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# A model for determining the optimal project life span and concession period of BOT projects

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**Abstract**

The concession agreement is the core feature of BOT projects, with the concession period being the most essential feature in determining the time span of the various rights, obligations and responsibilities of the government and concessionaire. Concession period design is therefore crucial for financial viability and determining the benefit/cost allocation between the host government and the concessionaire. However, while the concession period and project life span are essentially interdependent, most methods to date consider their determination as contiguous events that are determined exogenously. Moreover, these methods seldom consider the, often uncertain, social benefits and costs involved that are critical in defining, pricing and distributing benefits and costs between the various parties and evaluating potentially distributable cash flows. In this paper, we present the results of the first stage of a research project aimed at determining the optimal build-operate-transfer (BOT) project life span and concession period endogenously and interdependently by maximizing the combined benefits of stakeholders. Based on the estimation of the economic and social development involved, a negotiation space of the concession period interval is obtained, with its lower boundary creating the desired financial return for the private investors and its upper boundary ensuring the economic feasibility of the host government as well as the maximized welfare within the project life. The outcome of the new quantitative model is considered as a suitable basis for future field trials prior to implementation. The structure and details of the model are provided in the paper with Hong Kong tunnel project as a case study to demonstrate its detailed application.

The basic contributions of the paper to the theory of construction procurement are that the project life span and concession period are determined jointly and the social benefits taken into account in the examination of project financial benefits. In practical terms, the model goes beyond the current practice of linear-process thinking and should enable engineering consultants to provide project information more rationally and accurately to BOT project bidders and increase the government's prospects of successfully entering into a contract with a concessionaire. This is expected to generate more negotiation space for the government and concessionaire in determining the major socioeconomic features of individual BOT contracts when negotiating the concession period. As a result, the use of the model should increase the total benefit to both parties.


*Keywords:* Project management; Build-operate-transfer; Project life span; Concession period; Optimization

## 1. Introduction

The public sector is traditionally responsible for infrastructure development within its jurisdiction and is the sole financer of the projects involved. However, this form of procurement is becoming increasingly outdated due to a perceived over-reliance on public

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finance, soft budget constraints, deficiencies in managing financial risks, lack of user responsibility and inefficiencies in the construction and operation processes. It is against this backdrop that, since the 1980s, the private sectors of Western nations are increasingly participating in infrastructure development (Delorme et al., 1999; Bao, 2009).

The build-operate-transfer (BOT) contractual arrangement is today an important example of such participation. Here, the government provides the private investor/concessionaire with the specific concession period (for brevity, the terms 'private investors' and 'concessionaire' are used interchangeably). This period, termed the transfer point, is purposely set to enable the concessionaire to collect revenues by operating and maintaining the infrastructure involved before its transference back to the government (Levy, 1996) at the end of the period. The BOT model, therefore, provides an effective way of utilizing private funds in the provision of public infrastructure while affording the opportunity for the use of the innovative technologies, management skills and operational efficiencies possessed by private businesses (Shen et al., 2007).

The BOT approach makes an important contribution to the development of infrastructure both in developed and developing countries and a significant research effort has investigated the methods needed to help in its effective application. Most of this effort focuses on the identification and distribution of risks (e.g. Wibowo and Wilhelm Alfen, 2014), project pricing and finance arrangements (Yang and Meng, 2000; Devapriya and Pretorius, 2002), as well as sustainable organizational structures and characteristics (Lokiec and Kronenberg, 2003). Research has also been conducted on the methods and tactics involved in project financing (Smith et al., 2004) and still other studies investigating the role of government in BOT-led infrastructure development (e.g., Ye and Tiong, 2000; Kumaraswamy and Zhang, 2001; Wibowo and Wilhelm Alfen, 2014) in providing an important theoretical basis for their financing, pricing, managing and implementation.

The concession agreement is the core feature of a BOT project, with the concession period being the most essential feature in determining the time span of the various rights, obligations and responsibilities of the government and concessionaire, e.g. ownership and user rights (Qin, 2005; Khanzadi et al., 2012). Ye and Tiong (2010) conducted a systematical introduction of the concession period design, which includes the concession period structure, length of concession period and the incentive scheme. In this paper, the discussion of concession period particularly focuses on the 'length' rather than 'structure' or 'incentive scheme'. There are many studies of the BOT concession period length. Of these, two approaches are apparent: *descriptive research* and *analytical research*. *Descriptive research* is usually only to report what have been "observed"—aiming to identify the affect factors and their relationship with the concession period of a specific BOT project. For example, it is found that the concession period depends upon the negotiations between government and investors (Shen et al., 2002; Wang et al., 2008; Ye and Tiong, 2010). *Analytical research*, on the other hand, examines the internal mechanism about how the factors lead to the results—in this case aiming to explicate the decision-making methods for determining the concession period by quantitative analysis. Of the many treatments are asset pricing methods (Shen and Wu, 2005; Garvin and Cheah, 2004; Wu et al., 2011; Xu et al., 2012); fuzzy-Delphi related techniques (Ng et al., 2007; Islam and Mohamed, 2009; Mostafa et al., 2010; Shen and Wang, 2010; Khanzadi et al., 2012); the net present value (NPV) approach (Shen et al., 2002; Xu and Moon, 2013); bargaining game theory (Shen et al., 2007; Wang et al., 2011; Hanaoka and Palapus, 2012; Song et al., 2012); real option models (Ho and Liu, 2002; Huang and Pi, 2013); and simulation or programming enabled methods, such as genetic algorithm based time–cost tradeoff analysis (Li et al., 2010), web-based analysis (Zhang, 2011) and simulation with optimization programming (Lai, 2012). Some research deals with uncertainties in the determination of the concession period, e.g. through risk allocation (Carbonara et al., 2014; Wibowo and Kochendörfer, 2005), guarantees, compensation and penalties (Wibowo, 2004; Xiong and Zhang, 2014).

