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Thomas Ng, S.; Xie, Jingzhu; Skitmore, Martin; Cheung, Yau Kai

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S. Thomas Ng [1]
Jingzhu Xie [2]
Martin Skitmore [3]
Yau Kai Cheung [4]

Please contact:

Dr. S. Thomas Ng
Department of Civil Engineering
The University of Hong Kong
Pokfulam Road, Hong Kong

Tel: Int+ (852) 2857 8556
Fax: Int+ (852) 2559 5337
Email: tstng@hkucc.hku.hk

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[1] Associate Professor, Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, email: tstng@hkucc.hku.hk
[2] PhD Candidate, Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, email: h0595526@hkusua.hku.hk
[3] Professor, School of Construction Management and Property, Queensland University of Technology, GPO Box 2434, Q4001, Australia, email: rm.skitmore@qut.edu.au
[4] Professor, Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, email: hreccyk@hkusua.hku.hk

A FUZZY SIMULATION MODEL FOR EVALUATING THE CONCESSION ITEMS OF PUBLIC-PRIVATE PARTNERSHIP SCHEMES

Abstract:

The investment return, tariff regime and concession period are the most important items that influence the success of a concession-based Public-Private Partnership (PPP) project. From the public partner's perspective, whether a scheme is value-for-money or not dominates the decision making process. However, a seemingly favorable deal may turn out to be the least value-for-money option should it cause unnecessary social upheaval, such as excessive tariff increases or complaints. A scheme which is truly value-for-money is one which balances the interests of the public partner, investor and end-users. In this paper, a simulation model is proposed to assist a public partner to identify the concession period based on the expected investment and tariff regime. The needs for establishing different scenarios to represent the risks and uncertainties involved are presented, and a fuzzy multi-objective decision model is introduced to trade-off the associated three concession items. The combined features of the simulation and fuzzy multi-objective decision models enable the scenario most likely to result in a "win-win-win" concession scheme to be identified. A hypothetical example is used to illustrate the proposed model. This highlights the importance of the decision-makers' perception of the concession items in influencing their selection, and the influence of the group decision-making involved.

Keywords: Concession period, fuzzy sets, public-private partnership, simulation, tariff regime

INTRODUCTION

An increasing number of construction industry stakeholders are striving to exploit the potential of opening up publicly owned and operated facilities/services to the private sector. Public Private Partnerships (PPP) offer one means of achieving this by attaining a "win-win-win" situation among the government, business sector and end-users (*cf:* Angeles and Walker, 2000; Akintoye *et al*, 2003). In fact, there is no shortage of successful PPP examples (Confoy *et al*, 1999; Magub and Hampson, 1999; Miller and Evje, 1999; Delmon, 2000; Pietroforte and Miller, 2002; Vorster *et al*, 2002). These have often provided significant overall cost savings for the project (HM Treasury, 2000; Chege and Rwelamila, 2001; New South Wales Government, 2001; Victorian Government, 2001), more timely delivery of facilities/services (Clifford Chance, 2001) and better productivity performance and innovation (Earl and Regan, 2003).

In one of the most popular PPP alternatives, the concession scheme, the investor raises the necessary funding and provides the physical facility as well as maintaining and operating the completed asset (Zhang and Kumaraswamy, 2001). In return, they recover their capital investment according to the terms set out in the concession agreement *viz*. the concession period, a proposed tariff regime and an expected investment return (Ngee *et al*, 1997). To ensure the scheme is financially viable and attractive, the investor might seek to initiate a higher expected investment return especially when the concession period is short. With an assured minimum profit proviso, the concessionaire may increase the tariff in case the scheme fails to reach its expected investment return. Yet, any upward adjustment in tariff will attract criticisms from the user and pressure groups. From the government's perspective whether or not a PPP scheme is of value-for-money is the prime concern; and those with unrealistically high expected returns and/or excessively lengthy concession periods may be conceived as a transfer of interest (Efficiency Unit, 2003). Hence, there is a legitimate need to balance the interests of all the stakeholders before a concession agreement is reached.

In practice, the government relies on the Pay Back Period (PBP) under the minimal Internal Rate of Return (IRR) as expected by the concessionaire to determine the concession period (Shen and Li, 2000). This enables the PBP to be easily computed by the conventional Net Present Value (NPV) method. As an alternative, Ngee *et al* (1997) have developed a multiple linear regression model which enables the value of any concession item to be calculated when the other two items are known. Both these approaches, however, are dominated by high levels of risk and uncertainty (fluctuations in interest rate, inflation, cost, revenue, etc.). An overly optimistic estimate based on the cash flow evaluation, for instance, could mean that the return rate expected by the concessionaire may never be realized during the agreed concession period. Therefore, when establishing the concession items, due consideration of the effects of the risks and uncertainties involved is needed. A further salient issue is the need to embrace the views of various stakeholders – the public partner, the investor and the end-users – when the concession items are determined.

