# Win–Win Concession Period Determination Methodology

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**Abstract:** In infrastructure development through public-private partnerships (PPPs), governments worldwide often preset the concession period to a fixed length and then invite the private sector to bid on other aspects of the project. This practice has potential economic, financial, and social problems as shown in a case study of Hong Kong tunnel projects. To overcome these problems, this paper has proposed a win–win concession period determination methodology, in which PPPs are addressed as a principal-agent maximization problem. Both deterministic and simulation-based methods are provided to determine the concession period, with detailed step-by-step procedures. These methods take into consideration the financial characteristics of PPPs and the construction and operation requirements. In particular, the simulation-based approach combines the critical path method and Monte Carlo simulation technique in an effort to quantify construction and market risks for informed decision making. Furthermore, some issues related to the proposed methodology also have been discussed. These issues include (1) factors in determining a reasonable rate of return to the concessionaire's equity investment; (2) advantages and disadvantages of rate of return regulation; (3) concession period as a tender evaluation criterion; (4) efficiency check of the concessionaire's cost performance; (5) workable pricing mechanism; and (6) a practical approach to establishing statistical construction cost/duration distributions.

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## Introduction

Public-private partnerships (PPPs) are contractual relationships between public and private sectors. There are two main partners in PPPs: a government client (the public partner, hereinafter referred to as the government) and a company or consortium (the private partner, hereinafter referred to as the concessionaire). The government awards a long-term contract (hereinafter referred to as the concession) to the concessionaire to design, build, finance, and operate an infrastructure project. The concessionaire fulfills these responsibilities and provides relevant services/products in return for payments either directly from the end users or indirectly from the government itself.

PPPs put the private sector into full play in a wide range of activities with long-term business opportunities. Consequently, PPPs have inherent incentives for the concessionaire to apply innovative methods and technologies and adopt life-cycle management strategies for improved efficiency and cost effectiveness. There is a broad spectrum of PPP models. For example, build–own–operate, build–operate–transfer (BOT), buy–build–operate, design–build–operate, and build–develop–operate have been deployed in the United States (USGAO 1999).

PPPs are a complicated approach to a long-term acquisition of public works and services. The design of concession period is crucial to financial viability of PPP projects, which involves the design of concession period structure, the determination of the concession length and incentive schemes (Ye and Tiong 2003). Many challenges and problems have been encountered due to unforeseen risks and uncertainties over a long concession period. Correspondingly, PPP practices need to be continuously improved drawing on past experience and lessons. One case in point is the common international practice in concession period determination for BOT projects, in which the government usually presets the concession period to a fixed length, requests the concessionaire to bid for tolls and other project aspects, and guarantees the concessionaire a certain level of internal rate of return on equity (IRRE) over this fixed concession period. For example, the first eight design–build–finance–operate roads in the United Kingdom (Highways Agency 1997) and the five BOT tunnel projects in Hong Kong (Zhang and Kumaraswamy 2001) all have a 30-year government-preset concession period.

The practice of a fixed-term concession and an auction based on bids for tolls and other project aspects does not generally lead to an efficient selection of concessionaires. This practice also induces the frequent failure or renegotiation of concession contracts (Gustavo and Rus 2004). For example, the BOT experience in Hong Kong (discussed in the following sections) has shown potential financial, economic, and social problems of the common international practice of presetting the concession period without sufficient justification. There is a need for the government to develop a methodology for informed concession period determination to overcome these problems. In this regard, Engel et al. (2001) have suggested the least-present-value-of-revenue method to determine the concession period of toll roads so that the concession period is adjusted endogenously to demand realization. Gustavo and Rus (2004) have proposed a concession mechanism based on a flexible-term contract and bidimensional bids for total net revenue and maintenance costs. Its main idea is to isolate concessionaires from revenue uncertainty by automatically ad-

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**Table 1.** BOT Tunnels in Hong Kong

| Tunnel | Length (m) | Design average daily traffic | Construction period (months) | | Cost (HK$ million) | Debt-to-equity ratio |
|---|---|---|---|---|---|---|
| | | | Planned | Actual | | |
| Cross Harbor Tunnel | 1,852 | 90,000 | 47 | 36 | 356 | 65:35 |
| Tate's Cairn Tunnel | 4,000 | 100,000 | 37 | 34 | 2,150 | 70:30 |
| Eastern Harbor Crossing | 2,255 | 90,000 | 42 | 37.5 | 4,400 | 75:25 |
| Western Harbor Crossing | 2,000 | 120,000 | 48 | 44 | 7,500 | 70:30 |
| Route 3 Country Park Section | 3,800 | 140,000 | 38 | 36 | 7,250 | 65:35 |



justing the term of the concession according to effective demand. The basic principle is that the concession period should be long enough to enable the concessionaire to recover its investments and earn a reasonable return over that period (Smith 1995).

Addressing PPPs as a principal-agent maximization problem, this paper has proposed a win–win concession period determination methodology to safeguard the multiple interests of the public sector and the profit-making interest of the private sector. Both deterministic and simulation-based approaches are provided, with detailed step-by-step procedures.

## BOT Experience and Lessons in Hong Kong

Since the 1960s, five large BOT tunnel projects have been developed in Hong Kong. They are Cross Harbour Tunnel (CHT), Eastern Harbour Crossing (EHC), Tate's Cairn Tunnel, Western Harbour Crossing (WHC), and Route 3 Country Park Section. The first one, the CHT, already completed its 30-year concession period and was transferred to the Hong Kong Government (HKG) in 1999. Some basic information of the five tunnels is provided in Table 1.