The basic economic consensus in analytical research concerns financial viability and the benefit/cost allocation between the host government and the concessionaire, much of which is addressed in the literature above. For example, Shen et al. (2002); Zhang (2011) and Fan et al. (2012) all argue that the concession period needs to be well designed to guarantee an attractive internal return rate for the concessionaire while meeting the budget constraints of the government, given the prediction of the cash flows occurring at different stages in the project life. However, most mechanism research methods to date consider the determination of the concession period and project life span as contiguous events that are determined exogenously. Bao and Wang (2010), however, criticize this by arguing that the concession period and project life span should be treated as interdependent, from both financial and social perspectives.

Moreover, analytical research methods have seldom considered the social benefits and costs in concession decision-making (e.g. Zhao and Tan, 2009; Bao and Wang, 2010), while it is well recognized that public works projects calculating only project financial outcomes is "absurd" (Foster and Beesley, 1963). The European PPP Expertise Centre reported on the assessment of the non-financial benefits of Public Private Partnership (PPP) projects, for example, highlighting the importance of incorporating non-financial benefits into the value for money analysis (EPEC, 2011). Consideration of social benefits and costs is critical in defining, pricing and distributing benefits and costs between the various parties and evaluating potentially distributable cash flows. Zhao and Tan (2009) extend the NPV approach to include the social benefit factor in the concession negotiation. Following their research, Bao and Wang (2010) propose a theoretical model to include social benefits and costs as well as incorporating the interdependency of the project life span and concession period in BOT contract formulations, and this paper is therefore motivated and developed from their work through model development and empirical validation.

The scope of the study here is to develop a comprehensive model for determining the concession period of a BOT project prior to soliciting bids from potential concessionaires, simultaneously taking into account project life span and associated net social benefits. This involves the consideration of the following issues to be covered in the next sections:

1. The inclusion of the concept of net social benefit;
2. The establishment of a new model for determining the concession period; and
3. A discussion of the impact of the uncertainty surrounding the total investment amount and net social benefits affected by the concession period decision.

The resulting model is described, explained and illustrated in the following sections. As will be seen, although the model presented is derived deductively, its founding assumptions are generally intuitively sound and provide a reasonable correspondence with what manifestly happens in practice. As demonstrated in the Case Study, unlike previous efforts, the model's structure represents a major step forward in encapsulating the major variables with real-life project data involved, including net social benefits, which have been conspicuously neglected hitherto. As observed later, this fulfills the main objective within the defined scope of the research, which is to develop such a model that is sufficiently well advanced to move forward as a precursor to eventual implementation.

## 2. Modeling process and assumptions

In general, BOT contracts are initiated by the government and entered into with the concessionaires upon completion of a bidding process. A BOT contract usually includes: the project property, project life span, construction period, total investment, expected return during operation period, operation and maintenance costs, concession period and the qualifications of the bidders.

The modeling process starts with the general public sector Benefit/Cost Analysis (BCA) model derived from welfare economics; and the typical private sector corporate finance capital investment evaluation (CIE) model, as generally modified for project financed/BOT-type infrastructure projects. These enable the evaluation of the cash flows occurring throughout the project life cycle, including the total investment involved in construction, operation and maintenance costs, net social benefits and toll income. Next, the NPV for both the government and concessionaire is calculated. Finally, the principle for determining the concession period interval is introduced.

The incentive structures for the BCA and CIE models are fundamentally different, which influences feasibility and the way benefits and costs are distributed, and frames the resulting cash flows and project evaluation by each sector. If the government decides to proceed with private sector participation after concluding a BCA, it has to consider which project benefits it can assign to the private sector in order to make it attractive for its participation.

The utilization of discounted cash flow, on the other hand, is common to both the BCA and CIE models. Public sector agencies ideally first determine if a (any) project is desirable through the conduct of a BCA based on a "social rate of return" for the particular economic activity, before considering BOTs or other procurement mechanisms that may include private sector participation. How clearly project benefits and costs are defined, priced and distributed between the various parties and how they translate into potentially distributable cash flows are therefore critical in BOTs. Of particular importance are the often-used additional incentives granted to private sector interests in BOT transactions (such as minimum revenue guarantees, taxation incentives, and the like), as these are not costless or resource-neutral to governments and are often hidden off-balance sheet.