This paper proposes a model to determine the concession items that best satisfies the various stakeholders involved in a PPP scheme. This firstly uses simulation techniques to deduce a concession period based upon the minimum expected IRR and tariff regime proposed. Fuzzy set theory is then applied to enable the concession items to be evaluated via a range of possible scenarios. This enables a non-inferior solution for conflicting objectives to be deduced. Through the model results, the public partner can select the most satisfactory alternative for proposal invitation and further evaluation. The paper begins by outlining the features of the simulation model. It is then followed by an introduction of the model components. Finally, a hypothetical example is applied to illustrate the operation of the model.

MODELING RISKS THROUGH SIMULATION

Acknowledging the strength of simulation in analyzing the effects of risks, models have been developed using the Monte Carlo approach to determine the concession period (Shen *et al*, 2002; Shen and Wu, 2005; Zhang and AbouRizk, 2006) and analyze the risks involved in concession projects (Malini, 1999) based on the simulated values of such financial indicators as NPV and IRR. However, the risk analysis model developed by Malini (1999) was based on deterministic parameters, which restricts its applicability to the selection of a concession period only from some finite scenarios. The model also assumes that some macro-economic indicators, such as interest and inflation rates, can be estimated with certainty. In reality these macro-economic indicators may well be major risks in themselves.

Figure 1 portrays a new simulation model to accommodate the complex implications of the various risks associated with concession-based PPP projects. In this model, the concession period is an output rather than an input parameter. Since securing a desirable return is the most important consideration of any commercial organization, it is sensible to assume that a reasonable tariff regime and a minimal IRR can be established in advance. By inputting the tariff regime and the IRR into the simulation model, the exact concession period in each simulation cycle can be computed from simulated costs and revenues. With sufficient iterations, a frequency distribution related to the concession period can be generated.

< Figure 1 >

Deterministic Parameters

Construction period (T_c): The concession period is composed of construction and operation periods. Under normal circumstances, the time required for completing the construction work is uncertain as project delay is common in practice. However, the construction period can be treated as a deterministic input in a concession scheme as the investor would enjoy a longer operation period by shortening the time for construction while the concession period remains the same (Yi and Tiong, 2003). By controlling the construction period, the identified risks may be converted into opportunities. Hence, the input data can be based simply on the most likely construction period as estimated by the public partner.

Return rate: The amount of money required to raise the finance through different types of capital, such as equity and debt, commonly known as the weighted average capital cost is the lowest return rate for an investment (Bierman and Smidt, 1993). It follows that the minimum expected IRR can be based on the weighted average capital cost of a concession scheme. For simulation purposes, it is necessary to determine the capital costs of the proposed scheme and the equity/debt ratio so as to compute the weighted average capital cost.

Tariff regime: The tariff regime is based on (i) the statistical data gathered from similar projects; (ii) the amount the end-users is willing to pay; and (iii) the micro economic forecast (Malini, 1999). To accommodate these constraints, different tariff regimes can be set for different scenarios to facilitate comparison.

Uncertain Parameters

Cost in year 't' (C_t)*:* This cost comprises all the expenses incurred in designing, constructing, operating, managing and maintaining the facility. However, the accuracy of the estimation is influenced by several risk factors such as changes in interest rates and inflation (Zayed and Chang, 2002). In the proposed model, it is necessary to (i) identify the major risk factors that could have serious effects on the cost; (ii) establish an empirical or assumed probability distribution for each of the identified risk factors (in discrete or continuous form); and (iii) examine the effects of the risk factors on the cost (*cf:* Cagno and di Milano, 2001). Since the estimated cost is more affected by changes in inflation rates, a (normal) probability distribution is assigned to represent the interest rate fluctuation in the model (*cf:* Wen and Kang, 2001).

Operation Revenue in year 't' (R_t)*:* The revenue of a concession-based PPP project is determined by the number of users as well as the tariff regime. While the tariff regime is agreed by the public and private partners, the number of users may vary according to the availability of alternatives and/or economic growth within the locality. In a concession-based PPP, the user/volume risk can be estimated by a projection of statistics of similar facilities. Figure 2 illustrates the annual traffic flow record of a PPP project. From this, the growth rate and stochastic errors can be established through, for example, linear regression analysis. Such data can be used to construct a normal distribution curve for user volume (Shen and Wu, 2005).

< *Figure 2* >

Income in year 't' (I_t): The annual income in the operation period is the difference between the revenue generated and the costs associated with the operation, management and maintenance of the asset in the corresponding year.

Simulation Output

Having established the input parameters, the simulation process can begin. By repeating the simulation for a 1,000 iterations, a cumulative frequency distribution of the concession period as shown in Figure 3 can be generated.

< Figure 3 >

Inspection of the simulation results enables the public partner to determine an appropriate concession period to guarantee the concessionaire a minimal IRR under the proposed tariff regime and associated confidence level. Therefore, by referring to the cumulative frequency distribution (Figure 3), if the goal was to ensure the investor achieves the minimum expected IRR with confidence level of 80%, then the government might wish to fix the concession period to 17 years, as there is 80.4% confidence that the concessionaire can attain the minimal return rate for this period. Likewise, with 90% confidence, the concession period must be set at 18 years.

MULTI-OBJECTIVE DECISION MODEL

By using the above simulation model, the public client can establish an appropriate concession period for each proposal. However, as public sector organizations are the only parties who can strike a balance of value-for-money, financial viability and social interests, they should aim to ensure the greatest satisfaction of not just themselves but also those of the private sector and end-users. A practicable strategy would be to institute feasible options based on the concession periods and different combinations of expected IRR and tariff regimes; and select one which would balance the interests of all major stakeholders.

