Developing a Program Organizational Performance Index for Delivering Construction Megaprojects in China: Fuzzy Synthetic Evaluation Analysis

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This version was the final accepted manuscript without copyediting, typesetting, pagination and proofreading, which may lead to differences between this version and the published version. Please cite the published version of this paper as: Hu, Y., Chan, A.P.C., Le, Y., Xu, Y., Shan, L. Developing a program organization performance index for delivering construction megaprojects in China: fuzzy synthetic evaluation analysis. Journal of Management in Engineering, 32(4), 05016007, 2016.

Abstract: The emergence of construction megaprojects has become a global phenomenon worldwide over the last two decades as a result of rapid urbanization. Program management has been increasingly promoted as a vital approach of ensuring megaproject success through the coordinated management of the dispensed execution of a program at the organizational level. Nevertheless, practicing this method in construction megaprojects is a continual improvement process that requires relevant guidelines and tools. This study proposes an innovative approach to evaluating a structured program organization in conjunction with the fuzzy synthetic evaluation method. Based on determinants of program organization identified from a Delphi survey previously conducted by authors in Shanghai Expo construction, combined with results of further Delphi and empirical surveys in the same project, the use of this new evaluation approach in the case project is illustrated step-by-step. By doing so, clients can better utilize the program management approach in their organizational design and improvement, and the organizational effectiveness for delivering megaprojects can be improved constantly.

Keywords: Fuzzy synthetic evaluation, program organization, construction megaproject, China

INTRODUCTION

In the past two decades, the number of urban and infrastructure megaprojects has increased exponentially worldwide because of rapid urbanization, particularly in developing countries (Flyvbjerg et al., 2003; World Bank, 2010). For instance, 203 construction megaprojects were initiated in China from 1990 to 2009, each one reaching the cost threshold of RMB 5 billion (almost USD 800 million)(Le, 2009). Apart from huge investments, multiple challenges in delivery management were faced by these megaprojects such as an extremely large construction scale, a compressed schedule, numerous parties (e.g. designers, contractors, and suppliers), and a significant amount of coordination works caused by adopting a dispensed construction mode (Beehler, 2009). Thus, these megaprojects are commonly beset with underperformance problems, such as cost overruns, quality defects, safety accidents, delivery delay, and environmental pollutions (Flyvbjerg et al., 2003; Le, 2009; Han et al., 2006; Xue et al., 2006). The reason for these problems is that most client organizations of these megaprojects are temporary in nature, and they lack necessary capability to coordinate and control the dispensed execution of the sub-projects of a certain project at the overall level.

Program management has been increasingly promoted as a vital approach of improving the performance of megaprojects through the coordinated management of sub-projects of a megaproject at the organizational level (Beehler, 2009; Eweje et al., 2012; Rasdorf et al., 2010; Arrto et al., 2008). Pellegrinelli et al. (2011) emphasized that program management is "a framework to coordinate, communicate, align, manage, and control activities to achieve a desired synergy, benefits, outcome, or vision". A number of research studies has been conducted in recent years and provided several theoretical frameworks, such as Pellegrinelli's (2011) nine-aspect program management competency framework and Partington's et al. (2005) 17-atribute program management framework, but these frameworks cannot sufficiently reflect client requirements in managing construction megaprojects and do not provide pragmatic tools to assist their applications in practice. To address this gap, a program-organization capability framework consisting of 24 program organizational factors (POFs) have been formulated by the literature review and interviews (Hu et al., 2012), which represent environmental capability, core capacity, and motivational capability of a client's program organization for its megaproject.

Gil and Lundrigan (2012) stated that research on megaproject organizations should be grounded in performance issues. Thus the relationships between the above POFs and megaproject performance (Key performance indicators (KPI)) will be examined by developing a program organization performance index (POPI) with the aid of FSE analysis. Based on this analysis, the relationships between the program organization and megaproject performance can be clearly demonstrated.

FSE analysis is the main tool adopted to develop the POPI model in this study. This method is commonly used to quantify multi-attribute and multi-evaluations, such as reservoir water quality analysis (Lu et al., 1999), human resource management (Hsu and Yang, 1997), risk analysis (Xu et al., 2010), and contract risk assessment (Chan et al., 2011). Evaluating the performance of the program organization depends on identifying several significant POFs and on assessing these POFs against certain performance criteria. Because POFs and their effects on megaproject performance are often multilevel and inherently fuzzy, which rely on subjective opinions of experts, adopting the FSE technique is necessary to develop such a performance evaluation system for the program organization.

In summary, this study aims to develop a POPI based on the POF framework and FSE to assess the overall performance of the client's program organization for delivering certain construction megaprojects. Five steps for developing the POPI model are presented first in this study. Then the Shanghai Expo construction, a recently completed megaproject, is selected as a case study to illustrate a step-by-step application of the POPI model, followed by the discussion obtained from the case study. The validation of the newly developed POPI is also addressed in the end. By using this model, clients can assess the relationships between program organization design and megaproject performance to enhance and tailor fit a program organization for managing a particular megaproject.