Additionally, if a social cost emerges in the concession period, it may dramatically affect either party's benefit profile over the concession period, and the private sector may be allowed to socialize costs or bear them by itself. Also, if there is an unintended consequential benefit to the private sector, it may be expected to share this benefit only to the extent that it is contractually obliged to do so. However, of course, challenges exist in estimating social benefits and costs, and these are discussed in more detail below.

### *2.1. Optimal project life span and optimal concession period*

The project life span covers the construction and operation periods of the concessionaire and the government until the end of the project, and usually is a variable to be determined by the government. The optimal project life span,$T_f$, is defined as the ideal period such that, during $[0,T_f]$, the total benefit, including economic and net social benefits, is maximized. $\tilde{T}_f$ denotes the optimal concession period for the private concessionaire. This is the period during which $[0, \tilde{T}_f]$, the highest economic benefit of the project occurs, and enables the upper boundary of the negotiation space from the investors' perspective to be determined.

### *2.2. Length of construction period and amount of total investment*

Assume the length of the construction period is $T_0$. $T_0$ is influenced by the total investment in the construction period, the quality of construction and other contingencies. $I$ denotes total investment, which comprises the total construction cost occurring between the start of construction work and $T_0$.

### *2.3. Annual income during operation period, $Q_t$*

The annual income, $Q_t$, is mainly realized by collecting toll fees or facility service fees, i.e. $Q_t = q_t$ (the number of payment units per year) × $p_{t.}$ (the toll fee or service fee). Normally, the government requires $p_{t.}$ to be fixed or confined within a reasonable range. Following Shen and Wu (2005), the cumulative distribution of $q_t$ is assumed to follow a sigmoidal shape, the payments involved being much less in both the earlier and later stages of the project. In other words, the expected shape of $q_t$ resembles an inverted-U curve, reaching its acme when the project operation is experiencing a stable period.

### 2.4. Operation and maintenance cost, $C_t$

$C_t$ denotes the cost of managing operations and maintaining the facilities. A reasonable assumption is that the shape of $C_t$ is a U curve. Intuitively, in the early years of operation, $C_t$ decreases—as the operation and maintenance teams accumulate experience in keeping up the smooth operation and maintenance of the facilities—until reaching a stable period. The facilities depreciate over time and, after some years of stability, maintenance costs quickly increase.

### 2.5. Tax, λ

The private investors have to pay tax periodically on the net income, which is equivalent to $\lambda(Q_t - C_t)$, where λ is the tax rate. λ is considered to be 'constant' unless tax-favored conditions are included in the BOT concession contract.

### 2.6. Net social benefit, $V_t$

The development of infrastructure projects generally aims to generate social benefits for the local community and society. Riahi-Belkaoui (2004) argue that developing countries with a surplus of labor prefer infrastructure projects that are labor intensive and with a higher employment potential, compared with other projects that provide fewer employment opportunities. Profitability is an important factor affecting the social desirability of a project, making projects with higher profitability more preferable.

The measurement of social benefits includes the financial and non-financial benefits that society is likely to receive from the project (EPEC, 2011). Following the argument in EPEC (2011), social costs could be regarded as the opportunity costs of social benefits. The net social benefit is the difference between the two.

There are extreme complexities associated with the measurement of social benefits and their distribution over time. Although research into social benefits is still in its infancy, some (albeit imprecise) techniques have been initiated for adoption by companies or institutions in publishing social income statements or social impact reports to back up their investment decisions. EPEC (2011) categorize non-financial social benefits into three aspects of delivery speed, delivery quality and wider social impacts. The former two aspects can be measured financially by referring to the performance of similar projects, while the latter is more descriptive and is subjectively assigned with certain weights. Although lacking in rigor to some extent, this at least allows the formation of total weighted non-financial benefits. Therefore, the net social benefits in the model are obtained in two steps: 1) estimation of the social benefits of projects to local businesses; and 2) evaluation of the social impact and assignment of an appropriate weight.

### 2.7. Private sector financing

Ordinarily, the concessionaire involves several participants or companies. Their available initial investment is usually limited and other financing arrangements are necessary. It is assumed that the initial investment, $I_0$, accounts for α of the total investment $I$, which represents what may technically be considered as the equity investment (if the project is a separately incorporated entity, whether public or private) and reflects a periodic cash outflow as might be expected with servicing a debt over its term to maturity. According to existing BOT project practice in China, the government usually requires that $\alpha \geq 30\%$ (Wang et al., 2008). The remaining amount of construction investment is mainly raised by loans, which the concessionaire has to repay in a prescribed way. The return rate of the loan is denoted by $R$, which has a significant negative impact on NPV, i.e $-(1-\alpha)IR$.

