# Risk Concession Model for Build/Operate/Transfer Contract Projects

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**Abstract:** This paper extends the build–operate–transfer (BOT) concession model (BOTCcM) to establishing a risk concession model for BOT contract projects. The decision for a concession period is one of the most important decisions in determining a BOT contract. BOTCcM presents an alternative method to assist in determining a concession period that can protect the basic interests of both the investor and the government concerned. However, there is a major limitation in using the model, namely it gives no consideration to the impacts of risks on the estimation of various economic variables in the model. This study considers the risk impacts to the BOTCcM model and presents an additional risk concession model. This model provides an approach for formulating a concession period to consider the impacts of risks and, at the same time, protect the basic interests of both the investor and the government concerned. A hypothetical case is used to show the procedures of formulating the risk concession period through the assistance of the Monte Carlo simulation method.

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## Introduction

Build–operate–transfer (BOT)-type contracts have been proven effective in arranging the finance for infrastructure projects in both developed and developing countries. In general, implementing infrastructure projects requires a large capital investment. As governments, particularly in those developing countries, usually find it difficult to provide sufficient capital for public infrastructure development, the BOT contract is widely used to attract private capital to assist in developing public infrastructure. By using the BOT contract, a grantor provides a private company with a concession to build and operate a project. This contractual arrangement provides a mechanism for using private finance, thus it allows governments to construct more infrastructure services without the use of additional public funds. Typical infrastructure projects using BOT contracts include highways, railways, ports, tunnels, bridges, power plants, hydraulic structures, and reservoirs (Shen et al. 1996). In fact, the BOT method has been in use for a long time. The first BOT contract project in modern times was the building of the Suez Canal which was constructed in 1854 (Levy 1996). In this contract, the private company, Compagnie Universelle du Canal Maritime de Suez, obtained a 99-year concession from the Egyptian government for the construction and operation of the canal connecting the Mediterranean and Red Seas. Nevertheless, the method was not widely used until the middle of the 1980's (Huang 1995). Since the 1980's, the application of the BOT method has made an important contribution to the development of infrastructure work throughout the world.

The use of BOT system has attracted interest from researchers. Previous research has developed various methods and models, mainly focusing on financing, pricing, managing, and engineering in implementing a BOT contract (Miller 1997; Malini 1999; Devapriya and Pretorius 2002; Yang and Meng 2002). One recent research initiative has developed a BOT concession model (BOTCcM) for formulating a concession period that can protect the interests of both the government concerned and the private investor (Shen et al. 2002). BOTCcM provides a methodology for calculating a concession period that incorporates both the investor's and the concerned government's interests. It is a development in using the BOT system as it offers a quantitative tool to find a concession period between the private sector and the concerned government where both parties gain benefits. However, one limitation found in the use of BOTCcM is that it does not consider the impacts of risks to the estimates of the various economic variables present in the process of completing a BOT contract. Risk exists at all stages of the project life cycle. Since BOT-type projects not only require a large amount of investment but also span long time periods, there are many uncertainties and risks affecting the performance of implementing the project during concession period. A study by Delmon (2000) suggests that the impact of risks to project objectives in completing a BOT project are usually significant, and these risks are from multiple sources including capital budget, construction time, construction cost, operation cost, politics and policies, market condition, cooperation credibility, and economic environment. It is essential therefore for both the private sector and the concerned government to take into account the impact of these risks when considering engaging in a BOT contract. This paper describes the ex-

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**Table 1.** Example Build–Operate–Transfer (BOT) Projects with Different Concession Periods

| BOT project and region | Investment (US$/million) | Concession period (year) | Year of investment |
|---|---|---|---|
| 1) Metropolitan Waterworks and Sewerage System in Manila, Philippines | 7,000 | 25 | 1997 |
| 2) Laibin B Power Plant, China | 600 | 18 | 1997 |
| 3) Linha Amerala Road, Brazil | 174 | 10 | 1996 |
| 4) Dabhol 695-MW Power Plant, India | 922 | 20 | 1995 |
| 5) Bangkok Highway, Thailand | 880 | 30 | 1993 |
| 6) Mexico City Toluca Toll Road, Mexico | 313 | Guarantees traffic volumes | 1992 |
| 7) East Harbor Tunnel, Hong Kong | 565 | 30 | 1989 |
| 8) Dartford Bridge, U.K. | 310 | 20 | 1989 |
| 9) South-North Highway, Malaysia | 1,800 | 30 | 1988 |
| 10) Channel Tunnel, U.K. and France | 10,300 | 55 | 1987 |

tension of the BOTCcM model to establish a risk concession model (BOTCcM-R) for assisting in formulating a concession period which incorporates risk impacts.