LITERATURE REVIEW

Driven by the needs of infrastructure renewal and urbanization, construction megaprojects, such as skyscrapers, airports, freeways, metros, and bridges, have emerged as a global phenomenon with growing attention from the government, the industry and the academic community. These megaprojects refers to a extremely large and complicated construction undertaking with a budget of about 0.01% of GDP of the located country or region (Hu et al., 2015a). Aside from large investments, construction megaprojects are usually characterized with a mega construction scale (Merrow, 1988), great contextual sensitivity (Miller and Lessard, 2000), significant execution complexity (Fiori and Kovaka, 2005), and a large amount of internal and external parties involved (Hu et al., 2015b). Owing to these project characteristics, the megaprojects usually have significant underperformance risks such as cost and schedule overruns, quality defects, safety incidents, and environmental pollution. Consequently, evaluating the performance of megaprojects and associated risk have played an essential role in existing megaproject research. As early as the 1980s, Merrow (1988) conducted an investigation on the performance of 52 civil megaprojects undertaken between the mid-1970s and 1980s, which were distributed throughout the U.S., Canada, U.K., Indonesia, Israel, Brazil, Mexico, South Africa, and Saudi Arabia. He found that these megaprojects were seriously beset with cost overruns, schedule slippage, and insufficient profitability. Later on, the International Program in the Management of Engineering and Construction sampled 60 large engineering projects throughout North American, European and Asian continents (including 38 construction megaprojects) in the 1990s, which had a similar finding as reported by Merrow (1988) (Miller & Lessard, 2000). In particular, the results revealed that the sampled megaprojects faced greater risk in project effectiveness (e.g. functionality and profitability) than in project efficiency (e.g. cost and schedule) (Miller and Lessard, 2000). A growing number of research studies from both developed and developing countries (e.g. Flyvbjerg et al., 2003; Gil & Beckman, 2008; Han et al., 2009) have confirmed to the earlier findings by Merrow (1988) and Miller and Lessard (2000). A similar situation exists in Chinese megaprojects (Xue et al., 2008).

Measuring the performance of construction megaprojects largely replies on the "iron triangle" KPIs related to underperformance in megaprojects: cost, time, and quality (Flyvbjerg et al., 2003; Toor and Ogunlana, 2010). Impacted by developments in the research on KPI measurement and megaproject risks, several new KPIs such as health and safety performance, environmental performance, and client satisfaction, have been proposed to measure the performance of megaprojects in practice over the past decade. Given difficulties in the use of subjective KPIs (e.g., client satisfaction) and the limitations of project characteristics (e.g., energy efficiency), a review of recent megaproject cases around the world such as the London Olympics venues (Dodd and Yu, 2009), the Second Bangkok international airport (Toor and Ogunlana, 2010), the three gorges dam (Dai et al., 2006), and Beijing Olympics venues (Wu and Liu, 2008) have indicated that the five quantitative KPIs are still the most frequently used ones, including schedule, cost, quality and functionality, occupational health and safety, and environment.

In recent years, program management has been increasingly advocated for a key approach to improving megaproject performance through the coordinated management of constituent projects within a megaproject (Beehleer 2009; Rasdorf et al. 2007; Eweje et al. 2012). A construction megaproject is usually divided into several constituent projects and executed separately, thus requiring a centralized control and coordination to achieve the pre-defined objectives at the overall level. In a theoretical perspective, program management approach is deemed as appropriate to deal with this problem (Rasdorf et al., 2010). Beehleer (2009) emphasized the merits of this method in managing megaprojects by comparing it with two traditional procurement approaches: design–bid–build and design–build. Despite these studies, limited literature is available on the effectiveness of program management approach in managing megaprojects.

RESEARCH METHODOLOGY

This study adopted the FSE process advocated by Xu et al. (2010) and Yeung et al. (2007). The whole process included five steps: (1) Identifying the POFs; (2) Selecting the principal POFs; (3) selecting the megaproject KPIs; (4) Constructing the membership functions for each megaproject KPI; and (5) developing a POPI model.

Identifying POFs

The first step to establish the fuzzy synthetic model is to identify the POFs, which are regarded as indicators of the program organization. Literature review and interview methods were both employed in this study to identify POFs. A list of 24 POFs was identified and reported earlier in the study (Hu et al., 2012).

Selecting Principal POFs Associated with Construction Megaprojects

After identifying the POFs, appropriate POFs were selected as basic factors used for the FSE analysis. Principal POFs were extracted and used for FSE analysis in this study (Xu et al., 2010). The principal POFs were first identified based on the relative importance indicated by experts in a Delphi survey, and then refined by Pearson correlation analysis. Only POFs with relative importance ratings that are equal to or greater than the threshold value are regarded as principal POFs and selected for the subsequent analysis (Xu et al., 2010). Pearson correlation analysis is conducted to examine whether a multiplier effect exists among the resulting principal POFs. Only those principal POFs that are not highly correlated with each other are used as basic factors in the subsequent analysis.

Selecting Megaproject KPIs

KPIs are commonly used to evaluate the factors crucial to the success of construction megaprojects (Partington et al., 2005). Five KPIs, namely, time performance (KPI 1), cost performance (KPI 2), functionality and quality performance (KPI 3), occupational health and safety (OHS) performance (KPI 4), and environmental performance (KPI 5) were selected to measure the performance of the Shanghai Expo construction megaproject. These KPIs are commonly regarded as key measures of megaproject success in China and other countries (Flyvbjerg et al., 2013; Le, 2009). The correlations of these KPIs in the case study were first assessed before adopting the five KPIs to avoid the multiplier effect among individual KPIs.