Such arrangements will not only help ensure the identification of an appropriate concession period for the purposes of proposal invitation, but the corresponding tariff regime and investment return can also serve as a basis for proposal evaluation at a later stage, as this should be the most preferred scenario for all parties. However, to select an appropriate scenario (with due consideration of the concession period, expected IRR and tariff regimes amongst different alternatives) is never a simple task due to the diverse perspectives of decision-makers concerning concession items. The diversity of interests of the public sector, investors and end-users makes the evaluation a multi-objective decision problem (see Eqn. 1):

$$\begin{cases} \max IRR \\ \min Tariff\ \ regime \\ \min Concession\ period \end{cases} \qquad [1]$$

Since the objectives are conflicting, there is hardly any alternative which could fulfill all the three objectives at the same time. Characterized by conflicting and vague objectives, it is inevitable for the decision-makers to rely on their own judgment during the decision making process. As a result, an effective means to deal with the perceptions of decision-makers is needed. Being recognized as an effective technique for modeling imprecise domains and solving multi-objective decision problems (Roman, 1998; Zimmermann, 2001), fuzzy set theory should help provide an effective solution with due consideration of all different options.

Fuzzy set ideas were first introduced by Lukasiewica in 1920 and subsequently developed by Zadeh into a formal system of mathematical logic for representing issues without precise boundaries. Fuzzy set theory can be defined as a branch of logic based on the degrees of membership in sets rather than strict (crisp) true/false membership. Following Zadeh (1965, 1971) and Zimmermann (2001), the concept of fuzzy sets can be represented so that if X is a collection of objects denoted generically by x, then a fuzzy set $\tilde{A}$ in X is a set of ordered pairs:

$$\tilde{A} = \left\{x, \mu_{\tilde{A}}(x) \mid x \in X\right\} \qquad [2]$$

where $\mu_{\tilde{A}}(x)$ is a membership function taking values from [0,1] specifying to what degree x belongs to $\tilde{A}$.

For a multi-objective decision problem where the objectives are conflicting, makes it difficult to obtain an optimal solution:

$$\max/\min\left\{f_i(x) \middle| x \in X, i = 1,2,...,m\right\} \qquad [3]$$

This can then be transformed into a fuzzy multi-objective decision model as follows:

$$\max\left\{\mu_{\tilde{f}_i}(x)\middle|x \in X, i = 1,2,...,m\right\} \quad [4]$$

where $\tilde{f}_i$ is a fuzzy set in field $X_i = \left\{x\middle|f_{i\inf} \le f_i(x) \le f_{i\sup}, x \in X\right\}$; $f_{i\inf}$ and $f_{i\sup}$ are the inferior and superior boundaries of $f_i(x)$ respectively; $\mu_{\tilde{f}_i}(x)$ is the degree of membership that x belongs to $\tilde{f}_i$, where $\mu_{\tilde{f}_i}(x)$ is simply denoted as $\mu_i(x)$ in the following part).

For the maximization objectives, the membership function is determined by:

$$\mu_i(x) = \left[\frac{f_i(x) - f_{i\inf}}{f_{i\sup} - f_{i\inf}}\right]^{p_i} \quad [5]$$

while, for the minimization objectives, the membership function is determined by:

$$\mu_i(x) = \left[\frac{f_{i\sup} - f_i(x)}{f_{i\sup} - f_{i\inf}}\right]^{p_i} \quad [6]$$

where p_i is a exponential parameter and usually a set value of 1.

For some subjective goal, where the evaluations for alternatives are linguistic ranked such as “very unsatisfied”, “unsatisfied”, “moderate”, “satisfied” and “very satisfied”, the fixed degrees can be set to represent the ranks, for example {0.1, 0.3, 0.5. 0.7. 0.9}, to present the above ranking set.

Here the max-min composition approach is adopted to derive a non-inferior solution (Ragab and Emmam, 1995; Luoh *et al*, 2002), as it is a simple and feasible method to solve the fuzzy multi-objective decision problem (Sanchez, 1976; CMU, 1993; Li, 1997; Slowinski, 1998; Chrr and Tah, 2001). Despite being relatively conservative (Zimmermann, 2001), the max-min composition approach can avoid non-inferior solutions from having a minimal membership value. In other words, the minimal membership value of the derived solution would not be the worst result when compared with that of the other alternatives. Therefore, the non-inferior solution is deduced by the max-min composition as expressed by:

$$\mu_{i^* j^*} = \max_j \min_i \{\mu_i(x_j)\} \qquad [7]$$

where $\mu_i(x_j)$ is simply denoted as μ_{ij} in the following part (*cf:* Kandasamy and Smarandache, 2004).

The above equation implies that each objective has an equal weight, but if the decision-makers set different weight for each objective, then the composition becomes:

$$\mu_{i^* j^*} = \max_j \min_i \{(\mu_{ij})^{\omega_i}\} \qquad [8]$$

where ω_i is the weight of objective *i*.