## Major Principles in Using the Build–Operate–Transfer Concession Model

The study by Shen et al. (2002) presents a methodology for identifying a concession period that can protect both the concerned government's and the investor's interests. Generally, a longer concession period is more beneficial to the private investor, but a prolonged concession period may induce loss to the concerned government. Alternatively, if the concession period is too short, the investor will either reject the contract or be forced to increase the service fees in the operation of the project. Consequently, the risk burden due to the short concession period will be shifted to the public who use and pay for the facilities. Thus, an appropriate concession period is one of the most important decisions when agreeing upon a BOT contract. Moreover, as different projects will incur different cash flow profiles during their future operations, different concession periods are adopted in different applications. Table 1 provides examples of concession periods used for different types of BOT projects (Walker and Smith 1995; World Bank 1997, 2001).

The BOTCcM model presented by Shen et al. (2002) calculates a concession period that balances the interests of the private investor and the concerned government, defined as

$$IR \leqslant \mathrm{NPV}(T_c) \leqslant \mathrm{NPV}(T_f) \tag{1}$$

where $T_c$ denotes the concession period in a BOT contract; $T_f$ = project economic life; $I$ = the investor's capital investment; $R$ = investor's expected return rate; $\mathrm{NPV}(T_c)$ = net present value generated from operating the project during the concession period; and $\mathrm{NPV}(T_f)$ = net present value generated from operating the project during the project economic life.

$\mathrm{NPV}(T_c)$ and $\mathrm{NPV}(T_f)$ may be written as

$$\mathrm{NPV}(T_c) = \sum_{t=1}^{T_c} \frac{\mathrm{NCF}_t}{(1+r)^t} = \sum_{t=1}^{T_c} \frac{(I_t - C_t)}{(1+r)^t} \tag{2}$$

$$\begin{aligned}\mathrm{NPV}(T_f) &= \sum_{t=1}^{T_f} \frac{\mathrm{NCF}_t}{(1+r)^t} \\ &= \sum_{t=1}^{T_c} \frac{\mathrm{NCF}_t}{(1+r)^t} + \sum_{t=T_c+1}^{T_f} \frac{\mathrm{NCF}_t}{(1+r)^t} \\ &= \sum_{t=1}^{T_c} \frac{(I_t - C_t)}{(1+r)^t} + \sum_{t=T_c+1}^{T_f} \frac{(I_t - C_t)}{(1+r)^t}\end{aligned} \tag{3}$$

where $\mathrm{NCF}_t$ denotes the net cash flow in year $t$; $I_t$ = income for the year $t$, $C_t$ = cost (or expense) in year $t$; and $r$ = discounted rate taking into account the effects of both interest and inflation.

The BOTCcM model assumes that the variables $I_t$, $C_t$, and $r$ in formulas (2) and (3) can be estimated with deterministic values. Based on this assumption, a NPV curve developed when operating a BOT project was produced. An example is shown in Fig. 1.

In Fig. 1, the two specific time points, namely, $T_{c\_L}$ and $T_{c\_U}$, are identified with corresponding values $IR$ and $\mathrm{NPV}(T_f)$ measured on the vertical axis. The two time points form an interval $(T_{c\_L}, T_{c\_U})$ within which the concession period $T_c$ can assume any value. By using this concession period, $T_c$, the basic interests of both the investor and the concerned government can be protected (Shen et al. 2002).

## Simulation Analysis of the Impact of Risk on the Concession Model

The BOTCcM model is a deterministic model where the estimates of the variables $I_t$, $C_t$, and $r$ are given with deterministic values.