### Preset Fixed Concession Period

The HKG has predetermined the concession of each of the five BOT tunnels to be 30 years and specified this as a "must" criterion to be satisfied by the concessionaire. Then, it invites the private sector to bid on other aspects of the BOT tunnel and consequently evaluates the potential concessionaire through a multicriterion evaluation method. For example, in WHC, three-package criteria are used: (1) financial and general; (2) land and engineering; and (3) operation and transportation. Each package contains several subpackages and each subpackage contains a number of criteria. As shown in Table 2, the packages and subpackages are assigned weights and the individual criteria are assigned maximum achievable score points to reflect their relative importance.

**Table 2.** Evaluation Criteria for Western Harbor Crossing

| Main package criteria | Weights (%) | Subpackage criteria | Weights (%) |
|---|---|---|---|
| I. Financial and general assessment | 60 | 1. The consortium (strength, experience, corporate/ financial structure) | 20 |
| | | 2. Financial proposals | 20 |
| | | 3. Toll regime | 30 |
| | | 4. The timetable | 15 |
| | | 5. Impact on the government | 15 |
| | | Subtotal (1–5) | 100 |
| II. Engineering assessment | 20 | 1. Environmental proposals | 12 |
| | | 2. Construction and program | 14 |
| | | 3. Security | 4 |
| | | 4. Consortium ability | 16 |
| | | 5. Utilities and drainage | 7 |
| | | 6. Land issues | 5 |
| | | 7. Immersed tube | 18 |
| | | 8. Structures | 10 |
| | | 9. Quality | 14 |
| | | Subtotal (1–9) | 100 |
| III. Operation and transport planning assessment | 20 | 1. Highway layout and design | 20 |
| | | 2. Traffic Engineering | 20 |
| | | 3. Electric and mechanical systems | 20 |
| | | 4. Tunnel operation | 20 |
| | | 5. Transport planning | 20 |
| Total weights of main packages | 100 | Subtotal (1–5) | 100 |



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**Table 3.** Comparison of Required Minimum Net Revenue and Actual Net Revenue

| Revenue (HK$ million) | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | Cumulative |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum net revenue | 154 | 201 | 253 | 506 | 713 | 794 | 880 | 1,190 | 1,455 | 1,549 | 7,695 |
| Actual net revenue /(loss) | (208) | (52) | 59 | 172 | 299 | 325 | 400 | 492 | 567 | 658 | 2,712 |
| Shortfall | 362 | 253 | 194 | 334 | 414 | 469 | 480 | 698 | 888 | 891 | 4,983 |

The five BOT tunnels have been going well in general so far. Nonetheless, there are still some financial, economic, and social problems. These problems are partly because of the practice of presetting the concession period without sufficient financial and economic justification. In particular, all of the five tunnels have been fixed at the same duration of 30 years even though the physical length, design capacity, traffic demand, construction time, construction cost, complicity of construction, and financial instruments deployed are quite different one tunnel from another. These problems are discussed in the following based on the experience of the three alternative harbor crossings, CHT, EHC, and WHC.

## *Contrasting Financial Status*

### Cross Harbor Tunnel

The CHT was financially very successful and the concessionaire had obtained huge profits over the concession period. One indicator is that it paid all debt off within 5 years of operation, whereas it was predicted that the debt would be paid off between the 10th and 19th year of the concession. This financial success was mainly due to three reasons. First, the actual traffic demand had been much higher than that expected. The CHT reached its predicted average daily traffic (ADT) of 40,000 vehicles after one year of operation, and exceeded its design ADT of 90,000 vehicles in 1980s. Thereafter, the CHT had borne an annual ADT of 100,000–120,000 vehicles. Second, the interest rates used in the financial analysis were 6–8%, whereas the actual rates were just around 5%. Third, there were two devaluations of sterling in 1967 and 1976. This made the repayment of the sterling-denominated debt much easier by the local currency, Hong Kong dollars.

### Eastern Harbor Crossing

The actual annual toll revenue of the EHC has been less than the predicted values since its opening in 1989 due to the lower-than-expected traffic flow. The ADT was forecasted to be 40,000 vehicles upon opening, whereas the actual ADT was merely 20,800 vehicles. The 2002–2006 5-year ADT average is 68,607 vehicles, whereas the design ADT is 90,000 vehicles. Two toll increases were implemented in 1998 and 2005, which had improved the financial situation. For example, the annual toll revenue rose by 21% following the 2005 toll increase. However, as of the end of 2006, the IRRE is only 11.3%, still much lower than the perceived "reasonable" rate of 15–17% (New Hong Kong Tunnel Company Limited 2006, 2007).