Adopting the above concepts for evaluating various options of concession items leads to an evaluation model as follows:

Let $X = \{IRR,\ Tariff\ Regime,\ Concession\ Period\}$: = a set of objectives [9]

$A = \{Alternative_1,\ \ldots,\ Alternative_N\}$: = a set of alternatives [10]

and a weight set on $X : W = \{\omega_1, \omega_2, \omega_3\}$ expresses the weight of each factor in X [11]

Then, the MOD problem is to select an optimal alternative leading to:

$$\begin{cases} \max IRR \\ \min Tariff\ \ regime \\ \min Concession\ period \end{cases}$$

and transfer the objective value of each alternative to the membership value according to the membership functions in Eqns. 5 and 6. Once the fuzzy relationship is established, it is easier to deduce the non-inferior solutions by using Eqn. 7 or 8.

HYPOTHETICAL EXAMPLE

In order to demonstrate how the simulation model and the evaluation method work, the following simple road project is used:

- the construction period is 5 years,

- the construction cost is $100,000,000 (which, for simplicity, will be apportioned in accordance with a 5-year construction period at 10%, 20%, 30%, 20%, and 20% respectively),
- the annum operation and maintenance cost is 15% of the annum operation revenue,
- the estimated traffic volume and proposed tariff regime is as shown in Table 1,
- the minimum expected IRR is 13%, and
- the concession period is 15 years.

< Table 1 >

Conventional NPV analysis was first conducted to analyze the data. The results show the NPV to be $6,982,300 while the PBP is 13.59 years. The initial analysis indicates the scheme is viable (NPV>0) and the concessionaires can recover their investment before the end of the concession period (PBP<15).

Incorporating Risk Factors in the Simulation Process

It is assumed that the following are the major risk factors that could affect the cash flow of the above hypothetical example:

- inflation rate – the rate of change follows a normal distribution with mean and standard deviation equivalent to 2.5% and 2% respectively,
- traffic flow – the estimated average annual traffic volume follows a normal distribution with standard deviation to 20% of the first year's traffic volume, and
- operation cost – the annual operation and maintenance costs follow a uniform distribution in the interval [0.13, 0.17].

The above data (Scenario 1) was entered into the simulation model developed in Matlab™ to generate the cumulative probability of the concession period. After running the simulation procedure 1,000 times, the cumulative frequency distribution as shown in Figure 4 was derived. From Figure 4, it is apparent that the cumulative probability of the minimum expected IRR in the 15th year is 0.4550. This suggests that the initial decision of fixing the concession period to 15 years is rather risky to the investor, as there is a 45.5% chance that such a period can just ensure the minimum expected IRR of 13% be realized. In other words, there is a 54.5% chance that the IRR will not reach the minimum level. Therefore, the scheme is unlikely to be accepted by the concessionaire and it will also be difficult for the two sides to arrive at an agreement based on this concession period.

< Figure 4 >

When it is necessary to ensure the concessionaire could gain the minimum expected IRR with a high confidence level (say 0.90), the decision-makers would favor extending the concession period to 16.37 years (see Figure 4).

As discussed earlier, it would be preferable for decision-makers to consider several alternatives before a final decision is reached. For example, a more optimistic scenario might be found to reflect the possibility of having a risk seeking investor who is prepared to accept a lower IRR and tariff regime. Likewise, a pessimistic alternative can also be considered by the decision-makers. To illustrate the concept, two further scenarios are proposed to represent the optimistic and pessimistic alternatives respectively:

Scenario 2:

- Discount rate (the minimum expected IRR) = 0.12
- Tariff regime: the tariff is 10% less than the most likely tariff

Scenario 3:

- Discount rate (the minimum expected IRR) = 0.14
- Tariff regime: the tariff is 20% more than the basic tariff

Running the simulation model in accordance with the conditions stated in Scenarios 2 and 3 respectively, the cumulative probability curves shown in Figure 5 were generated. Applying the above criteria for determining the concession period, the appropriate concession periods for the optimistic and pessimistic scenarios are 17.40 years and 14.17 years respectively.

< Figure 5 >

Evaluating the Three Scenarios

The results generated by the simulation model would enable the decision-makers to evaluate each scenario according to the three factors – the minimum expected IRR, tariff regime, and concession period – which constitute the set of objectives (*X*). The details of concession items for each scenario are summarized in Table 2.

< Table 2 >

Assuming that the decision-makers set a possible interval for IRR as [8%,20%] and for concession period as [10,25], then the degree of membership can be derived according to Eqns. 5 and 6. Therefore, the degree of membership for Alternative 1 to the objective of maximal IRR can be calculated as below:

$$\mu_{11} = \frac{13\% - 8\%}{20\% - 8\%} = 0.42$$

and the degree of membership of Alternative 1 to the objective of minimal concession period can be calculated as:

$$\mu_{13} = \frac{25 - 16.37}{25 - 10} = 0.58$$

while the other degrees of membership can be derived in a similar manner.

Since the tariff regime is not represented by a single value, Eqn. 6 cannot be applied to derive the degree of membership. As a result, a representative from the end-users group is selected to evaluate each tariff regime. Let the evaluation results for these three tariff regimes be moderate, satisfied and unsatisfied, then 0.5, 0.7 and 0.3 are the degree of membership for those tariff regimes. The degree of membership can be summarized in Table 3.