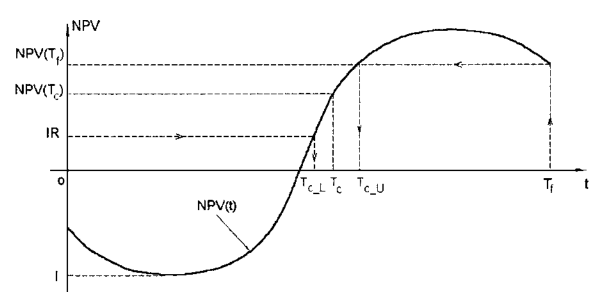


**Fig. 1.** Net present value profile and concession period in the concession model by Shen et al. (2002)

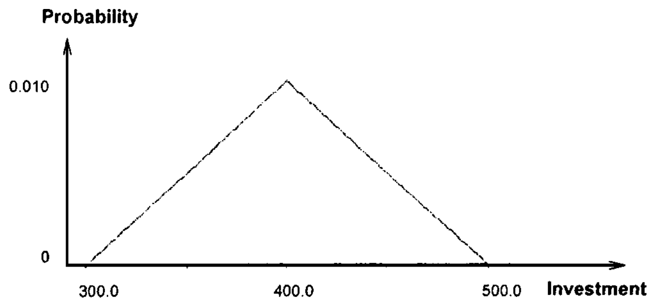


**Fig. 2.** Probability distribution of capital investment ($I$)

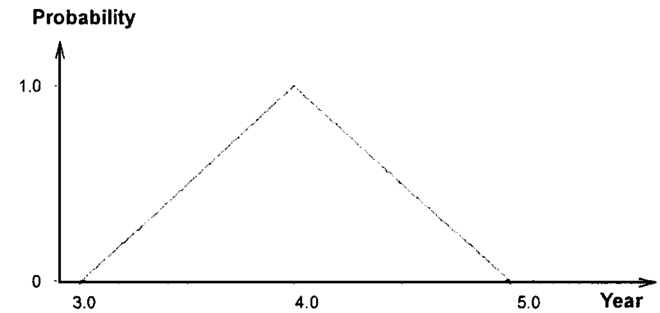


**Fig. 3.** Probability distribution of construction time ($t_0$)

However, this assumption is a major limitation because the values of these variables are uncertain due to the existence of various risks. For example, the capital budget and the construction time may be changed, and cost and income may vary during the lengthy concession period. The impacts of risks to the performance of a BOT-type project have been highlighted by previous research, for example, Huang (1999) and Zayed and Chang (2002). When risk is taken into account in determining a concession period, the BOTCcM model needs to be modified. This may be illustrated by using a hypothetical example which highlights the improvements in the model.

Assume that an investor is to tender for a BOT contract for building a toll bridge (named Sanchuan Bridge), aiming for an economic life of 34 years including a construction period, $t_0$. Consider that negative income will be incurred during the construction period and that positive income will be generated during postconstruction period, namely, the operating period. The following formula is used to calculate the NPV profile in the operating the bridge:

$$\mathrm{NPV}(T) = -\sum_{t=1}^{t_0} \frac{I_c}{(1+r)^t} + \sum_{t=t_0+1}^{T} \frac{q \times p - c_m}{(1+r)^t} \tag{4}$$

where $t_0$ denotes the construction period; $q$=annual traffic volume; $p$=toll price; $c_m$=annual maintenance cost; $r$=annual discount rate; and $I_c$=annual capital investment during project construction period.

Consider the existence of various risks in the whole process of implementing the project. The estimates on the variables $q$, $p$, $c_m$, $r$, and $I_c$ in the model are given various probability distributions rather than deterministic values. It is important to note that these estimates are hypothetical and used only for demonstrating the principle of formulating a risk concession period.

### Annual Capital Investment ($I_c$)

It is assumed that the total capital investment, ($I$), is evenly consumed during the construction period, $t_0$. Thus, the annual capital investment, $I_c$, may be written as $I_c = I/t_0$. The total capital investment, $I$, is estimated in a triangular probability distribution, with the most likely value of \$400 million, the minimum (or the optimistic estimation) of \$300 million, and the maximum (or the pessimistic estimation) of \$500 million, as shown in Fig. 2.

### Construction Time ($t_0$)

The construction time, $t_0$, is estimated with a triangular probability distribution with the most likely estimation of 4 years, the minimum time (or the optimistic estimation) of 3 years, and the maximum time (or the pessimistic estimation) of 5 years, as shown in Fig. 3. This assumes that the government imposes a limited construction duration of 4 years beyond which liquidated damages at a rate of \$0.2 million/week will be charged. On the other hand, if the construction time is less than 4 years, the investor can start to generate income early by operating the bridge.

### Toll Price ($p$)

Toll prices enable income to be made during the period of operating the bridge. Toll prices may be changed in line with market changes or policy changes. A discrete distribution with three estimates is adopted for describing the toll price, namely, a pessimistic estimate, a most-likely estimate, and an optimistic estimate. It is also considered that different toll prices are adopted at different stages during a project concession period. For example, in order to promote the traffic volumes during the initial 5 years of using the bridge, the price will be cheaper. The price will be higher during the 10-year period after the initial operation period. During the later stages of operation, it is assumed that the toll price will drop gradually because alternative traffic bridges may be available. Table 2 provides the summary of the estimation on the toll price. The data included in the table are presented graphically in Fig. 4.