### 2.8. Expected average return rate and investor's internal return rate

The expected average return rate, $R(t)$, is a time-dependent variable covering the period from the start of construction to a certain time $t$. The internal return rate, $R_1$, is the lowest return rate required by the concessionaire. Both in Shen et al.'s (2002) alternative concession model (ACM) model and Fan et al.'s (2012) optimal concession model, $R_1$ determines the lower boundary of the negotiation space of the concession period. Hence, $R(T_C) \geq R_1$, where $T_C$ denotes the concession period.

### 2.9. Interest rate

As with Fan et al. (2012), compound interest is used due to the long time span involved in most infrastructure projects. However, uncertainty surrounding future interest rates increases the risks involved. In order to clearly articulate the model, and without loss of generality, a simplified version is used in the illustrative example, where the interest rate is assumed to be fixed and all the data affected by time is discounted.

## 3. Determining the concession period

The government's focus is on total benefit, including both economic and net social benefits, occurring during the whole project life, so that

$$NPV_G\left(T_f\right) = -(1-\alpha)IR\text{-}I + \int_{T_0}^{T_f} (Q_t + V_t\text{-}C_t)dt. \quad (1)$$

The concessionaire is assumed to always focus on the economic benefits involved, so

$$NPV_G\left(\tilde{T}_f\right) = -(1-\alpha)IR\text{-}I + \int_{T_0}^{\tilde{T}_f} (1\text{-}\lambda)(Q_t\text{-}C_t)dt \quad (2)$$

where $T_f$ is the optimal project life span for the government and $\tilde{T}_f$ is the optimal concession period for the concessionaire. **(*1*)** and **(*2*)** differ in two respects. First, the time span in **(*2*)** is from $T_0$ to $\tilde{T}_f$, but from $T_0$ to $T_f$ in **(*1*)**. Second, the net social benefit is included only in **(*1*)**. As given, the two equations are expressed in continuous form. In discrete form, the integration sign is simply replaced by a summation sign.

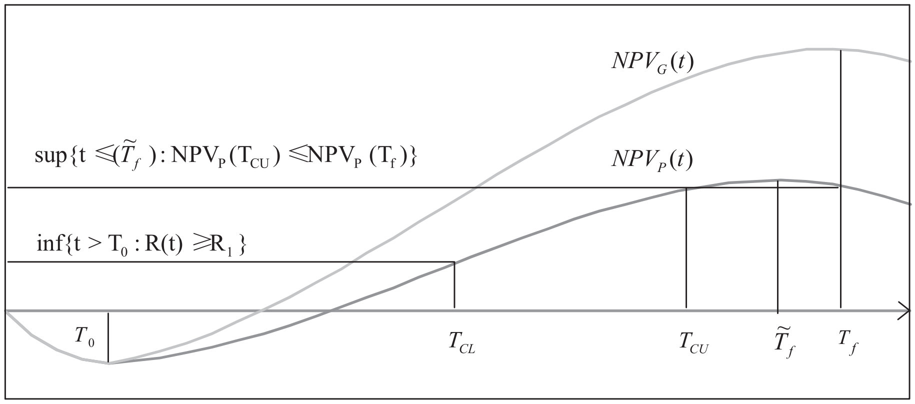


Fig. 1. NPV curves and determination of the concession period.

The derivative of NPV over time has an economic meaning. That is, the concessionaire (or the government) always benefits more by continuing with the BOT project, unless the marginal economic benefit (or total benefit) is less than or equal to 0. This leads to the formulation of $\tilde{T}_f$ (the optimal concession period for the concessionaire) and $T_f$ (the optimal project life span) as shown in Fig. 1 and

$$\tilde{T}_f = \inf\{t > T_0 : Q_t - C_t \leq 0\} \tag{3}$$

$$T_f = \inf\{t > T_0 : Q_t + V_t - C_t \leq 0\} \tag{4}$$

where the infimum denotes the need calculate the earliest time for the cessation of marginal revenue. Considering possible discrete versions of the model, the use of infimum is still better than the minimum.

This establishes a model for determining the concession period interval according to the principle of creating a bigger cake for project stakeholders to share while simultaneously guaranteeing an attractive return for the concessionaire. In other words, the project life span should end at $T_f$, as expressed in **(4)**, so that the total benefit is maximized and the internal return rate required by the concessionaire is sufficient to make the BOT project attractive for concessionaires. That is

$$R(T_C) \geq R_1 \Leftrightarrow NPV_P(T_C) \geq I(1+R_1)^{T_C} - I. \tag{5}$$

The BOT procurement system is particularly useful in helping fund the infrastructure projects of governments that lack sufficient finance. Therefore, it is reasonable to assume that the government's contribution should not jeopardize its financial situation:

$$\mathrm{NP}V_p(T_C) \leq \mathrm{NP}V_p(T_f). \tag{6}$$

As shown in Fig. 1, the upper boundary of the concession period is $T_{CU}$, as a transfer point before $T_{CU}$ will generate a positive economic benefit for the government during the whole of the post-transfer period and vice versa.