Constructing Membership Functions for Each Megaproject KPI

The construction procedure of fuzzy membership function advocated by Xu et al. (2010) is used in this study because of its rationality and simplicity. This procedure has been widely advocated in construction management research (Li et al., 2013; Liu et al., 2013). The procedure contains the following six steps:

(1) The set of basic factors (criteria) are assumed to be $\pi = \{f_1, f_2 \ldots f_m\}$, where m is the number of factors.

(2) The set of grade categories are defined as $E = \{e_1, e_2, e_3 \ldots e_n\}$, where n is the number of grade categories. In the five-point Likert scale, the grade categories for selection are described as {1, 2, 3, 4, 5}, where 1 = very low; and 5 = very high.

(3) The weighting for each factor is obtained as $W = \{w1, w2 \ldots w_m\}$. The weighting of each factor can be determined through surveys.

(4) The membership function for each factor is established, which is a fuzzy subset of grade set in terms of ratings from the expert group. The FSE result is derived by computing the fuzzy composition of the weighted fuzzy evaluation matrix. Four alternative models can be used to calculate the results of the evaluation results (Xu et al., 2010). This study adopted the following Model (Equation 1) because it can handle the evaluation involving multiple factors with non-significant weighting differences. Other three models are not considered in this study either because they cannot evaluate single-item problems when only considering the major criteria or because they may neglect some information with smaller weighting.

$$\text{Model 3: } M(\cdot, \oplus), b_j = \min(1, \textstyle\sum_{i=1}^{m} wi \times rij) \quad \forall bj \in B \quad (1)$$

(5) The fuzzy evaluation is normalized, and a POPI for a particular megaproject KPI is calculated as follows:

$$POPI = \textstyle\sum_{k=1}^{4} R \times L \quad (2)$$

Where $POPI$ —the program organizational performance index

R—the degree of membership function of the program organization for a particular megaproject KPI

L—the linguistic variables where 1= very low; 2=low; 3=moderate; 4=high; 5=very high

Developing a POPI

Yeung et al. (2007) proposed a linear and additive model to develop a performance index for construction projects. Similarly, the POPI for the five KPIs can be computed as follows:

$$POPI = \sum_{i=1}^{n} POPI_i \times W_i \qquad (3)$$

Where $POPI$—the program organizational performance index regarding all selected KPIs

$POPI_i$—a particular $POPI_i$

W_i—the weighting of a particular KPI_i

The weighting of a particular KPI can be computed by using the following Eq. (Chow, 2005):

$$W_{KPIa} = \frac{M_{KPIa}}{\sum_g M_{KPIa}} \quad \text{for a} = 1 \qquad (4)$$

Where W_{KPIa}—the weightings of a particular selected KPI;

M_{KPIa}—the mean of a particular selected KPI;

$\sum_g M_{KPIa}$—the summation of meaning ratings of all the selected KPIs.

CASE STUDY

As one of the most prominent Chinese megaprojects, the Shanghai Expo has the largest exposition site in history. To deliver the project on time, the client has successfully utilized the program management approach by establishing an integrated program organization to coordinate and integrate management tasks of the 10 sub-projects. The established program organization helped the client to accomplish prescribed objectives in schedule, cost quality, environment as well as occupational health and safety. The successful application of the program management approach in the client organization was regarded by the client as a key to achieving project success (Bureau of Shanghai Expo Coordination (BSEC) & Shanghai Commission of Urban and Rural Construction and Transportation (SCURCT), 2010).

Identifying the POFs

A total of 24 POFs were identified in the literature review, and then were refined through the interviews in the case study (Hu et al., 2012). The POFs represented almost all indicators of the program organization of a construction megaproject.

Selecting the Principal POFs

To extract the principal POFs, a two-round Delphi survey (Rounds 1 and 2) was conducted in the case study. This survey method enables a structured group communication process that allows a group of individuals as a whole to solve a particularly complex problem (Chan et al., 2001). The Delphi expert panel consisted of 10 experts, of which six were from the client and four were form the consultant involved in the client organization. The selected size of the expert panel satisfies the normal requirement of the Delphi survey, that is, a range of 8 to16 experts (Hallowell and Gambatese, 2010). These experts were involved with almost all of the major tasks (e.g., schedule, cost, quality, safety, and environment) related to the overall control of the megaproject objectives. The composition of the expert panel provided good representation and knowledge base, which were critical in ensuring the validity of the Delphi survey (Hon et al., 2012). The backgrounds of the 10 experts have been reported in an earlier paper (Hu et al., 2015b). As most of the two-round Delphi questionnaires were disseminated though face-to-face interviews, the response rate was 100%.

After the two-round Delphi survey, 12 principal POFs were identified as shown in Table 1 (Hu et al., 2015b). Table 1 also shows that the 12 principal POFs represent a major part of the 24 POFs with a ratio of over 60% in the sum of normalized values of the 24 POFs. .