### Annual Traffic Volume ($q$)

A normal distribution is assigned to represent the annual traffic volume during project operation period. Furthermore, considering that traffic volume will be different at different stages, different

**Table 2.** Discrete Estimation for the Toll Price (\$/Vehicle)

| | | Operation period (after construction stage) | | | | |
|---|---|---|---|---|---|---|
| Discrete estimation | Probability | 1–5 | 6–15 | 16–20 | 21–25 | 26–30 |
| Pessimistic expectation | 0.3 | 9.0 | 10.0 | 8.0 | 6.0 | 3.6 |
| Most likely expectation | 0.4 | 10.8 | 12.0 | 9.6 | 7.2 | 4.8 |
| Optimistic expectation | 0.3 | 13.5 | 15.0 | 12.0 | 9.0 | 6.0 |

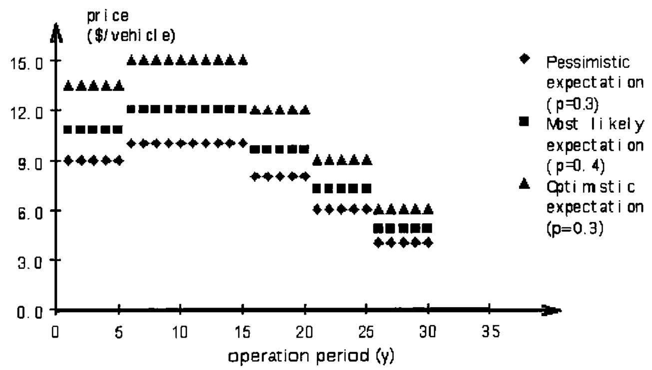


**Fig. 4.** Discrete estimation on the toll price ($p$) during operation period

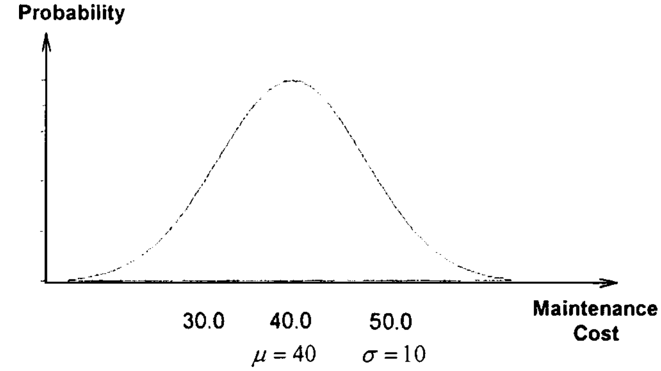


**Fig. 6.** Probability distribution of annual maintenance cost ($c_0$)

distributions are used to represent the volume. During the initial and final stages, it is assumed that the traffic volume will be less than the volume during the middle stage of operation. For example, during the initial 5 years of using the new bridge, the old facilities may still be available. These old facilities will share a certain amount of traffic. During the final stage (for example, the final 15 years), when more maintenance will be carried out and other alternative bridges will be available, the traffic volume will decrease. Based on this assumption, a normal distribution with a mean of 5 million and standard deviation of 1.25 million is adopted as the estimation of the annual traffic volume during the initial and final stages in operating the project. This is shown in Fig. 5(a). A normal distribution with a mean of 10 million and standard deviation of 2.5 million is used for the estimation of traffic volume during the middle term, as shown in Fig. 5(b).

### *Annual Maintenance Cost* ($C_m$)

A normal distribution with a mean of \$40 million and standard deviation of \$10 million is used to describe the basic annual maintenance cost, $C_0$. This is shown in Fig. 6.

Previous research suggests that the maintenance costs for operating a BOT project are much higher during the initial and final stages. (Patton 1982; Wen and Kang 2001). On this basis, an adjustment coefficient, $k$, is used to modify the basic annual maintenance cost. The modified annual maintenance cost, denoted as $C_m$, can be therefore written as $C_m = kC_0$. The coefficient, $k$, allows the user to adjust maintenance costs in a way that higher value maintenance costs appear during initial and final stages, and lower costs appear in the middle term. A lower cost will be adjusted if $k$ is less than 1, and a higher cost will be incurred when $k$ is larger than 1. A quadratic function is used to serve the purpose of this coefficient, written as