Therefore, the benefit space of the concessionaire corresponds with the negotiation space for the concession period:

$$\begin{cases} T_C \in [T_{CL}, T_{CU}] \\ T_{CL} = \inf\{t > T_0 : R(t) \geq R_1\} \\ T_{CU} = \sup\{t \leq \tilde{T}_f : NPV_p(T_{CU}) \leq NPV_p(T_f)\} \end{cases} \tag{7}$$

Of course, although all the equations are presented as continuous functions, the model is equally appropriate for discontinuous and discrete functions (and the reason for using "inf" and "sup" instead of minimum and maximum).

Note that there will be a feasible solution if and only if $T_{CL} \leq T_{CU}$ in **(7)**. However, exceptional situations may occur, such as when the economic benefits reduce very rapidly in the later stages of the project while considerable net social benefits remain (Bao and Wang, 2010). In this case, the government has at least two choices. One is to abandon or redesign the project. The other is to shorten the project life span in order to ensure that the project is still profitable both for the government and concessionaire. In this situation, the project life span should satisfy:

$$T_f = \sup\{t > T_{CU} : \mathrm{NP}V_p(T_{\mathrm{CU}}) \leq \mathrm{NP}V_p(t)\} \tag{8}$$

(where the sign "≤" becomes "=" when the model is continuous).

In conclusion, determining the concession period is viewed as an optimization problem such that

$$Max_{(T_{CL}, T_{CU}, T_f)} : NPV_G(T_f) = -(1-\alpha)IR - I + \int_{T_0}^{T_f} (Q_t + V_t - C_t)dt$$

$$s.t. \begin{cases} NPV_p(t) = -(1-\alpha)IR - I + \int_{T_0}^{T_t} (1-\lambda)(Q_s - C_s)ds \\ T_{CL} = \inf\{t > T_0 : R(t) \geq R_1\} \\ T_{CU} = \sup\{t \leq \tilde{T}_f : NPV_p(T_{CU}) \leq NPV_p(T_f)\} \\ T_{CL} \leq T_{CU} \end{cases} \tag{9}$$

with solutions (given in $f\{t>T_0:R(t)\geq R_1\}$) always existing

$$\text{(a)}\begin{cases} T_f = \inf\{t>T_0 : Q_t + V_t - C_t \leq 0\} \\ T_C \in [T_{CL}, T_{CU}] \\ T_{CL} = \inf\{t>T_0 : R(t)\geq R_1\} \\ T_{CU} = \sup\{t>\tilde{T}_f : NPV_p(T_{CU})\leq NPV_p(T_f)\} \end{cases} \tag{10}$$

when $T_{CL}\leq T_{CU}$ and

$$\text{(b)}\begin{cases} T_f = \{t>T_{CL} : NPV_p(T_{CL})\leq NPV_p(t)\} \quad \textit{otherwise} \\ T_C = T_{CL} = \inf\{t>T_0 : R(t)\geq R_1\} \end{cases} \tag{11}$$

In view of the difficulties involved in measuring net social benefit, an additional scenario analysis may generate further useful information and be helpful in improving the decision-making involved in BOT concession contracts. Since the definition of net social benefit is still vague and its measurement lacks accuracy, it is necessary to evaluate it on several levels based on the economic benefit brought to the local community. For instance, the decision concerning the length of concession period is affected to some extent by the magnitude (great, fair or small) of the social benefit. In the following illustrative example of a toll highway BOT project, we will demonstrate the workings of the concession determining model presented in this paper and how the scenario analysis of net social benefit can help improve the decision making process.

## 4. Illustrative example: the Hong Kong Eastern Harbor Tunnel (EHT) project

The application of the model is demonstrated through a BOT project carried out in Hong Kong, the Eastern Harbor Tunnel (EHT). The concession for the construction and operation of the Eastern Harbor Tunnel (EHT) was awarded to the New Hong Kong Tunnel Company Limited in August, 1986. The concession period is 30 years and the tunnel will be transferred to the government in 2016. The project is being operated smoothly but its financial performance is below expectations. This is because the internal return rate for private investors was 13.4% in 2011, which is less than the expected rate of 15–17%. The details of the project are provided below, with accurate statistical data being retrieved directly from annual reports issued by the New Hong Kong Tunnel Company Limited. Due to the limited availability of information, relevant statistical data for earlier years are estimated from the EHT annual report. The units are in HKD million unless otherwise stated.

It is known that the risk-free interest rate in Hong Kong is equivalent to the yield of short term US bonds, i.e. 0.2% (Chau, 1997). The impact power of interest rates in 30 years is about 6.1%, which can be ignored. The effect of the interest rate is therefore not considered in this case study.

### 4.1. Construction period and total investment

The length of construction period $T_0$ = 37 months and the total investment is $I$ = \$2326 with debt of \$1576 (\$1464 in the construction period and \$112 in the early years of the operation period) and equity of \$750.