(Please insert Table 1 here)

Pearson correlation analysis was conducted to examine whether any multiplier effect existed among the 12 principal POFs. Table 2 presents the correlation matrix of the 12 principal POFs, which reveals that scope management (POF7) correlates highly with the PMO (POF9), matrix organization structure (POF8), and partnership with key stakeholders(POF10). Thus, scope management could be subsumed in these highly correlated factors and was removed from the list of principal POFs in the subsequent analysis. The remaining 11 principal POFs are uncorrelated at the 5% significance level. Therefore, these 11 principal POFs were adopted to develop the FSE model.

(Please insert Table 2 here)

Selecting the Megaproject KPIs

Five KPIs, namely, cost performance, time performance, functionality and quality performance, OHS performance, and environmental performance, were considered as the key performance measures of megaproject success in the case study (BSEC & SCURCT, 2010). A questionnaire survey was conducted to assess the relative importance of the megaproject KPIs. Respondents were asked to evaluate the importance of KPIs based on a five-point Likert scale: 1 = very low, 2 = low, 3 = medium, 4 = high, and 5 = very high. The target survey respondents included client staff, industrial participants and researchers involved in the Shanghai Expo construction to obtain a balanced view. All respondents were involved in the Shanghai Expo construction and had sound knowledge of performance management in megaproject practices. Invitations were sent to the target respondents by e-mail or personally through the Shanghai Expo Group Corporation (the former client of Shanghai Expo construction) and the Department of Construction Management and Real Estate at Tongji University, which have been engaged as program management consultants in managing the Shanghai Expo construction. Subsequently, 11 valid questionnaires were recorded for the subsequent data analysis.

Table 3 shows the mean score of each megaproject KPI calculated in terms of Equation (4). Time performance ranked the first with a mean score of 4.73 as a result of the extremely compressed schedule as the client had to complete the construction within 33 months before the inaugural day of the Shanghai Expo (BSEC & SCURCT, 2010). The construction speed of the case project nearly doubled that of the Lujiazui Financial zone, a nearby newly developed area (BSEC & SCURCT, 2010). Quality and functional performance received the second ranking because the client also had to take duty of managing the operation of all constructed municipal utilities and building within the Expo site. Cost performance ranked the third with a mean score of 4.07, followed by OHS performance with a very closer mean score of 4.00. With the recognition that the Shanghai Expo construction was a major public megaproject located in Shanghai downtown area with high public and media concerns, related governmental agencies carried out full-process audits and strict safety supervision on site for sustaining cost effectives and avoiding safety incidents. The lowest ranking of the environmental performance may be because this issue was managed by a functional division of the client organization who also had to supervise functional and quality as well as OHS performance. Thus, this KPI received relatively less attention from the division.

(Please insert Table 3 here)

Pearson correlation analysis was again conducted to examine the correlations among these KPIs. As shown in Table 4, environmental performance was highly correlated with OHS performance at the 5% significance level. Only OHS performance was selected and used for subsequent analysis to avoid the multiplier effect between OHS and environmental performance. Therefore, the remaining four KPIs were adopted to develop the FSE model (Yeung et al., 2007). The weighting of each selected megaproject KPI was calculated in terms of Equation (4) as shown in Table 3.

(Please insert Table 4 here)

Constructing the Membership Functions for Each Megaproject KPI

The 11 principal POFs were selected and used to construct the membership functions for the four KPIs. Another two-round Delphi survey (Rounds 3 and 4) was initiated to examine the effect of each of the 11 principal POF on each selected megaproject KPI in the case study. The 10 experts involved in first two-round Delphi survey also participated in Round 3 and 4 Delphi survey, who were asked to make ratings on the impact of each selected principal POF on each KPI. The set of basic factors (principal POFs) in the FSE model are assumed to be π = *{f1, f2 ... f11}*. The grades for the impact of each principal POF on a particular KPI are defined as E = {1, 2, 3, 4, 5} where 1 = very low, and 5 = very high (for each of the four KPIs). For each principal POF, the membership function can be established in terms of ratings of experts provided in Round 4 Delphi survey. For example, 40% of the respondents considered the impact of PMO on cost performance as moderate, 30% as high and 30% as very high. The PMO's membership function is expressed by Equation (4) as follows:

$$Principal\ POF1 = \frac{0.00}{\text{very low}} + \frac{0.00}{\text{low}} + \frac{0.40}{\text{moderate}} + \frac{0.30}{\text{high}} + \frac{0.30}{\text{very high}} \quad (5)$$

This function can also be written in the form of (0.00, 0.00, 0.40, 0.30, 0.30). In a similar manner, the membership functions of the remaining 10 principal POFs for construction megaprojects can be derived as indicated in Table 5.