$$k = at^2 + bt + c \tag{5}$$

The model is considered as a symmetric function with the symmetric axis at the middle point ($t_m$) in the project operation period. Thus, the function may be rewritten as $k = a(t - t_m)^2 + c$. For simplicity, considering the construction period of 4 years, the point $t_m$ will be

$$t_m = 4 + \frac{34 - 4}{2} = 19$$

Thus

$$k = a(t - 19)^2 + c \tag{6}$$

It is assumed that the initial maintenance cost is the same as the final maintenance cost but that the maintenance cost at the middle point ($t_m$) is one-fourth of the cost at the initial or final point, namely

$$k_{t=4} = k_{t=34} = 4k_{t=19} \tag{7}$$

The coefficient $k$ assumes various values at different time points. These values may be less or more than 1. It is assumed that the

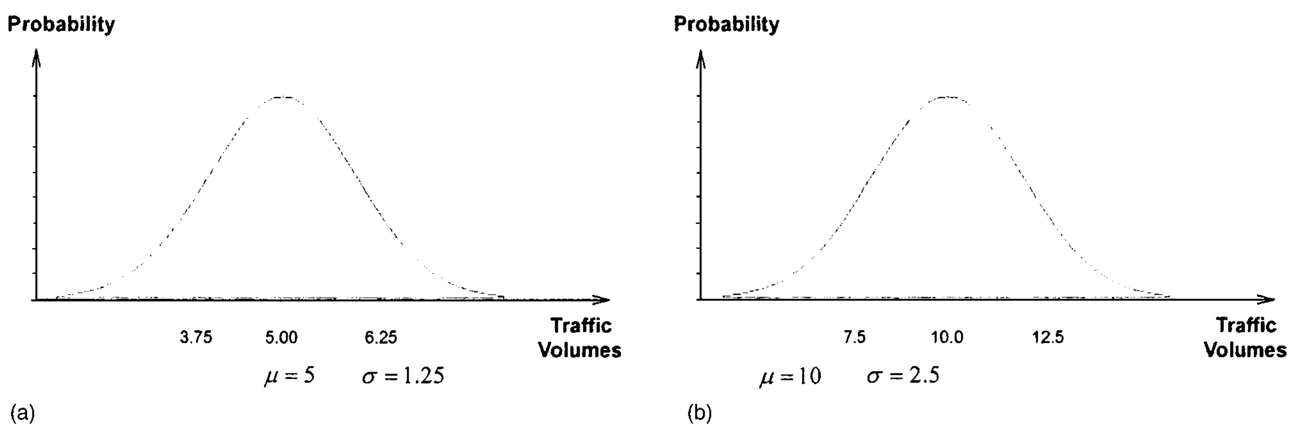


**Fig. 5.** Probability distribution of annual traffic volumes ($q$) during operation period: (a) operation years for 1–5 and 16–30 and (b) operation years for 6–15

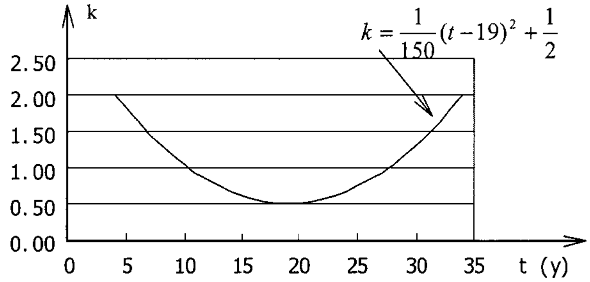


**Fig. 7.** Adjustment coefficient of annual maintenance cost

average value of $k$ in the operation period is 1. This may be described as

$$\frac{1}{30}\int_{4}^{34} k dt = \frac{1}{30}\int_{4}^{34} [a(t-19)^2 + c] dt = 1 \tag{8}$$

Incorporating Eqs. (7) and (8) into Eq. (6), the values of the parameters $a$ and $c$ can be calculated:

$$a = \frac{1}{150}, \quad \text{and } c = \frac{1}{2}$$

Thus, $k$ and $C_m$ can be obtained

$$k = \frac{1}{150}(t-19)^2 + \frac{1}{2}$$
$$C_m = \left[\frac{1}{150}(t-19)^2 + \frac{1}{2}\right] C_0 \tag{9}$$

The variable $k$ is graphically presented in Fig. 7.

### *Annual Discount Rate* ($r$)

The annual discount rate for this hypothetical project is also described by a normal distribution with a mean of 8% and standard deviation of 2%. This is shown in Fig. 8. It is also assumed that the discount rate should not be less than 0.