### 4.2. Annual income in the operation period, $Q_t$

According to the annual report, 96% of the annual income, $Q_t$, is generated from the toll charge in the operation period up to 2011. The toll price was raised by 50% and 66.7% on 1 January 1998 and 1 May 2005 respectively. As Fig. 2 shows, the overall shape of income follows an inverted-U curve and with a significant increase of the income over time, mainly as a result of the increases in toll price. Assume $Q_t = at^2 + bt + c\,(a<0)$, where $t$ = 0 means 'year 1989', $t$ = 1 means 'year 1990' etc. Incorporating all the income data from 2005 to 2011,

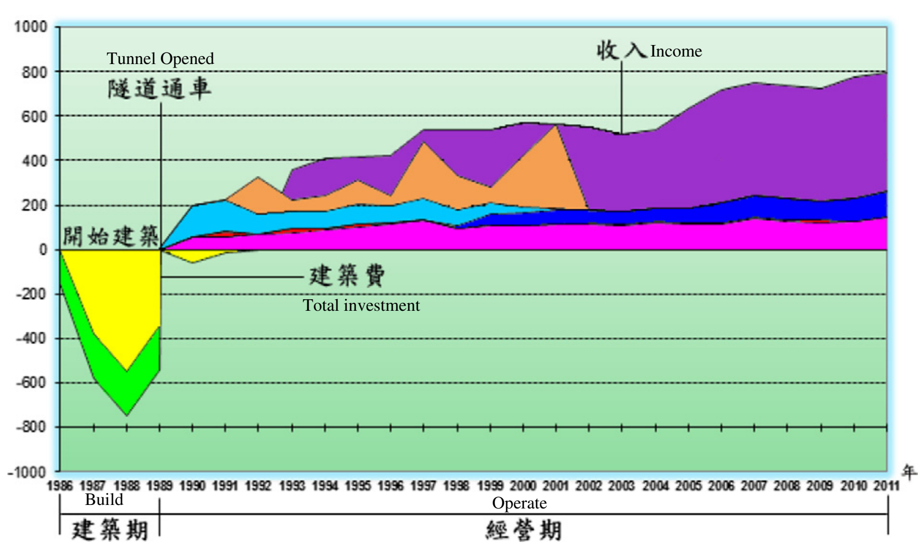


Fig. 2. Cash flows of the EHT project (source: annual report of the Eastern Harbor Tunnel project, 2011).

the minimized square error parameters are $a = -0.8694$, $b = 54.9040$, $c = 0.2117$. Hence;

$$Q_t = -0.8694t^2 + 54.9040t + 0.2117, \quad t \geq 16. \tag{12}$$

### 4.3. Operation and maintenance costs, $C_t$

As mentioned above, the operation and maintenance (O&M) costs are viewed as having an upward trend, yet with a very slow slope in the EHT project. Assume $C_t = at^2 + bt + c\,(a > 0)$. Incorporating all the O&M costs data from 2005 to 2011, the minimized square error parameters are $a = 0.3815$, $b = -6.4306$, $c = 194.2966$. Hence;

$$C_t = 0.3815\ t^2 - 6.4306t + 194.2966, \quad t \geq 16. \tag{13}$$

### 4.4. Net social benefit, $V_t$

Traditionally, the method of measuring the benefits of transport development to the society includes national income increases, producers' cost savings, shippers' cost savings and rents/land value increases (ESCAP and AITD, 2009). A bigger traffic volume also occurs, along with an increased willingness to pay a greater transportation fee, with the improved residents' income situation of the local community. Considering the leverage effect of the wider social impacts, it is assumed here that the net social benefit is an approximate proportion of the annual income for the operation period:

$$V_t = \beta Q_t \quad : \quad t \geq T_0, \beta > 0 \tag{14}$$

where $\beta$ is the proportion coefficient for use in the scenario analysis.

### 4.5. Concessionaire finance

In the EHT project, all debt has been paid off by 2002 with a total interest of \$942, i.e. the return rate of financing is $R = 942/1576 = 59.77\%$ for the loan of 16 years. This is the financial cost to the concessionaire, i.e.$-(1-\alpha)IR = 942$. The percentage of equity over total investment is $\alpha = 750/2326 = 32.24\%$.

### 4.6. Concessionaire internal return rate

In 1997 and 2005, two arbitration events occurred that resulted in the fair internal return rate of the concessionaire becoming 15–17%. Hence, we assume the discounted return rate $R_1$ to be 15%.

### 4.7. Solution process

*Optimal project life and concession period for the concessionaire*

As the functions $Q_t$, $V_t$ and $C_t$ are continuous in this demonstration, **(3)** and **(4)** can be simplified by solving the two separate equations

$$Q_t - C_t = 0 \text{ and } Q_t + V_t - C_t = 0. \tag{15}$$

Substituting **(11)**, **(12)**, **(13)** and **(14)** into **(15)** gives

$$T_f = \begin{cases} 50.39, \beta = 0.5 \\ 53.10, \beta = 1.0 \\ 56.09, \beta = 2.0 \end{cases}, \text{and } \tilde{T}_f = 45.63.$$

### 4.8. The optimization problem ($\beta = 1.0$)

According to the annual reports of the EHT project, the accumulated net income after tax is \$5577 from 1989 to 2011. The cash flow from 2005 to 2011is accessible from the annual reports, with a total net revenue of \$3603. The remaining \$1974 is assumed to be distributed linearly from 1989 to 2004. The net revenue was \$0 in 1989, \$17.55 in 1990, \$35.10 in 1991 to \$263.25 in 2004.