**Table 4.** Average Daily Traffic (2004–2006)

| Year | CHT | EHC | WHC |
|---|---|---|---|
| 2004 | 122,000 | 73,000 | 39,000 |
| 2005 | 123,000 | 64,000 | 41,000 |
| 2006 | 124,000 | 61,000 | 44,000 |

### Western Harbor Crossing

The financial status of the WHC has been much worse than that was predicted. It was estimated that the ADT would be 85,000 vehicles at the early stage of the concession and that the ADT would ultimately grow to 120,000 vehicles. This is in sharp contrast to the actual ADT that has fallen short of these estimates. The ADT was only 22,000 vehicles in 1997 and rose to 44,000 vehicles in 2006. Consequently, as shown in Table 3, there has been an annual net revenue shortfall from 1998 to 2007 of the minimum net annual revenue required for the concessionaire to obtain a reasonable IRRE. The total cumulative net revenue shortfall over this period is HK$4,983 million (Western Harbor Tunnel Company Ltd. 2007). The WHC concessionaire has decided to increase tolls for different categories of vehicles with effect from January 2008 although the HKG has urged it to take into account the public interests, affordability and the acceptability in adjusting the tolls.

## *Uneven Traffic Distribution among Three Harbor Crossings*

The three harbor crossings compete with one another for users. The traffic distribution among them has been seriously uneven. For example, as shown in Table 4, the 2004–2006 3-year ADT average of the CHT strongly contrasts to that of the EHC and to that of the WHC over the same period. The average ADT of the CHT is 123,000 vehicles (36.67% higher than its design ADT), whereas that of the EHC is only 66,000 vehicles (26.67% less than its design ADT) and that of the WHC is only 41,333 vehicles (65.56% less than its design ADT).

Two main factors might have led to this seriously uneven traffic distribution. One is the less convenient locations of the EHC and WHC than that of the CHT. The other is the sizable toll differences between the three harbor crossings. As shown in Table 5, for the a same category of vehicles, the EHC's toll is substantially higher than that of the CHT and the toll of the WHC is considerably higher than that of the EHC.

**Table 5.** Toll Comparison as of July 2007 (HK$)

| Vehicle type | CHT | EHC | WHC |
|---|---|---|---|
| Motorcycle | 8 | 13 | 40 |
| Private car | 20 | 25 | 80 |
| Taxi | 10 | 25 | 80 |
| Light bus | 10 | 38 | 90 |
| Light goods vehicle | 15 | 38 | 120 |
| Medium goods vehicle | 20 | 50 | 165 |
| Heavy goods vehicle | 30 | 75 | 245 |
| Single-deck bus | 10 | 50 | 90 |
| Double-deck bus | 15 | 75 | 130 |
| Extra axle | 10 | 25 | 80 |



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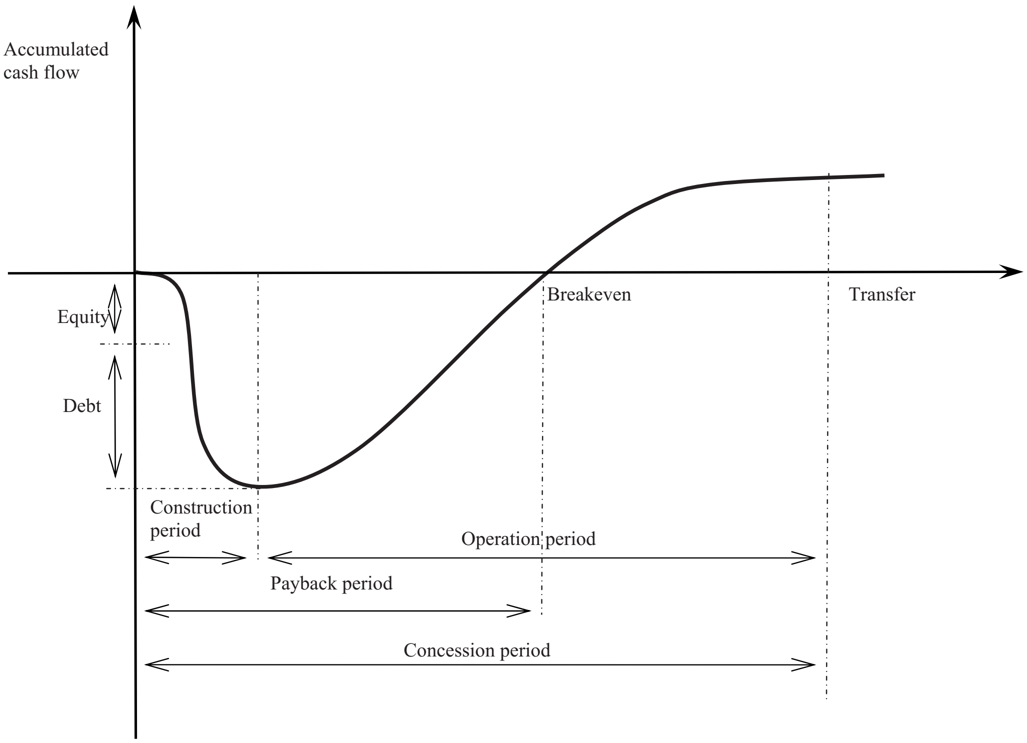


**Fig. 1.** Typical cash flow profile of a BOT project

### *Economic and Social Problems*

The uneven traffic distribution creates problems of congestion at the CHT and on its adjacent roads and junctions. In contrast, the EHC and WHC have been underutilized. Toll increases at the EHC and WHC have further worsened this situation. For example, the 2005 toll increase of the EHC resulted in a 15.9% drop of traffic through it. In addition, these sharp toll increases (e.g., the 2005 EHC toll increase by 62.5% for all categories of vehicles) have caused social problems of public affordability and acceptability, and affected people's livelihoods. For example: (1) some motorists changed to public transport or cancelled vehicular trips; (2) a district council member asked legal experts to study the possibility of filing a lawsuit in the court to stop the toll increase at the EHC; and (3) some legislators called on the HKG to take full control of all tunnels in the future rather than relying on the private sector, claiming that the toll variation mechanisms of the EHC and WHC have worked against the public interest (Ng 2005).