When the above estimations are input into the model (4), the impacts of risk to the NPV can be analyzed. To accommodate the various probability distributions, the analysis is conducted by employing the Monte Carlo simulation technique (Brandimarte 2001; Moore and Weatherfore 2001). The simulation method is a numerical method which involves the substitution of numerical values within individual distributions for the variables. The substitution process is conducted through experimentation. The experiment can be repeated many times, which can generate many alternative results. The range of alternatives reflects the nature of uncertainty. There are various commercial packages available for conducting Monte Carlo simulations analyses. In this demonstration exercise, the package *CRYSTAL BALL* was used. In total, 425,000 analyses were simulated in the exercise. These calculations took nearly 8 h to simulate on a Pentium III/1.2G computer. Fig. 9 demonstrates some examples of the simulation results of the NPV for specific years during the project's economic life. For any year, the value NPV is given with a distribution. The maximum and minimum estimates for individual distributions are shown in Table 3. When these values are plotted graphically, an estimation zone for NPV across project is formulated, as shown in Fig. 10. The zone estimation for NPV in Fig. 10 reflects the nature of many possible future outcomes. This information is considered more realistic than the single curve estimation presented in Fig. 1.

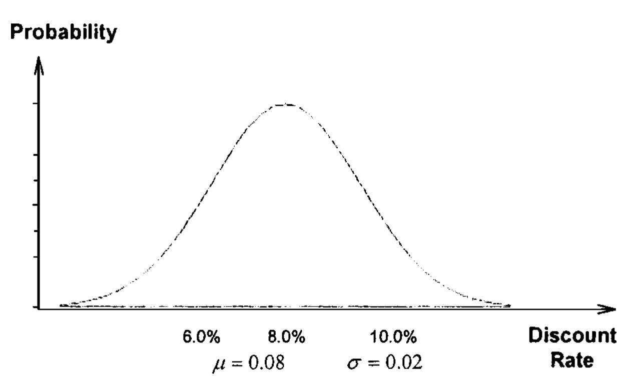


**Fig. 8.** Probability distribution of discount rate ($r$)

## Risk Model for Determining the Concession Period

The previous section demonstrates that risk impacts on NPV when implementing a BOT contract are significant. The estimate of NPV is therefore given with a distribution rather than a deterministic value. From Fig. 9, a NPV estimation distribution to a particular year, $t$, can be reasonably considered as a normal distribution with mean, $\mu(t)$, and standard deviation, $\sigma(t)$. From this normal distribution, different NPV values may be obtained when the number of standard deviations, $\beta$, assumes different values. These may be expressed as follows:

$$\mathrm{NPV}^{\beta}(t) = \mu(t) + \beta\sigma(t) \tag{10}$$

In Eq. (10), $\beta$ = confidence coefficient indicating the degree of confidence for an individual risk level. For example, when $\beta$ assumes 1.645, the applicant has 95% confidence that the NPV is over $\mu(t)$. When a larger $\beta$ is applied, it indicates that the applicant is more confident about the estimation and vice versa. Thus, $\beta$ is applied as a risk confidence indicator. Table 4 displays the estimations of NPV for all 34 years through the project economy life when different $\beta$ values are adopted. When a specific value of $\beta$ is adopted, a NPV curve can be developed. Fig. 11 presents five examples of NPV curves when $\beta$ assumes $-1.645$, $-1$, 0, 1, and 1.645, respectively.

For determining the concession period on the NPV zone profile presented in Fig. 10, there are three scenarios to be considered. (1) The private investor and the concerned government agree to a common risk confidence level, namely, $\beta_P = \beta_G = \beta$, where $\beta_P$ and $\beta_G$ denote the risk confidence levels allocated by the private investor and the concerned government, respectively. (2) Compared to the government concerned, the private investor is less confident and considers that the future NPV involves more risk. Namely, the private investor has a smaller value of $\beta$ than that given by the government concerned, namely, $\beta_P < \beta_G$. (3) Compared to the government concerned, the private investor is more confident and considers that future NPV involves less risk, namely, $\beta_P > \beta_G$. The following discussions are undertaken to identify the concession period $T_c$ in each of these three scenarios.

