in Fig. 5, the vertical projection distance between B and X in line BC (one-dimensional Euclidean distance between B and O, d_{BO}) can be used in the proposed method to substitute the Euclidean distance between B and X. The simplified closeness can be described by Eq. (17)

$$C_k^* = \frac{tg\alpha}{tg\beta} = \frac{d_{XO}/d_{BO}}{d_{XO}/d_{OC}} = \frac{d_{OC}}{d_{BO}} = \frac{d_{BC}-d_{BO}}{d_{BO}} = \frac{d_{BC}}{d_{BO}} - 1 \tag{17}$$

Based on Eqs. (17) and (12), the relative closeness to the positive ideal objective level [Eq. (12)] can be equivalent to the simplified closeness [Eq. (17)], which can reflect the difference between the different decisions (solutions). Obviously, d_{BO} can reflect the degree of closeness of the solutions because d_{BC} is constant in Eq. (17). Hence the preference order can be obtained according to the raking of d_{BO}. Furthermore, the comparison between decisions can be conducted by comparing the distance between B and the projective point of each decision vector in line BC, which is d_{BC}. Compared with the method of Euclidean distance, the vertical projection distance is easier to understand and clearer to depict. Meanwhile, $\|b-c\|$ is the constant for each decision vector, which let Eq. (12) be simplified to

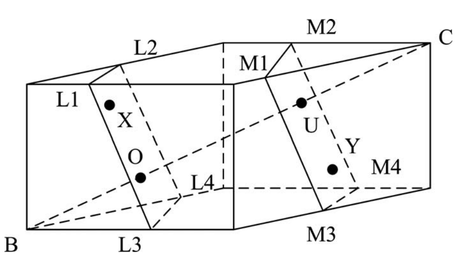

Fig. 4. 3D view of decision solution

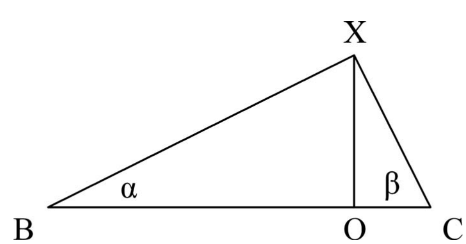

Fig. 5. Profile map of projection distance

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$$P_i = \left|(b-c)\cdot(x-y)\right| = \left|(b-c)\cdot(b-T_k)\right| \quad (18)$$

where b=positive ideal solution after translation (S_i^{*+}, $\{0,0,\ldots,0\}$); c=negative ideal solution after translation (S_i^{*-}); and T_k=kth row vector in the matrix T. Finally, the simplified closeness is equivalent to P_k, which can be calculated by

$$P_k = \left|S_i^{*-}\cdot T_k\right| = \sum_{i=1}^{15} S_i^{*-}\times t_{ki} \quad (19)$$

Smaller P_k means a better solution. The objective level with the smallest P_k would be the best solution.

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