< Table 3 >

Here we assume that the weightings of the three concession items are equal. Then, the non-inferior solution can be deduced based on the degree of membership matrix through the max-min composition as Eqn. 7:

$$\mu_{i^*j^*} = \max_j \min_i \{\mu_i(x_j)\}$$

$$= \max_{1\le j\le 3} \min_{1\le i\le 3} \begin{pmatrix} 0.42 & 0.33 & 0.50 \\ 0.50 & 0.70 & 0.30 \\ 0.58 & 0.51 & 0.72 \end{pmatrix}$$

$$= \max_{1\le j\le 3} (0.42 \quad 0.33 \quad 0.30)$$

$$= 0.42 = \mu_{11}$$

From the above results, decision-makers can conclude that Scenario 1 is the most preferable with the preference order being Scenarios 1, 2 and 3. This implies that Scenario 1 can provide the greatest degree of satisfaction to the decision-makers.

In the above example, it was assumed that the decision-makers would assign an equal weighting to the three concession items. Changing the weighting set to $W = \{0.3,0.5,0.2\}$, gives a different the evaluation result. By using Eqn. 8:

$$\mu_{i^*j^*} = \max_j \min_i \{(\mu_{ij})^{\omega_i}\}$$

$$= \max_{1\le j\le 3} \min_{1\le i\le 3} \begin{pmatrix} 0.77 & 0.72 & 0.81 \\ 0.71 & 0.84 & 0.55 \\ 0.90 & 0.87 & 0.94 \end{pmatrix}$$

$$= \max_{1\le j\le 3} (0.71 \quad 0.72 \quad 0.55)$$

$$= 0.72 = \mu_{21}$$

While Scenario 2 is the most preferable, the preference order now becomes Scenarios 2, 1 and 3.

CONCLUSIONS

This paper proposes a method by which both simulation and fuzzy comprehensive evaluation can be combined to establish the most satisfactory concession item options for PPP projects. By incorporating the complex impact of risks involved, an appropriate concession period can be deduced by a simulation based on the minimum expected IRR and tariff regime. However, as the actual IRR and tariff regime would not be known at the proposal invitation stage, alternative scenarios need to be generated for consideration. The purpose of the fuzzy comprehensive evaluation process is to enable decision-makers to select the most preferable alternative from a list of possible scenarios, such that the concession period would be used for proposal invitation, while the corresponding tariff regime and investment return could serve as a basis for proposal evaluation at a later stage. The simulation process and the application of fuzzy theory have also been illustrated through a hypothetical example.

The proposed simulation model could assist decision-makers establish a concession period for a PPP project that is acceptable to both the public and private partners; i.e. (i) to ensure the concessionaire gains a reasonable return, and (ii) to allow the public client to reclaim the facility at an appropriate time. After devising different possible alternatives of the concession items using the simulation technique, decision-makers could then evaluate the three concession items (i.e. IRR, tariff regime and concession period) of each alternative. The results would provide the fuzzy relations between the three items and alternatives. Then, through the fuzzy composite method, the non-inferior solution could be obtained to maximize the satisfaction of all the three parties.

While the proposed simulation model and fuzzy MOD could provide decision-makers with a useful tool for establishing an optimal alternative of concession items for a PPP project, further improvement may be needed to make the process more implementable. For instance, it may not be easy for decision-makers to accurately predict the risk factors affecting the uncertain parameters. In addition, there is no clear method for determining the weighting that each concession item contributes to the evaluation. There is also a need to combine various composition methods other than the more conservative max-min method to deduce the non-inferior solution for decision-makers with different risk attitudes.

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REFERENCES

Akintoye, A., Beck, M. and Hardcastle, C. (2003) *Public-Private Partnerships: Managing Risks and Opportunities*, Blackwell Science, Oxford.

Angeles, N.H. and Walker, D. (2000) BOOT schemes – a project delivery system for a new millennium, *Chartered Building Professional*, March, 21-23.

Bierman Jr., H. and Smidt, S. (1993) *The Capital Budgeting Decision: Economic Analysis of Investment Projects*, Macmillan Publishing Co., New York.

Cagno, E. and di Milano, P. (2001) Risk analysis to assess completion time of a tram-line, *Project Management*, **7**(1), 26-31.

Chege, L.W. and Rwelamila, P.D. (2001) Private financing of construction projects and procurement systems: an integrated approach, *Proceedings: CIB World Building Congress, Performance in Product and Practice*, Duncan (ed), April 2-6, Wellington, NZ.

Chrr, V. and Tah J.H.M. (2001) A fuzzy approach to construction project risk assessment and analysis: construction project risk management system, *Advances in Engineering Software*, **32**, 847-857.

Clifford Chance (2001) *Public Private Partnerships Newsletter*, January, Clifford Chance, London.

CMU (1993) *What is a Fuzzy Expert System?* School of Computer Science, Carnegie Mellon University, http://www.cs.cmu.edu/Groups/AI/html/faqs/ai/fuzzy/part1/faq-doc-4.html

Confoy, B., Love, P.E.D, Wood, B.M. and Picken, D.H. (1999) Build-own-operate: the procurement of correctional services, In *Profitable Partnering in Construction Procurement*, S. Ogunlana (ed), E and F.N. Spon, London, 461-474.