### *Scenario 1:* $\beta_P = \beta_G = \beta$

When $\beta_P = \beta_G = \beta$, a concession period, $T_c$, can be derived from analyzing the curve in Fig. 12. Considering model (1), the concession period, $T_c$, has to satisfy the condition:

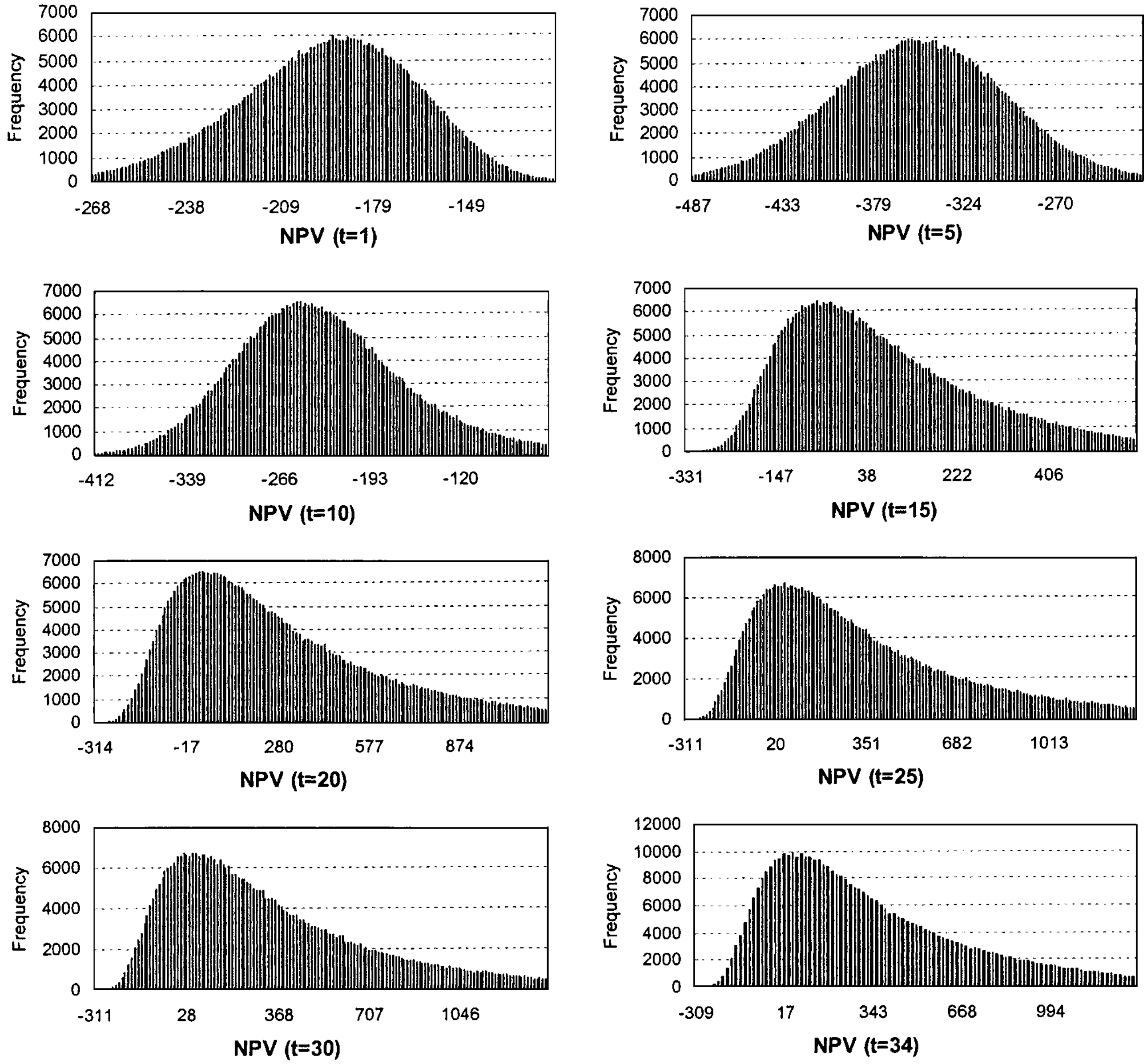


**Fig. 9.** Examples of net present value–frequency distribution at specific year during project life period

$$I^{\beta}R \leqslant \mathrm{NPV}^{\beta}(T_c) \leqslant \mathrm{NPV}^{\beta}(T_f) \tag{11}$$

where $I^{\beta}$ denotes the investor's total capital investment with the risk confidence level $\beta$. The use of capital investment is considered to contribute negative value to NPV. As assumed before, the total capital investment is evenly consumed during the construction period. During this period when there is no income, the value of the total capital investment can be measured from the NPV curve by

$$I^{\beta} = \left| \operatorname*{Min}_{t=1}^{T_f} \{\mathrm{NPV}^{\beta}(t)\} \right| \tag{12}$$