As shown in Table 5, the weighting of each principal POF was calculated based on their relative importance ratings obtained from the first two-round Delphi survey in terms of the methods mentioned above. Based on the weightings and membership functions (level 2) of all 11 principal POFs, the membership function for each of the four KPI at Level 1 was calculated in terms of Equation (6). The results are shown in Table 5.

$$\begin{bmatrix} Weighting_{POF1} \\ Weighting_{POF2} \\ Weighting_{POF2} \\ \ldots \\ Weighting_{POF6} \\ Weighting_{POF8} \\ Weighting_{POFk} \\ \ldots \\ Weighting_{POF12} \end{bmatrix} \bullet \begin{bmatrix} Membership\_function_{POF1} \\ Membership\_function_{POF2} \\ Membership\_function_{POFj} \\ \ldots \\ Membership\_function_{POF6} \\ Membership\_function_{POF8} \\ Membership\_function_{POFk} \\ \ldots \\ Membership\_function_{POF12} \end{bmatrix} = \mathrm{KPI}_i\_Membership\_\mathrm{function} \quad (6)$$

(Please insert Table 5 here)

After computing the membership function of Level 1, the POPI for a particular KPI was calculated using Equation (2). For instance, the POPI for cost performance was calculated as follows:

0.00×1+ 0.00×2+0.09×3+ 0.67×4+0.25×5=4.200

Similarly, the POPIs for the three KPIs, functionality and quality performance, time performance, and OHS performance were determined as follows:

0.00×1+ 0.01×2+0.17×3+ 0.58×4+0.24×5=4.050 (Functionality and quality performance)

0.00×1+ 0.00×2+0.08×3+ 0.39×4+0.53×5=4.450 (Time performance)

0.02×1+ 0.05×2+0.31×3+ 0.56×4+0.08×5=3.690 (OHS performance)

Developing the Case Study POPI for the Four KPIs

The overall POPI in the case study with regard to the four KPIs can be developed as follows:

Overall POPI= 0.2342×*KPI1* + 0.2658×*KPI2* +0.2709×*KPI3* + 0.2291× *KPI4* (7)

Based on the four POPIs obtained, the overall POPI can be calculated as follows:

4.450×0.2342+4.200×0.2658+4.050×0.2709+3.690×0.2291=4.10

The overall POPI is 4.10, which is higher than the “high” value of 4.00. Therefore, the performance level of the program organization in the case study is better than “high,” with a great and positive performance level. Moreover, the program organization framework consisting of the 11 principal POFs developed in this study can be considered significant in improving organizational efficiency and in sustaining megaproject performance. Fig. 1 shows the POPI model of the case study.

(Please insert Fig. 1 here)

The effect of the program organization on each KPI in the case study was examined to ensure in-depth analysis. According to the maximum membership principle, the evaluation value of a membership function belongs to the category (domain) where the function achieves its maximum. The performance level of the program organization on each KPI is presented in Table 6. Analysis results indicated that the design and operation of the program organization consisting of the 11 principal POFs were consistent with the client's prioritization of four KPIs in the case study. Among the four KPIs in the case study, the program organization had the largest contribution to time performance (4.450), followed by cost performance and functionality as well as quality performance (4.200 and 4.050, respectively). This model also indicated high performance in OHS (3.690).

(Please insert Table 6 here)

Although this calculation was specific to the Shanghai Expo construction, the developed methodology and program organization framework could be replicated to other megaprojects. Clients with different settings on the priority of KPIs in construction megaprojects may replicate the methods of identifying principal POFs and evaluating their relationships with KPIs using the POF framework to tailor fit their own program organizations.

VALIDATION OF THE MODEL

Validation is the final and indispensable step in each research cycle to test whether the quality of a developed model has achieved an acceptable requirement. Gupta stated that the aim of model validation was to determine the degree of the system in fulfilling user needs (Hon et al., 2012). Walsh suggested that ethnographic research could be verified through respondent validation and triangulation. Thus, in addition to the qualitative validation using empirical data (e.g. archives and interviews) obtained from the megaproject case, this study further conducted qualitative validation of the developed models and relevant tools by interviewing with experts that were not involved in the case megaproject (Gupta, 1991).

Validation of this study mainly considered construct, external and internal validity in terms of seven developed validation questions. The three validity aspects are regarded as indispensable aspects in model validation (Walsh, 1998; Bacharach, 1989). To examine these validity aspects, seven questions were designed and used as an instrument for the subsequent structured interviews. Five selected experts in the practice and research of construction megaprojects in China were invited to attend the interviews in late July 2013. All interviewees also met the following criteria: (1) seven year industrial experience or above, (2) non-involvement in the development works of the models and relevant tools in this study, and (3) sound knowledge and understanding of client organizations that manage construction megaprojects. Majority of these interviewees have not been involved in the Shanghai Expo construction megaproject but have participated in other construction megaprojects in China. In each interview, the five respondents were asked to comment on each of the seven validation questions after the overall research process and major research findings were explained. Table 7 lists all the validation questions and their mean values provided by interviewed experts.

(Please insert Table 7 here)

Construct validity evaluates whether theoretical constructs are appropriate for operationalization [29]. Almost all of the interviewees (4 out of 5) agreed that the conceptual POF framework was comprehensive and adequate to include all the organizational elements within the client program organization managing a megaproject. All of the interviewees agreed that the categorization of the POFs was appropriate. An expert pointed out that although the categorization was simple, it was appropriate and practical. Another expert I had a slightly different opinion on the categorization of a specific POF, but he confirmed the appropriateness of the POF categorization.

External validity refers to the generalizability of research results (Walsh, 1998). Although minor differences existed in the ranking of the principal POFs, the majority of the interviewees agreed that the selected principal POFs and their individual weightings were appropriate in terms of their megaproject experiences. An expert noted that the use of PBS/WBS tools should be ranked before program leadership because this principal POF referred to the fundamental issue of constructing client program organizations to manage megaprojects. But the findings of this study have high external validity when considering the relevant findings are obtained from a single case study.