Delmon, J. (2000) *BOO/BOT Projects: A Commercial and Contractual Guide*, Sweet and Maxwell, London.

Earl, G. and Regan, M. (2003) From the three P's to the three W's – Public Private Partnerships and Beyond, *Proceedings: 9th Annual Conference of the Pacific Rim Real Estate Society (PRRES)*, P. Elliott & T. Boyd (eds), January 19-22, Customs House, Brisbane, 22 pages.

Efficiency Unit (2003) *Serving the Community by Using the Private Sector – An Introductory Guide to Public Private Partnerships (PPPs)*, The Government of HKSAR, Hong Kong.

HM Treasury (2000) *Public Private Partnerships: The Government Approach*, Stationery Office, London.

Kandasamy, W.B.V. and Smarandache, F. (2004) *Fuzzy Relational Maps and Neutrosophic Relational Maps*, Hexis, http://www.gallup.unm.edu/~smarandache/NRM.pdf

Li, D. (1997) Fuzzy multiattribute decision-making models and methods with incomplete preference information, *Fuzzy Sets and Systems,* **106**, 113-119.

Luoh, L. Wang, W. and Liaw, Y. (2002) New algorithms for solving fuzzy relation equations, *Mathematics and Computers in Simulation*, **59**(4), 329-333.

Malini, E. (1999) Build operate transfer municipal bridge projects in India, *Journal of Management in Engineering*, ASCE, **15**(4), 51-58.

Magub, A. and Hampson K. (1999) Sydney's Olympic stadium: a world class event? *Proceedings: International Conference for Construction Process Re-engineering, Construction Process Re-engineering '99*, July 12-13, University of New South Wales, Sydney, 121-132.

Merna, A. and Smith, N.J. (1996) *Projects Procured by Privately Financed Concession Contracts*, Asia Law and Practice Press, Hong Kong.

Miller, J.B. and Evje, R.H. (1999) The practical application of delivery methods to project portfolios, *Construction Management and Economics*, **17**, 669-677.

New South Wales Government (2001) *Working with Government – Guidelines for Privately Financed Projects*, New South Wales Government, Sydney.

Ngee, L., Tiong, R.L.K. and Alum, J. (1997) Automated approach to negotiation of BOT contracts, *Journal of Computing in Civil Engineering*, ASCE, **11**(2), 121-128.

Pietroforte, R. and Miller, J.B. (2002) Procurement methods for US infrastructure: historical perspectives and recent trends, *Building and Research Information*, **30**(6), 425-434.

Ragab, M.Z. and Emam, E.G. (1995) On the min-max composition of fuzzy matrices, *Fuzzy Sets and Systems*, **75**(1), 83-92.

Slowinski, R. (1998) *Fuzzy Sets in Decision Analysis, Operations Research, and Statistics*, Kluwer Academic Publishers, Boston.

Sanchez, E. (1976) Resolution of composite fuzzy relation equation, *Information and Control*, **30**, 38-48.

Shen, L.Y. and Li, Q.M (2000) Decision-making model for concession period in BOT contract infrastructure project, *Journal of Industrial Engineering and Engineering Management*, **14**(1), 43-47.

Victorian Government (2001) *Partnerships Victoria: Guidance Material – Practitioners Guide*, Department of Treasury and Finance, Victoria, Australia.

Vorster, M., Songer, A.D. and Morgan, H. (2002) Public-private partnerships for infrastructure development: case study of the 895 connector project, *Proceedings: CIB W92 Procurement Systems Symposium, Procurement Systems and Technology Transfer*, T.M. Lewis (ed), January 14-17, The University of The West Indies, Trinidad and Tobago, 41-51.

Zadeh, L.A. (1965) Fuzzy Sets, *Information Control*, Vol. 8, 338-353

Zhang, X.Q. and Kumaraswamy, M.M. (2001) Hong Kong experience in managing BOT projects, *Journal of Construction Engineering and Management*, ASCE, **127**(2), 154-162.

Zimmermann, H.J. (2001), *Fuzzy Set Theory and its Applications*, Kluwer Academic Publishers, Dordrecht.