### *Potential Need to Modify Original Concession Agreement*

There are public pressures on the HKG to take measures to achieve economic utilization of the three harbor crossings and to maintain an integrated and coordinated transport pricing system (Legislative Council Panel on Transport 2007). In particular, there is an urgent need to divert some traffic away from the severely congested CHT to the contrastingly underutilized WHC. Correspondingly, the HKG has enhanced the accessibility to the EHC and WHC. For example: (1) new road links to the WHC have been built to smooth traffic flow at nearby road junctions and (2) road markings and more directional signs have been provided to guide motorists to the WHC. However, these measures are still not effective to attain a balanced traffic distribution. This is mainly because of the large differences of tolls between the three harbor crossings. It is necessary to reduce the tolls at the EHC and WHC in order to divert some traffic from CHT to EHC and WHC. However, experience has shown that reducing tolls will result in lower annual toll revenues of the EHC and WHC concessionaires, which have already been suffering from lower annual revenues than those required for them to obtain a reasonable return. To resolve the conflict of the need of a balanced traffic distribution with the need of a reasonable return to the concessionaire, the HKG has been negotiating with the concessionaires to explore measures that safeguard the interests of both parties. For example, it may be necessary to increase the concession period of the EHC and WHC simultaneously reducing their toll levels.

## Concession Period Defined on Win–Win Principle

In view of the financial, economic, and social problems encountered in Hong Kong BOT tunnels, this paper has proposed an improved mathematical definition of the concession period and the corresponding deterministic and simulation-based techniques to determine it. This allows informed governmental decision making in concession period determination.

### *Financial Characteristics of PPP Infrastructure Projects*

A PPP infrastructure project usually involves a large amount of financial capital (equity and debt) to be arranged by the concessionaire to build the facilities associated with the project. This huge capital construction cost is intended to be recovered through revenues from the service/product provided by the project in the future operation period. The typical cash flow profile of a BOT project is shown in Fig. 1.



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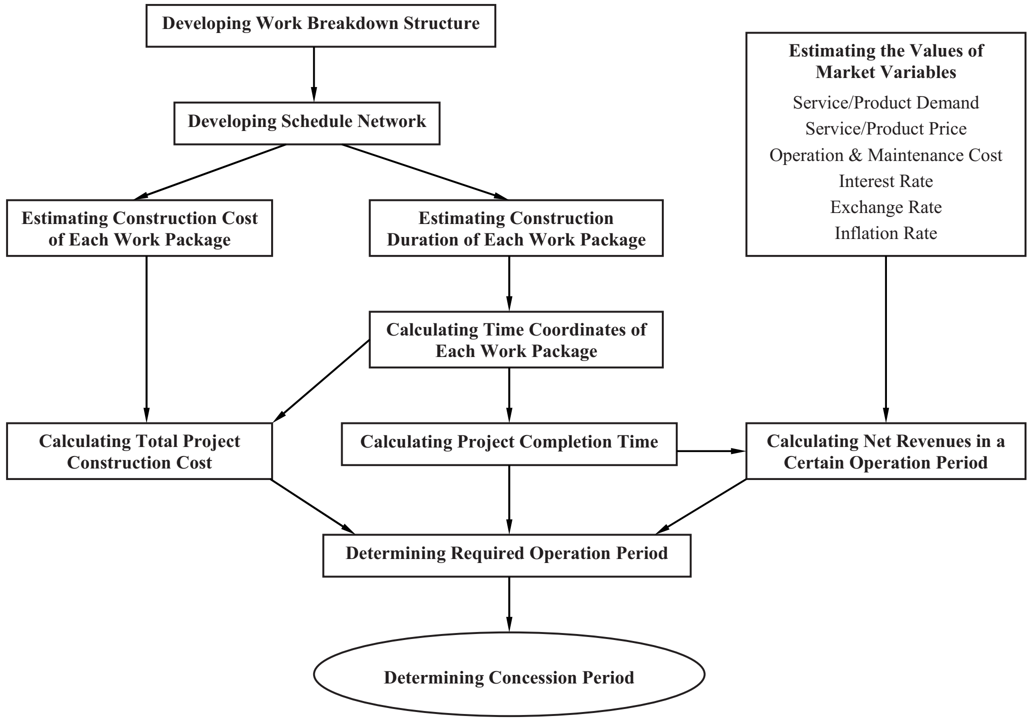


**Fig. 2.** Deterministic concession period determination methodology

### Public-Private Win–Win Principle

PPPs are a principal-agent maximization problem, in which the principal is the government and the agent is the concessionaire. Successful solution to a principal-agent maximization problem has to satisfy two constraints (Laffont and Martimort 2001): participation constraint and incentive compatibility constraint. Essentially, satisfying the two constraints requires a win–win approach. In the context of PPPs, on the one hand, the participation constraint requires that the concession should be long enough to allow the concessionaire to obtain a reasonable IRRE. Otherwise, investors will withdraw from this project and turn to other more profitable opportunities. On the other hand, the incentive compatibility constraint requires that the concessionaire acts in the interest of the government. For example, the concessionaire may be required to (1) continuously improve efficiency, cost effectiveness and service quality; (2) sustain a stable and public-affordable price regime; and (3) transfer excessive profits to the government.