Internal validity is the causality that derives the relationships among data (Lucko & Rojas, 2010). All of the interviewees agreed that the performance of a program organization was the most challenging and essential work for clients who wanted to apply the program management approach in managing megaprojects. The FSE technique is innovative and appropriate for this purpose because it can enable clients to use the program organization in practice in a quantitative manner. Clients can perform their evaluation process using the POPI model. With regard to the research methodology, all of the interviewees said that the overall research design was logical and appropriate. An expert also commented that this research methodology should be replicated in similar cases to generalize the existing findings.

According to Table 7, this study received high mean ratings of 8.0 or above in all three validity aspects, particularly in internal validity. This result suggests that the implementation and findings of this study are valid and reliable. Thus, the findings of this study can be useful for clients who want to design and evaluate program organizations to manage construction megaprojects.

CONCLUSIONS AND FUTURE DIRECTIONS

With the rapid emergence of construction megaprojects over the past decades, program management has been increasingly supported as a contextual and pragmatic means of procuring construction megaprojects worldwide due to its ability in the efficient coordination of the dispersed execution (Arrto et al., 2008; Pellegrinelli et al., 2011). However, it is still an emerging area for research and practice (Pellegrinelli et al., 2011), especially for the construction industry (Rasdorf et al., 2010). By focusing on a specific subject of the client program organization for construction megaprojects, this study has adopted a novel method to validate the effectiveness of a program organization framework proposed in an earlier study (Hu et al., 2012). These findings have contributed to the establishment of a knowledge body of program management, a rapidly emerging area in project management field, by revealing the relationships between program management organization and its managed megaproject performance. This study also shed insight into the megaproject phenomenon by developing a pragmatic POPI for the success of construction megaprojects in China. The newly developed POPI model can be used as a tool by megaproject clients to develop their own program organizations and improve the operation of these organizations throughout the project lifecycle, particularly in China.

The main limitation of this study lies on limited empirical data from a single case megaproject. Construction megaprojects may have different types, characteristics, and requirements; thus, the program organization framework used in this study may require further refinements to adjust for other types of megaprojects. Considering that China is still undergoing societal transformation and has a different context from western societies (Tsui et al. 2004), the current study, which was based primarily on a single case study, might not have fully addressed the contextual effects on the formation and operation of program organization in megaprojects. Thus, future research should be conducted by examining more megaprojects under different institutional contexts.

With the recognition that the number of construction megaprojects has increased exponentially in both developed and developing countries in recent years (Flyvbjerg et al., 2003), the POPI model developed in this study has great potential as a practical tool for assisting professionals in designing an appropriate program organization to manage future megaprojects not only in China, but in other locations as well. Considering that developing a program organization for a particular megaproject is not a one-off exercise, regular reviews on the effectiveness of a program organization also require such a tool to realize continual improvements for better performance. Lastly not least, although the POPI model has been developed in China, the research methodology could shed light on the development of similar models in other countries for international comparisons. Producing similar models would assist in the understanding of managing megaprojects through program organizations across various countries.

ACKNOWLEDGEMENT

This work is based on the first author's PhD thesis completed at The Hong Kong Polytechnic University, Hong Kong. The work has been also funded by the National Nature Science Foundation of China under Grant Nos. 71390523 and 71501142. In addition, thanks are given to the Department of Construction Management and Real Estate, Tongji University, the Shanghai Expo Group Corporation as well as all the experts involved in the interviews and the four-round Delphi survey. The authors are grateful to the Associate Editor and three anonymous reviewers for their insightful comments and suggestions on earlier versions of the manuscript.

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Table 1 Results of the second round of the Delphi survey

Code	POFs	Mean	Ranking
POF1	Program strategy	4.80	1
POF2	Program leadership	4.70	2
POF3	Use of PBS/WBS tools	4.60	3
POF4	Communication management	4.60	3
POF5	Contextual understanding	4.50	5
POF6	Program governance	4.50	5
POF7	Scope management	4.20	7
POF8	Matrix organizational structure	4.20	7
POF9	Program management office (PMO)	4.20	7
POF10	Partnership with key stakeholders	4.20	7
POF11	Technology management	4.20	7
POF12	Team building	4.20	7

Table 2 Correlation matrix of the 12 principal POFs

	POF 1	POF2	POF3	POF4	POF5	POF6	POF7	POF8	POF9	POF10	POF11	POF12
POF1	1.000	-0.234	0.102	-0.408	-0.373	-0.500	0.583	0.250	0.468	0.583	0.250	0.250
POF2		1.000	0.255	-0.383	0.582	0.156	0.156	0.234	-0.083	-0.364	-0.547	-0.547
POF3			1.000	-0.250	-0.304	0.408	0.272	-0.102	0.491	0.272	-0.102	-0.612
POF4				1.000	0.000	0.000	-0.068	-0.102	0.218	-0.068	-0.102	0.408
POF5					1.000	-0.447	0.000	0.000	-0.398	-0.248	-0.373	0.000
POF6						1.000	-0.333	0.000	0.000	-0.333	0.000	-0.500
POF7							1.000	0.667*	0.802**	0.722*	-0.167	0.250
POF8								1.000	0.535	0.250	-0.250	0.375
POF9									1.000	0.579	-0.134	0.200
POF10										1.000	0.250	0.250
POF11											1.000	0.375
POF12												1.000