LIST OF CAPTIONS

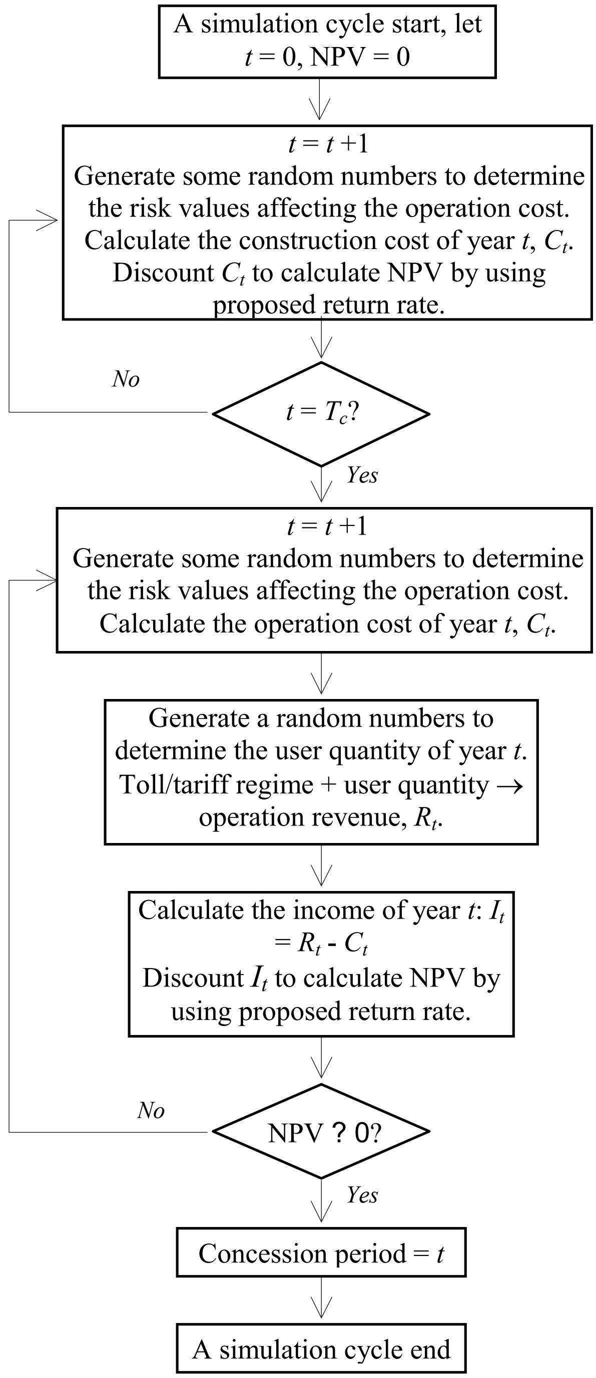

Figure 1: Simulation flow diagram for determining the concession period

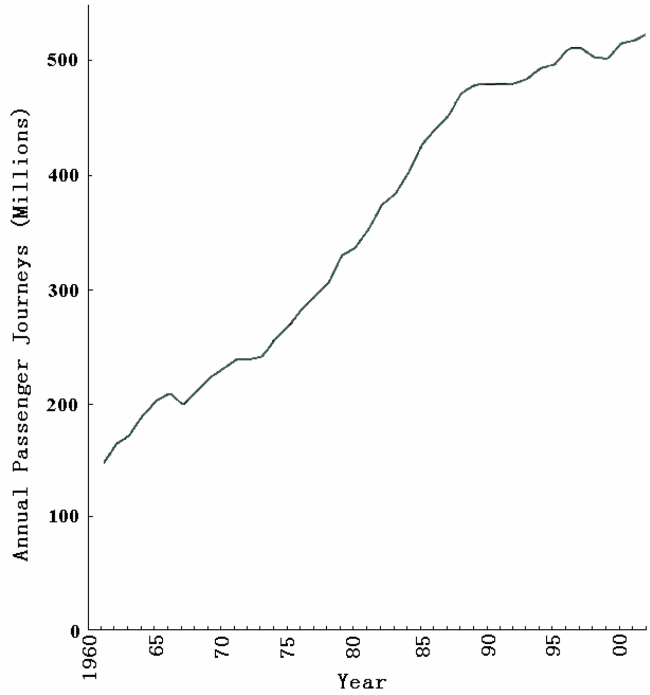

Figure 2: Annual traffic flow of the Cross Harbor Tunnel in Hong Kong
(Source: Traffic and Transport Digest, Transport Department, HKSAR)