Substituting the value of estimated cash flow, total investment (\$2326) and internal return rate $R_1 = 15\%$ into **(5)**, it is found that $T_{CL} = 25.64$ by July, 2014.

Substituting **(2)** into **(7)** and the value of $T_f$ and $\tilde{T}_f$ into **(5)** results in $= 1 T_{CU} = 37.15 > T_{CL}$.

Therefore, the solution (a) in **(10)** is the solution to the optimization problem **(9)**.

$$\begin{cases} T_f = 53.10 \\ T_C \in [25.64, 37.15] \end{cases}$$

This result indicates that the project life should expire around 2042 in order to obtain the optimal total benefits, including economic and net social benefits. The concession period interval obtained in this model is [25.64, 37.15], i.e. between 2014 and 2026. This should encourage private investors to be involved in the project, as their internal return rate is between 15.0% in 2014 and 15.6% in 2026. The actual BOT concession of the EHT project expires in August 2016 and the internal return rate is 13.4% in 2011.

From the above analysis, the New Hong Kong Tunnel Company Limited appears to be under pressure to keep the tunnel operating smoothly in order to achieve the desired internal return rate of 15%. This explains why, since 2010, the New Hong Kong Tunnel Company Limited has applied for another round of toll price rises. As for the government, it is able to create considerable benefits for the community without unduly jeopardizing its financial situation, as transferring the BOT project at any time before $T_{CU}$ can generate positive economic benefit for the government.

### 4.9. Uncertainty of net social benefits

Because the measurement of net social benefits is inaccurate, an additional scenario analysis following Zhao and Tan [40] is employed here in order to improve the validity of the model. If the net social benefit is lower, e.g. $0 < \beta < 1$, the project life is truncated according to **(4)**. In this situation, the concession period interval is lengthened as the upper boundary of the concession period moves from $T_{CU}$ to $T_{CU}^{(1)}$ (as shown in Fig. 3), and more negotiation space is therefore created for the government and private investors.

When net social benefit is relatively higher, e.g. $\beta > 1$, the project life is lengthened as the total benefit continues to grow at $T_f$. The resulting upper boundary of the negotiation space will then be $T_{CU}^{(2)}$, which is smaller than $T_{CU}$, as shown in Fig. 3. When net social benefit increases, the upper boundary of the concession period moves leftwards as shown in the Fig. 3. In this case there are three different possible solutions. First, when $T_{CL} < T_{CU}$ is still satisfied, the concession period interval continues to exist although it becomes shorter. Second, when $T_{CL} \approx T_{CU}$, the concession period interval degenerates into one time point. This is the situation discussed by Fan et al. (2012), and is now reflected in the model. Third, in the situation when $T_{CL} > T_{CU}$, solution (a) in **(*10*)** no longer applies, but instead solution (b) in **(*11*)** is appropriate and the optimal project life $T_f$ is obtained by **(*8*)** instead of **(*4*)**. This means that the government has to sacrifice the total benefit of the BOT project in order to ensure that no extra financial deficit will be incurred by the project. Another possible option for the government is to provide financial compensation for the project so a larger total benefit is created for the community.

## 5. Conclusions and limitations

Most research to date assumes the project life span and cash flows are pre-given, and the concession period of BOT projects is determined exogenously by policy. The model presented in this provides a more scientific approach to improve the accuracy, efficiency and effectiveness of concession period design by simultaneously determining both the BOT concession period interval and project life span prior to soliciting bids from potential concessionaires, by maximizing the combined benefits of stakeholders while guaranteeing an attractive return for the concessionaire. In addition to the economic benefits involved, the concept of net social benefits is incorporated into the quantification of the government's total benefit. This is echoed with calls from academia and industry to integrate social benefits into Value for Money analysis framework.

In addition to contributing to construction procurement theory, the dynamic and interdependent features of concession period determination in the proposed model provide theoretical reference beyond the current practice of linear-process thinking. The optimization algorithm could be realized through computer software, making the computer-aid non-linear determination process easier for practitioners to follow. Also, the model should enable engineering consultants to provide project information more rationally and accurately than hitherto when issuing BOT project bidding notices, and therefore increase the chance of the government and concessionaire of successfully forming a BOT contract. This should generate more negotiation space for the government and concessionaire in determining the major socioeconomic features of individual BOT contracts when negotiating the contractual concession period. Later, when there is sufficient project delivery related data and experience, the negotiation space obtained from the proposed model can be more accurate and practically feasible, and the efficiency of the negotiation process can be improved.

In terms of limitations, the model presented is derived deductively and is therefore only as good as the assumptions upon which it is based. However, as explained in the paper, most of the assumptions made are intuitively sound and reasonably correspond with what manifestly happens in practice. As demonstrated in the illustrative example, unlike previous efforts, the model's structure represents a major step forward in encapsulating all the major variables involved including net social benefits, which have been conspicuously missing hitherto.