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 3 The five KPIs and their corresponding weightings

Code	KPIs	Mean	Weightings
KPI 1	Time performance	4.73	0.2709
KPI 2	Cost performance	4.09	0.2342
KPI 3	Functionality and quality performance	4.64	0.2658
KPI 4	OHS performance	4.00	0.2291
KPI 5	Environmental performance	3.64	—
	Number (11)	*N*	

Table 4 The correlation matrix among the five KPIs

	KPI1	KPI2	KPI3	KPI4	KPI5
KPI1	1.00	-0.209	-0.334	0.399	0.152
KPI2		1	.134	0.239	0.474
KPI3			1	0.256	0.546
KPI4				1	0.698*
KPI5					1

* Correlation is significant at the 0.05 level (2-tailed).

Table 5 FSE results

Principal POF	Weighting	Membership function (Level 2)	KPI Membership function (Level 1)
Cost performance (from level 2 to level 1)			
POF1	0.0986	(0.00, 0.00, 0.00, 0.80, 0.20)	
POF2	0.0965	(0.00, 0.00, 0.00, 0.60, 0.40)	
POF3	0.0945	(0.00, 0.00, 0.00, 0.70, 0.30)	
POF4	0.0945	(0.00, 0.00, 0.20, 0.70, 0.10)	
POF5	0.0924	(0.00, 0.00, 0.10, 0.60, 0.30)	
POF6	0.0924	(0.00, 0.00, 0.00, 0.90, 0.10)	(0.00, 0.00, 0.09, 0.67, 0.25)
POF8	0.0862	(0.00, 0.00, 0.20, 0.50, 0.30)	
POF9	0.0862	(0.00, 0.00, 0.00, 0.60, 0.40)	
POF10	0.0862	(0.00, 0.00, 0.10, 0.60, 0.30)	
POF11	0.0862	(0.00, 0.00, 0.30, 0.60, 0.10)	
POF12	0.0862	(0.00, 0.00, 0.10, 0.70, 0.20)	
Functionality and quality performance (from level 2 to level 1)			
POF1	0.0986	(0.00, 0.10, 0.20, 0.50, 0.20)	
POF2	0.0965	(0.00, 0.00, 0.00, 0.50, 0.50)	
POF3	0.0945	(0.00, 0.00, 0.00, 0.70, 0.30)	
POF4	0.0945	(0.00, 0.00, 0.30, 0.60, 0.10)	
POF5	0.0924	(0.00, 0.00, 0.40, 0.60, 0.00)	
POF6	0.0924	(0.00, 0.00, 0.10, 0.80, 0.10)	(0.00, 0.01, 0.17, 0.58, 0.24)
POF8	0.0862	(0.00, 0.00, 0.30, 0.60, 0.10)	
POF9	0.0862	(0.00, 0.00, 0.00, 0.20, 0.80)	
POF10	0.0862	(0.00, 0.00, 0.10, 0.70, 0.20)	
POF11	0.0862	(0.00, 0.00, 0.40, 0.60, 0.00)	
POF12	0.0862	(0.00, 0.00, 0.10, 0.60, 0.30)	
Time performance (from level 2 to level 1)			
POF1	0.1333	(0.00, 0.00, 0.00, 0.30, 0.70)	
POF2	0.1067	(0.00, 0.00, 0.00, 0.40, 0.60)	
POF3	0.1040	(0.00, 0.00, 0.00, 0.30, 0.70)	
POF4	0.0667	(0.00, 0.00, 0.10, 0.60, 0.30)	
POF5	0.0800	(0.00, 0.00, 0.00, 0.20, 0.80)	
POF6	0.0773	(0.00, 0.00, 0.00, 0.50, 0.50)	(0.00,0.00, 0.08,0.39,0.53)
POF8	0.0693	(0.00, 0.00, 0.40, 0.50, 0.10)	
POF9	0.0587	(0.00, 0.00, 0.30, 0.50, 0.20)	
POF10	0.0560	(0.00, 0.00, 0.00, 0.20, 0.80)	
POF11	0.0907	(0.00, 0.00, 0.00, 0.20, 0.80)	
POF12	0.0960	(0.00, 0.00, 0.10, 060, 0.30)	
Occupational health and safety performance (from level 2 to level 1)			
POF1	0.0986	(0.00, 0.00, 0.50, 0.40, 0.10)	
POF2	0.0965	(0.00, 0.00, 0.20, 0.70, 0.10)	
POF3	0.0945	(0.00, 0.00, 0.20, 0.70, 0.10)	
POF4	0.0945	(0.00, 0.00, 0.00, 0.80, 0.20)	
POF5	0.0924	(0.00, 0.00, 0.40, 0.40, 0.20)	
POF6	0.0924	(0.00, 0.00, 0.20, 0.80, 0.00)	(0.02,0.05, 0.31,0.56,0.08)
POF8	0.0862	(0.20, 0.20, 0.60, 0.20, 0.00)	
POF9	0.0862	(0.00, 0.20, 0.50, 0.30, 0.00)	
POF10	0.0862	(0.00, 0.00, 0.40, 0.50, 0.10)	
POF11	0.0862	(0.00, 0.10, 0.10, 0.70, 0.10)	
POF12	0.0862	(0.00, 0.10, 0.30, 0.60, 0.00)	