### Win–Win Definition of Concession Period

PPP infrastructure projects involve a construction phase and an operation phase. In practice, either a single-period concession structure or a two-period concession structure is used (Ye and Tiong 2003). In the former, the concession period is fixed no matter whether the project is completed ahead of or behind the construction schedule. In the two-period structure, the length of the operation phase is fixed, but that of the construction phase is variable depending on the actual project completion time. In this paper, the single-period concession structure is adopted in view of its incentive to encourage early project completion and early opening to the public. The concessionaire benefits from increased revenues due to a longer operation phase when the project is finished earlier or suffers from reduced revenues because of less operation time when it is delayed.

Taking into consideration of the (1) financial characteristics; (2) win–win principle; and (3) the early-completion incentive of the one-period concession structure, concession period $T$ may be mathematically defined as

$$T = T_c + T_o \tag{1}$$

where $T_c$, $T_o$ and $T$ should satisfy the following conditions:

$$T_c \leqslant T_c^{\max} \tag{2}$$

$$T_o \leqslant T_o^{e} \tag{3}$$

$$R_T = R_a \tag{4}$$

where $T_c$=project completion time (total project construction duration); $T_o$=operation period; $T_c^{\max}$=maximum allowable project completion time; $T_o^e$=designed economic operation life of the project; $R_T$=IRRE calculated based on cash flows over concession period $T$; and $R_a$=reasonable IRRE as agreed on by the government and concessionaire in the bidding and negotiation stage.

## Deterministic Concession Period Determination Methodology

Based on the above-mentioned definition [Eqs. (1)–(4)], a deterministic methodology as shown in Fig. 2 is developed to determine concession period $T$. Some details of the methodology are provided in the following.

### Developing Project Work Breakdown Structure

A work breakdown structure (WBS) is a progressive hierarchical breakdown of a project into smaller and smaller work packages to



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the lowest practical level to which time and cost schedules are applied. Therefore, each work package is a deliverable product of the project. The WBS facilities project planning in terms of refining the project scope, sequencing work activities and estimating the construction duration and cost of each work package. It also enhances time and cost monitoring and control during the construction stage. In developing the WBS, the guidelines as provided by Project Management Institute (2000) may be followed.

### *Estimating Work Package Construction Cost and Duration*

Each work package is a cost center. Its cost can be estimated based on the historical data of same or similar types of projects and/or on expert knowledge. Different cost estimating methods may be used. The decision of which one to use is a trade-off between accuracy required and the cost incurred to obtain this accuracy. For a standard and straightforward work package, a less-costly and time-saving unit pricing method is normally acceptable in providing sufficiently accurate estimates. Unit pricing values may be obtained from standard estimating references such as R. S. Means Company's *Building Construction Cost Data* and F. R. Walker's *The Building Estimator's Reference Book*. For a unique work package for which unit pricing data may not be available or a special work package that is cost sensitive, a resource enumeration method as discussed in Halpin (2006) is more desirable.

In the process of estimating the cost of a work package, the quantity of this package and the production rate of the resource group deployed to carry it out would have been derived. Consequently, the construction duration of this work package can be calculated by dividing the quantity of this work package by the production rate of the resource group deployed.

### *Calculating Work Package Time Coordinates*

A schedule network (either an activity on node diagram or an activity on arrow diagram) can be established based on the WBS. Then, a schedule analysis can be performed using the idea of the critical path method (CPM). Through forward pass and backward pass calculations, the time coordinates (start and finish times) of each work package can be derived.

### *Calculating Project Completion Time*

The project completion time $T_c$ is the early finish time or later finish time of the last work package (early finish time=late finish time for this package) in the schedule network. Further, there is a need to check whether Eq. (2) is satisfied. If this condition is not satisfied, additional resources (e.g., labor and equipment) need to be deployed and the project plan and schedule adjusted so that Eq. (2) is satisfied.

### *Calculating Total Project Construction Cost*

The construction cost incurred in each year of the construction period can be determined based on the estimated construction cost and the start and finish times of each work package. This means that the construction cost in a year is the summation of all costs of all work packages or part of them that are carried out in that year. For simplicity, it is assumed that the construction cost of a work package is evenly distributed over its construction duration. Then, the net present value (NPV) of the total project construction cost can be calculated using the following equation:

$$\mathrm{NPV}_c = \sum_{i=1}^{T_c} \frac{C_i}{(1+R)^{i-1}} \tag{5}$$

where $\mathrm{NPV}_c$=NPV of total project construction cost; $C_i$=project construction cost in year $i$, which is the summation of the costs incurred in year $i$ for all packages; $R$=discount rate; and $T_c$ =project completion time.

### *Calculating Net Revenues in a Certain Operation Period*

The NPV of the net revenues in the operation period can be calculated as follows:

$$\mathrm{NPV}_o = \sum_{j=T_c+1}^{T_c+T_o} \frac{\mathrm{NCF}_j}{(1+R)^j} = \sum_{j=T_c+1}^{T_c+T_o} \frac{Q_j P_j - \mathrm{OM}_j}{(1+R)^j} \tag{6}$$

where $\mathrm{NCF}_j$=net cash flow (NCF) in operation year $j$; $\mathrm{NPV}_o$ =NPV of NCFs over the operation period; $Q_j$=service/product demand in operation year $j$; $P_j$=price of a unit of service/product in operation year $j$; and $\mathrm{OM}_j$=operation and maintenance cost in operation year $j$.