Some aspects of the model would also benefit from further consideration, e.g., the uncertainty surrounding the amount of total investment. The future cash flows of some infrastructure projects are likely to be affected by the total investment involved, as higher investment may lead to better facilities or quality of services. Further information concerning the impact of total investment on $Q_t$, $C_t$, and $V_t$ would also be beneficial. In addition, placing $R$ as a lump sum as an outflow outside the integral in **(*1*)** and **(*2*)** is a simplification that ignores the periodic cash flow implications of debt variables over loan life

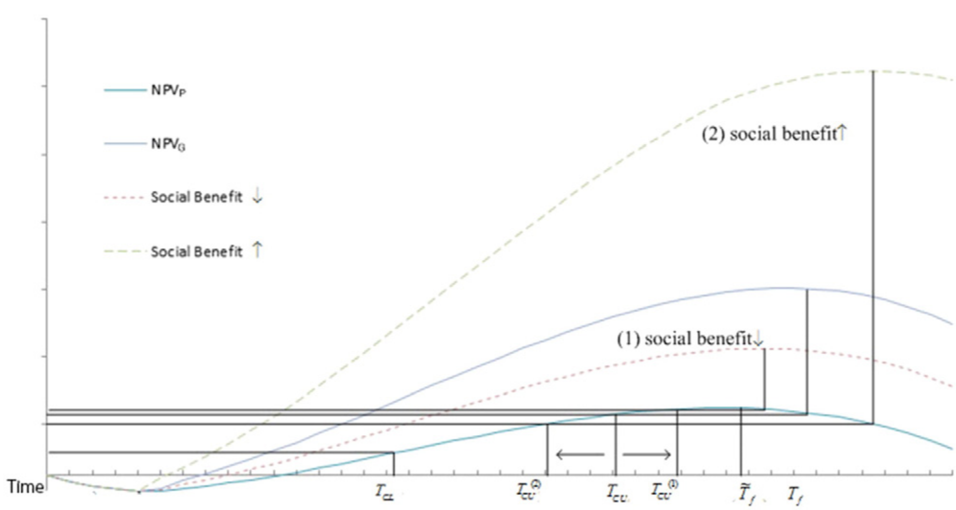


Fig 3. The impact of the uncertainty of social benefit on concession period.

(principal inflows, debt servicing outflows, principal repayments) and is in needed of consideration in future work as their size in private sector financed BOT transactions can big enough to dominate DCF outcomes, especially in the return on private sector equity invested.

In this respect, it is important to recognize the institutional realities affecting project cash flows. The loan contract in a BOT-type structure typically is structured following project finance principles, which aim to achieve at least two clear objectives. First, based on total debt capacity derived from the size and profile of expected periodic cash flows over the asset's expected operating life, lenders aim to advance as much debt as possible to the entity that is to "own" the asset for the concession period (typically 50–90% of total investment). Secondly, it aims to minimize the risk of distress of the entity in servicing the debt— which requires critical consideration of the cash flow profile of expected earnings. Debt inflows during construction creates a "flow-through" condition, i.e. only the equity investment shows up as (net) outflows over the project development phase— this is typical in private sector finance with BOTs. Following this, growth in inflows, particularly in the earlier years of operation, will be contractually constrained by prioritized allocation of cash flows, with debt servicing typically the second or third priority, thus moving significant net inflows to equity investors into later years. In combination, these factors make it unlikely in practice that a BOT project's net cash flow profile can be as smooth as assumed here—they are most likely stepped functions.

In order to advance the models developed in this paper into practice, therefore, further work is needed on the treatment of discount rates and interest rates and associated assumptions concerning the influence of the debt contract on cash flow profile with a less than the minimal interest rate structure as assumed here; while all debt-related periodic cash flows need to be subject to time-value considerations. Also, to be noted is that debt influences cash flows differentially in private and public sector applications. If the public sector entity is not budget constrained, there may be no project debt at all and no private sector participation, and so the BCA result could be neutral to debt. If there is substantial debt in the private sector entity, which is actually the point of the BOT procurement system, it will affect the cash flows and DCF return profoundly (note that EHCs in the illustrative example are in fact leveraged private sector returns). In short, if debt is in the project entity's capital structure, it fundamentally alters the cash flows and reasons for proceeding with the project, making interest rates and the cash flow profile of significant importance.

Finally, it should also be noted that the model does not yet incorporate contingency and incentive mechanisms. Of course, some contingences in the construction and operation periods profoundly affect the attitudes and performance of the government and concessionaire. Also, in response to the future uncertainties both in the construction and operation periods, specific incentive mechanisms could be employed to share the possible pains/gains for the sake of project viability. This can be accommodated to some extent by simulation methods. Indeed, to be ultimately of use to practitioners, it will be necessary to develop computer software to automate much of the processes demanded by the model. In addition, a more intensive study of the relationships between different types of risks, concession periods, total investment and project life spans is likely to be incorporated into the model for further improvement.

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