Table 6 Performance scores and levels of the case's program organization

KPIs	Score	Membership function	POPI (Categories)
Time performance	4.450	(0.00,0.00, 0.08,0.39,0.53)	Very high (5)
Cost performance	4.200	(0.00,0.00, 0.09,0.67,0.25)	High (4)
Functionality and quality	4.050	(0.00,0.00, 0.17,0.58,0.24)	High (4)
OHS performance	3.690	(0.02,0.05, 0.31,0.56,0.08)	High (4)

Table 7 Ratings of the five interviewees

Aspects	Validation questions	Mean ratings
Construct validity	1. Are the identified POFs comprehensive and practical?	8.6
	2. Are the categories of the POFs proper?	8.4
External validity	3. Are the principal POFs reasonable?	8.2
	4. Are the selected principal POFs pragmatic and generalized?	8.0
Internal validity	5. Can the fuzzy membership function effectively reduce the subjectivity of measuring the effectiveness of the program organization with regard to the selection criteria?	9.0
	6. Is FSE analysis applicable such that clients can utilize the program organization framework?	8.2
	7. Is the research design and methodology is logical and replicable?	8.6

Note: 0=very poor; 5=average; 10=excellent.

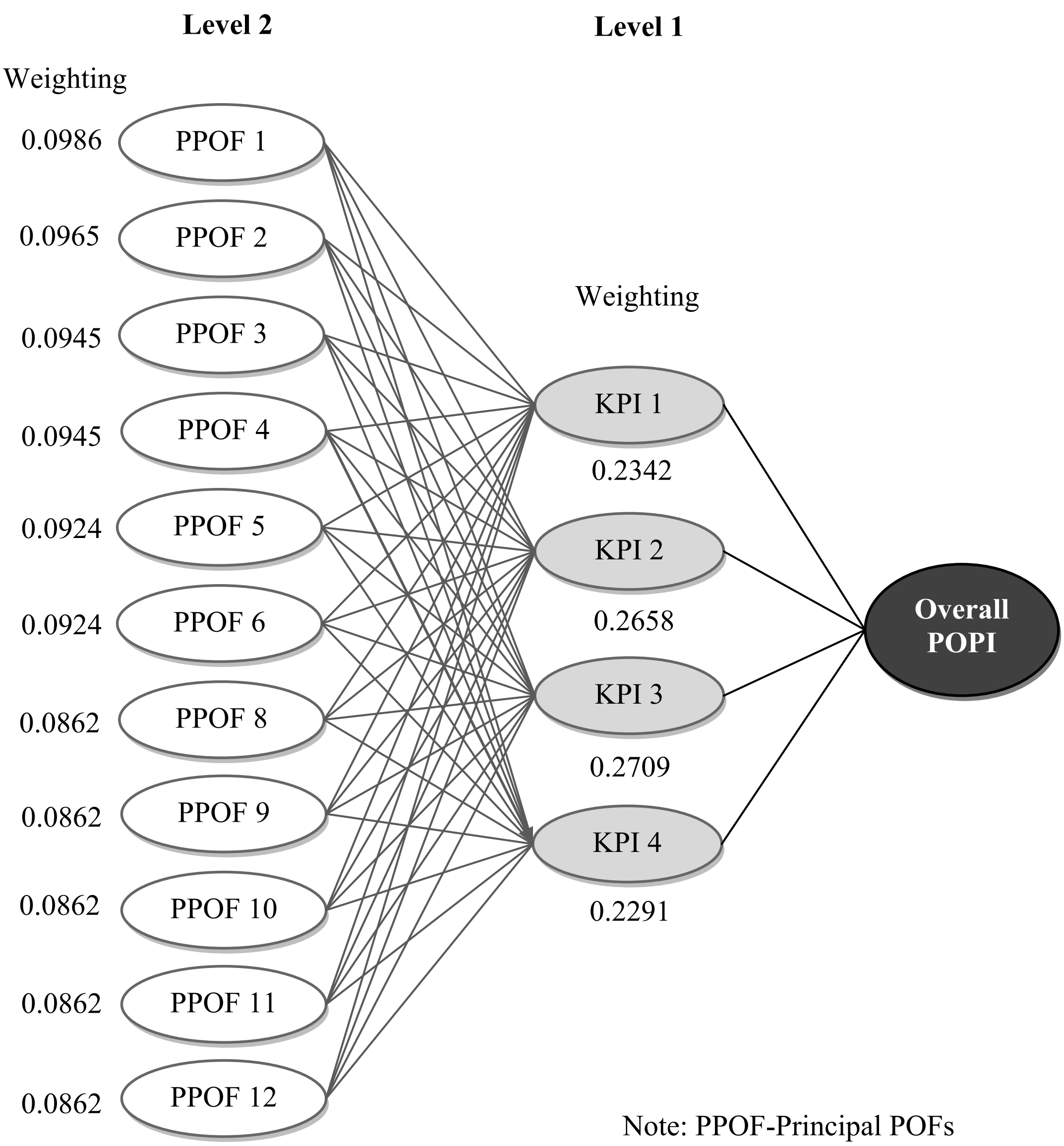

Fig. 1 POPI model of the case