### *Determining Operation Period*

The IRRE over concession period $T$ should be equal to the predetermined reasonable rate $R_a$. This means that the NPV of the project cash flow over the concession period is equal to zero at the discount rate of $R_a$. In other words, $\mathrm{NPV}_o$ is equal to $\mathrm{NPV}_c$ at the discount rate of $R_a$. Therefore, operation period $T_o$ can be found by solving the following equation:

$$\mathrm{NPV}_o = \mathrm{NPV}_c \tag{7}$$

that is

$$\sum_{j=T_c+1}^{T_c+T_o} \frac{Q_j P_j - \mathrm{OM}_j}{(1+R_a)^j} = \sum_{i=1}^{T_c} \frac{C_i}{(1+R_a)^{i-1}} \tag{8}$$

If the value of $T_o$ that satisfies Eq. (3) cannot be found through Eq. (8), this means that the project is not financially viable. This problem may be addressed by different approaches, for example, through the increase of the service/product price or by government subsidies for insufficient revenues of the concessionaire in the operation period.

### *Determining Concession Period*

Once $T_c$ and $T_o$ have been derived through the previously mentioned procedures, concession period $T$ can be determined by adding up $T_c$ and $T_o$.

## Simulation Approach to Concession Period Determination

### *Need to Quantify Construction and Market Risks*

Concession period $T$ is a function of a set of variables including $C_i$, $T_c$, $Q_j$, $P_j$, and $\mathrm{OM}_j$. These variables in turn are influenced by many other factors in the construction and operation phases. In



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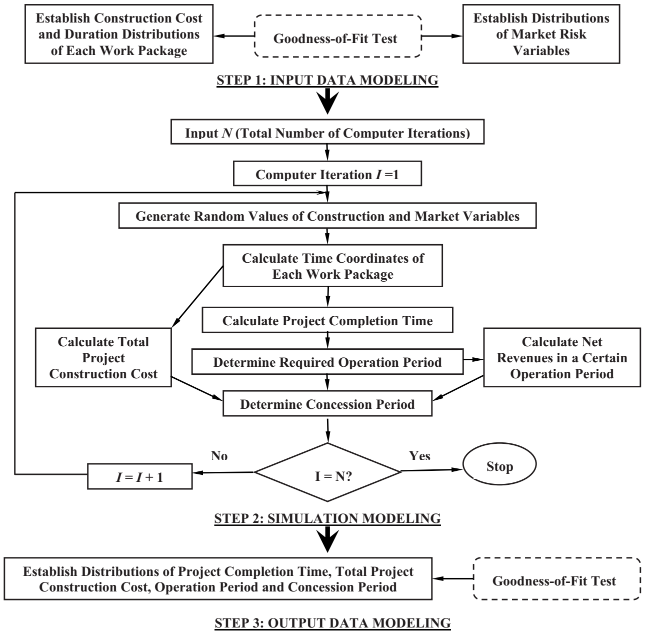


**Fig. 3.** Simulation-based concession period determination methodology



the construction phase, factors such as adverse weather conditions, design changes, and inflation of labor, material and equipment costs may significantly impact the values of $C_i$ and $T_c$. This is referred to in this paper as the construction risk. In the operation phase, factors such as economic conditions, market competition, inflation, technological advancements, substitute services/products, and change of the public needs may substantially influence the values of $Q_j$, $P_j$ and $\mathrm{OM}_j$. This is referred to in this paper as the market risk. It is very important to quantify these risks, particularly where (1) the scope of the project has not been clearly defined, (2) the project finance is high-leveraged, (3) construction works are very complex, and (4) the service/product demand in the operation phase is very difficult to predict. A computer simulation approach is taken in this paper to model construction and operation processes as stochastic ones that follow certain statistical distributions. The main idea of this simulation approach is illustrated in Fig. 3 and discussed in the following.

### Input Data Modeling

Estimating statistical distributions of random variables is a common approach to risk measurement and management. These distributions allow generalized analysis, modeling and inference of risks. The main objective of input data modeling is to establish the statistical distributions of key construction and market risk variables that affect the concession period. These risk variables include the construction cost and duration of each work package in the schedule network, service/product demand, inflation rate, interest rate, currency exchange rate (if foreign currency is utilized), and OM cost. Sample data of these variables can be obtained from historical data of similar projects and/or from national or regional statistics.