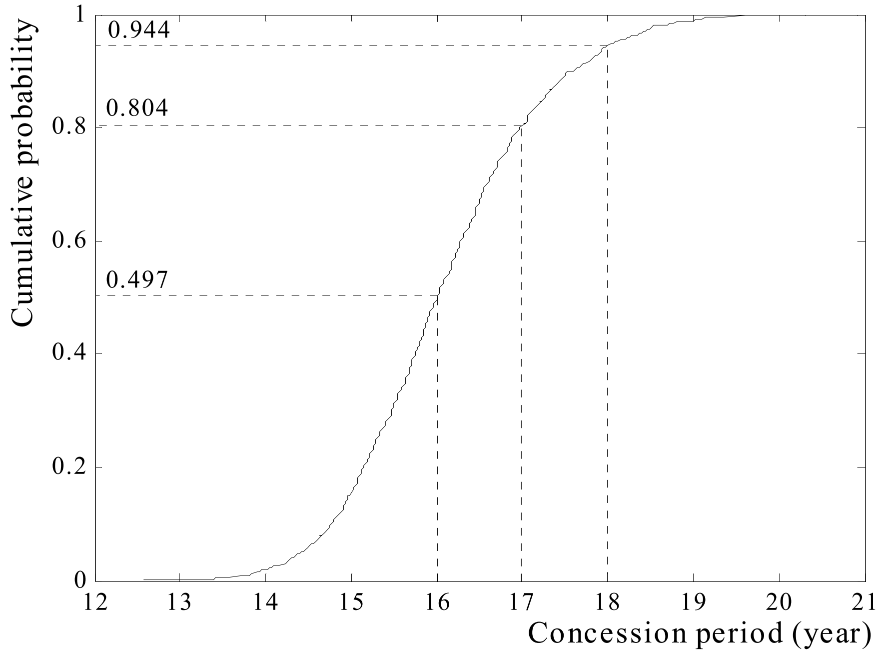

Figure 3: Simulated frequency distribution of the concession period

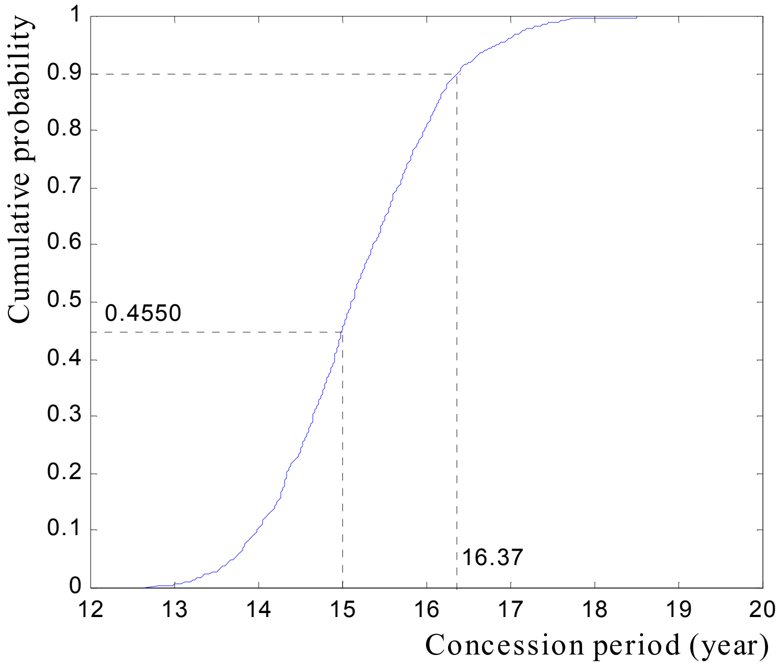

Figure 4: The cumulative probability curves of the concession period for scenario 1

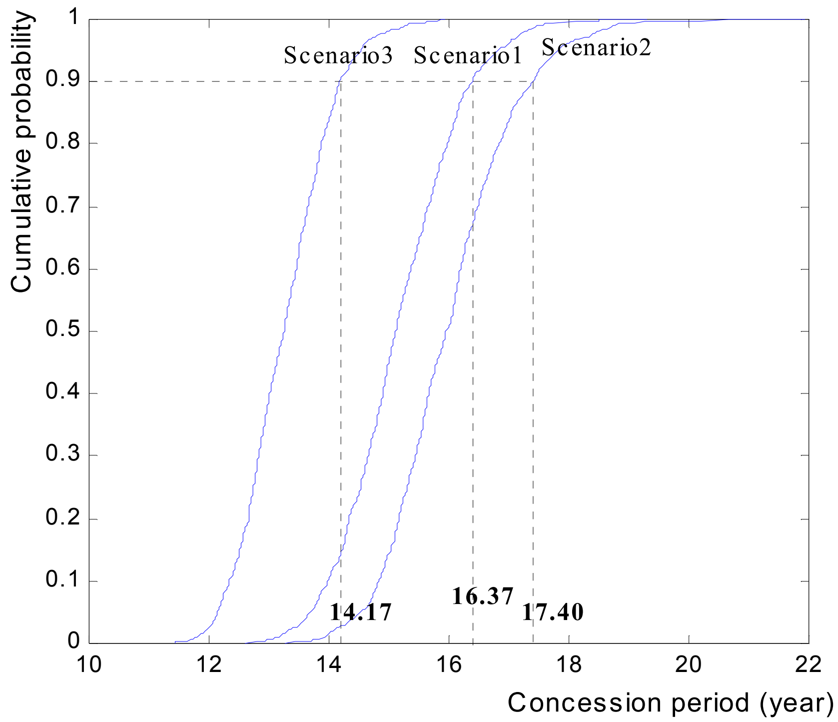

Figure 5: The cumulative probability curves of the concession period for the three scenarios

Table 1: Estimated traffic volume and basic tariff regime

Vehicle type	***Estimated number of vehicles (million)***	***Estimated annual growth rate (%)***	***Basic toll rate per trip***
Cars/vans	0.8	5	10
Buses	0.6	4	20
Trucks	0.3	5	20
Motorbikes	0.6	5	2

Table 2: Concession items for the three scenarios

Scenario / ***Concession items***	***Scenario1***	***Scenario2***	***Scenario3***
IRR	13%	12%	14%
Tariff regime	T (data in Table1)	0.9*T	1.2*T
Concession period	16.37 Years	17.40 Years	14.17 Years

Table 3: Degree of membership matrix for the three scenarios

A / X	*Scenario1*	*Scenario2*	*Scenario3*
IRR	0.42	0.33	0.50
Tariff regime	0.50	0.70	0.30
Concession period	0.58	0.51	0.72