Establishing the statistical distribution of a risk variable involves selecting a plausible theoretical distribution function (TDF), estimating its defining parameters, and evaluating the similarity between the empirical distribution function (EDF) and the TDF (Haschenburger and Spinelli 2005). First, the EDF of a risk variable, denoted by $F_n(x)$, can be determined based on the order statistics $X_{(1)} < X_{(2)} < \cdots < X_{(n)}$ that is derived from a random sample of historical data $X_1, X_2, \ldots, X_n$ as follows:

$$F_n(x) = \begin{cases} 0, & x < X_{(i)} \quad (9) \\ i/n, & x \leq X_{(i)}, \quad i = 1, \cdots, n-1 \quad (10) \\ 1, & x \leq X_{(n)} \quad (11) \end{cases}$$

Second, the histogram of this variable can be plotted based on its EDF to visualize the sample data distribution, detect outliers and propose a TDF. Transformation of the sample data may be carried out if necessary. Zhang (2005) has listed some commonly used TDFs. In the selection of a TDF for a risk variable, the nature of its sample data needs to be considered. Third, probability plots and quantile–quantile plots can be deployed to check whether the EDF matches the TDF. This is done by examining whether the points on the plot form a linear pattern. Fourth, goodness-of-fit test statistics can be calculated to further examining the similarity between the EDF and TDF. This is done by testing the null hypothesis that the sample data of the risk variable are a random sample from its specified TDF. Goodness-of-fit test statistics include Pearson chi-square, Shapiro–Wilk, Kolmogorov–Smirnov, Anderson–Darling, and Cramer–von Mises statistics.

### Simulation Modeling of Project Completion Time

The CPM assumes a deterministic value for all activities in the schedule network. To overcome this limitation in addressing risks and uncertainties, the Monte Carlo simulation (MCS) technique is combined with the CPM. This is hereinafter referred to as the CPM–MCS method. The basic idea of the CPM is still applied to calculate project completion time $T_c$. In particular, in each computer iteration, the CPM–MCS method first simultaneously generates random values for the construction durations of all work packages using their statistical distributions as established in input data modeling. Then, it calculates the start and finish times and the floats of all work packages, and the project completion time for this iteration. A great number of computer iterations can be carried out by repeating this process. Finally, the statistical distribution of project completion time $T_c$ can be derived based on the sample data randomly generated in this great number of iterations. Once the distribution of $T_c$ is known, $T_c$ at a particular percentile can be calculated.

### Simulation Modeling of Total Project Construction Cost

In each of the aforementioned computer iteration, the CPM–MCS method also randomly generates values of the construction costs of all work packages in the schedule network and values of other risk variables (e.g., interest rate, exchange rate, and inflation rate) using their established distributions. The randomly generated values of risk variables allow the calculation of the NPV of the construction cost of each work package based on its start and finish times. Consequently, $\mathrm{NPV}_c$ for this iteration can be calculated. Therefore, the statistical distribution of $\mathrm{NPV}_c$ can be established by a large number of computer iterations and $\mathrm{NPV}_c$ at a particular percentile calculated according to this distribution.

### Simulation Modeling of Operation Period

In each iteration, the CPM–MCS method also randomly generates values for $Q_j$, $P_j$, and $\mathrm{OM}_j$ in addition to the values for the con-



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struction durations and costs of all work packages and the values for interest rate, exchange rate, and inflation rate. These random values allow the calculation of $T_o$ for this iteration via Eq. (8). Therefore, the statistical distribution of $T_o$ can be established by a large number of iterations and $T_o$ at a particular percentile can be derived from this distribution.

### *Simulation Modeling of Concession Period*

In each iteration, the value of $T$ is calculated by adding $T_c$ and $T_o$. Therefore, the statistical distribution of $T$ can be established based on its values of a large number of iterations. It may be reasonably assumed that $T$ follows a normal distribution with mean $\mu_T$ and standard deviation $\sigma_T$. $\mu_T$ and $\sigma_T$ are the sample mean value and sample standard deviation of the randomly generated values of $T$ in a great number of iterations. $T$ corresponding to a specific percentile can be calculated based on this established distribution.

## Discussions on Some Issues of the Proposed Methodology

### *Reasonable IRRE*

To determine a reasonable IRRE for a PPP project, three factors need to be considered: (1) the cost of capital to the industry to which the project belongs; (2) the scope and severity of risks involved in the project; and (3) the rates of return (ROR) of same or similar type of projects in the current and future markets. For example, the IRRE for the WHC is set at 15–16.5% for the first three years of operation and at 15–18.5% for the remaining years of the concession in view of the ROR of similar projects in the Asia–Pacific region.

### *Advantages and Disadvantages of Rate of Return Regulation*

The win–win definition of concession period discussed in a previous section allows the concessionaire to obtain a reasonable rate of return as defined by Eq. (4). This in essence adopts a ROR regulation of PPP projects. The advantages of ROR regulation are that it enables necessary but risky infrastructure projects to be developed and that it usually leads to a low cost of capital. However, under ROR regulation, the concessionaire lacks incentives for efficiency (Averch and Johnson 1962; Burns and Estache 1999) in terms of (1) reducing capital expenditure and OM costs; (2) overcapitalization—the concessionaire tends to overinvest when the ROR of the PPP project is higher than that of alternative investment options; (3) gold-plating—to supply too high a level of service that is more than necessary; and (4) demanding information required to assess the actual ROR, which may be a regulatory burden on the government.

### *Concession Period as a Tender Evaluation Criterion*

The government may use concession period as a tender evaluation criterion for potential concessionaires to bid for instead of prefixing it for all concessionaires. The concessionaire needs to consider two aspects in determining a competitive concession period. One aspect is cost estimating, which includes construction cost and OM cost. The other aspect is the pricing strategy in order to recover costs through revenues to be generated in the operation period. Similarly, the government would examine the two aspects of each concessionaire against the concession period criterion in tender evaluation. The government needs to evaluate whether the costs to be incurred by the concessionaire are efficient and whether the pricing mechanism proposed by the concessionaire is workable. These are discussed in the following.

### *Cost Efficiency*

Construction cost and OM cost are two major cost components of a PPP project. The incentive compatibility constraint requires that the concessionaire manages the project efficiently and effectively. Therefore, these costs should be efficient costs that are essential for the concessionaire to provide the required services at the specified quality. These efficient and essential costs are the basis on which to determine the required level of revenues to be generated in the operation period. This in turn determines the length of the concession for an appropriate price level of the service/product. This means that the concession period should be of a length over which the revenues are just sufficient to cover the efficient and essential costs with a reasonable IRRE.

The "efficiency check" of the costs incurred by the concessionaire may be done by benchmarking the costs of an efficient company that provides a same or similar service/product. Alternatively, the efficiency check may be done through a public sector comparator (PSC). The PSC is a hypothetical, risk-adjusted cost by the public sector as a supplier to a same output specification as provided by the concessionaire (Treasury Taskforce 2000). The PSC can be used as a means to test whether a PPP project demonstrates value for money, i.e., whether it achieves a better outcome than a traditional public procurement approach.

### *Workable Pricing Mechanism*

A workable pricing mechanism is critical to the achievement of win–win results. This argument is supported by the experience in the Hong Kong BOT tunnels where sharp toll increases have caused social problems of public affordability and acceptability and affected people's livelihoods. A workable pricing mechanism should (1) clearly define the cost structure that is necessary for the concessionaire to maintain the project at a required level of service in the operation period and to cover the initial construction cost; (2) clearly define the price structure of different categories of users; (3) develop a sound methodology to assess the impacts of main factors that affect the cost structure and revenue structure; (4) take into account the economic condition in the city or region where the project is located and the public affordability; and (5) integrate the project with other projects to achieve economic efficiency through a coordinated management.

For example, the price to be charged on a particular type of users in each year of the concession may be determined as follows:

$$P_t \leqslant P_{t-1}[1+f_t-x_t] \leqslant P_t^{\max}, \quad t=2,3,\ldots,T-1,T \qquad (12)$$

where $P_t$=price charged in year $t$; $f_t$=inflation in year $t$; $x_t$=efficiency improvement in year $t$; and $P_t^{\max}$=maximum public-affordable price in year $t$.

$P_1$ is determined based on the actual or estimated capital expenditure, predicted OM costs, predicted annual service/product demand, affordability of the users, and the reasonable IRRE as agreed on by the government and the concessionaire.

## Practical Approach to Establishing Statistical Construction Cost/Duration Distributions

A typical infrastructure project may involve numerous work packages. The computation demand in establishing the statistical distributions of construction cost and duration of each work package could be daunting. However, according to Pareto's Law (the law of "the significant few" and "the insignificant many"), only a few work packages are critical as far as the project's bottom-line cost/duration is concerned. Therefore, analytical efforts should be focused on estimating the statistical distributions of critical work packages. For noncritical work packages, there is no need to estimate their distributions. Instead, deterministic cost and duration values as those of the target values in a traditional estimate may be used.

The idea introduced by Curran (1989) may be deployed to identify critical work packages. A critical work package is one whose actual value may vary from its target (either favorably or unfavorably) by such a magnitude that the bottom-line cost/duration of the project would change by an amount greater than the critical variance. The critical variance is the threshold value of the maximum variation that is tolerated by decision makers (say, 2%) in the bottom-line cost/duration of the project caused by a variation in a single work package. The deciding factor in determining criticality is a work package's potential for variation rather than its magnitude. A work package that accounts for a very large portion of the bottom-line cost/duration of the project may not be critical if it has very little potential for variation, that is, its actual value cannot be sufficiently different from its target value to produce a bottom-line change that is greater than the critical variance. In contrast, a work package that accounts for a very small portion of the bottom-line cost/duration may be critical if it can vary from its target value by such a degree that the bottom-line change would be greater than the critical variance.

## Conclusions

There are potential financial, economic, and social problems associated with the common international practice of presetting the concession period to a fixed length and then inviting the private sector to bid on other aspects of the project. An informed concession period determination methodology is needed to improve governmental decision-making in this regard to avoid these problems.

As a principal-agent maximization problem, PPPs necessitate a public-private win–win approach to safeguard the multiple interests of the public sector and the profit-making interest of the private sector. Correspondingly, this paper provides a mathematical definition of the concession period. This definition takes into account the financial characteristics of PPP infrastructure projects, the win–win principle, the early-completion incentive of the one-period concession structure and the designed economic operation life of the project. Both deterministic and simulation-based concession period determination methods are provided with detailed step-by-step procedures. In particular, the simulation-based approach combines the CPM and Monte Carlo simulation technique, in which input data modeling is a critical step. Input data modeling establishes the statistical distributions of key construction and market risk variables that affect the concession period. These distributions allow generalized analysis, modeling, and inference of risks.

Allowing the concessionaire to obtain a reasonable IRRE enables necessary but risky infrastructure projects to be developed. This also leads to a low cost of capital. However, this approach has inherent efficiency problems such as overcapitalization, gold-plating, and demanding information required. In tender evaluation, the government needs to evaluate whether the costs to be incurred by the concessionaire are efficient and whether the pricing mechanism proposed by the concessionaire is workable.

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