In Fig. 12, $T_c$ can assume any value within the interval $(T^{\beta}_{c\_L}, T^{\beta}_{c\_U})$. This is termed the concession interval. $T^{\beta}_{c\_L}$ is the lower limit of $T_c$, satisfying the investor's basic interests determined by $I^{\beta}R$, $T^{\beta}_{c\_U}$ is the upper limit of $T_c$, satisfying the government's basic interests determined by $\mathrm{NPV}^{\beta}(T_f)$. It may be noted that when $\beta$ assumes different values, different intervals $(T^{\beta}_{c\_L}, T^{\beta}_{c\_U})$ will be formulated. A smaller value $\beta$ will result in a smaller concession interval $(T^{\beta}_{c\_L}, T^{\beta}_{c\_U})$, and vice versa. For example, in Fig. 13, $(T^{(-1)}_{c\_L}, T^{(-1)}_{c\_U})$ is formed when $\beta=-1$, $(T^{(0)}_{c\_L}, T^{(0)}_{c\_U})$ for $\beta=0$ and $(T^{(1)}_{c\_L}, T^{(1)}_{c\_U})$ for $\beta=1$.

Nevertheless, if the value $\beta$ is too small, a situation, $T^{\beta}_{c\_L} > T^{\beta}_{c\_U}$, may occur. This situation indicates that there is no feasible concession period that can protect both the investor's and the government's basic interest as both sides have less confidence about the risk estimates of NPV.

### *Scenario 2: $\beta_P < \beta_G$*

When the situation $\beta_P < \beta_G$ appears, the private investor is more risk conservative. The investor and the government will perceive the future NPV profile differently. This is illustrated in Fig. 14. The concession period, $T_c$, will be within the concession interval

**Table 3.** Mean, Minimum, and Maximum of the 34 Net Present Value Distributions

| Year ($t$) | Mean ($\mu$) | Range minimum | Range maximum |
|---|---|---|---|
| 1 | −194 | −321 | −116 |
| 2 | −280 | −472 | −163 |
| 3 | −345 | −495 | −198 |
| 4 | −357 | −507 | −222 |
| 5 | −352 | −586 | −58 |
| 6 | −343 | −592 | −34 |
| 7 | −331 | −599 | 12 |
| 8 | −315 | −618 | 27 |
| 9 | −298 | −589 | 56 |
| 10 | −231 | −552 | 296 |
| 11 | −165 | −439 | 448 |
| 12 | −102 | −383 | 668 |
| 13 | −42 | −358 | 759 |
| 14 | 17 | −345 | 930 |
| 15 | 73 | −334 | 1,183 |
| 16 | 126 | −329 | 1,347 |
| 17 | 177 | −324 | 1,532 |
| 18 | 226 | −322 | 1,727 |
| 19 | 272 | −319 | 2,003 |
| 20 | 286 | −319 | 2,068 |
| 21 | 299 | −318 | 2,117 |
| 22 | 312 | −318 | 2,188 |
| 23 | 323 | −317 | 2,216 |
| 24 | 334 | −317 | 2,239 |
| 25 | 340 | −317 | 2,290 |
| 26 | 344 | −317 | 2,295 |
| 27 | 348 | −317 | 2,303 |
| 28 | 351 | −317 | 2,301 |
| 29 | 353 | −317 | 2,307 |
| 30 | 351 | −317 | 2,302 |
| 31 | 348 | −317 | 2,303 |
| 32 | 344 | −317 | 2,283 |
| 33 | 340 | −317 | 2,252 |
| 34 | 334 | −317 | 2,238 |

$(T_{c\_L}^{\beta_P}, T_{c\_U}^{\beta_G})$, where the lower limit is determined by the investor's perception on the NPV estimation, and the upper limit is determined by the government's perception.

### *Scenario 3:* $\beta_P > \beta_G$

The assumption $\beta_P > \beta_G$ indicates that the investor is prepared to take more risk than the government. The project NPV profile perceived by the two parties is shown in Fig. 15. The concession period, $T_c$, lies within the concession interval $(T_{c\_L}^{\beta_P}, T_{c\_U}^{\beta_G})$. The lower and upper limits of the interval are determined, respectively, by the perception of the investor and the government on the NPV estimate.

The above analysis on these three scenarios leads to a general model, termed the risk concession model, for use in a BOT contract (BOTCcM-R) when determining the concession period $T_c$. The model is described as:

$$T_{c\_L}^{\beta_P} \leqslant T_c \leqslant T_{c\_U}^{\beta_G}$$

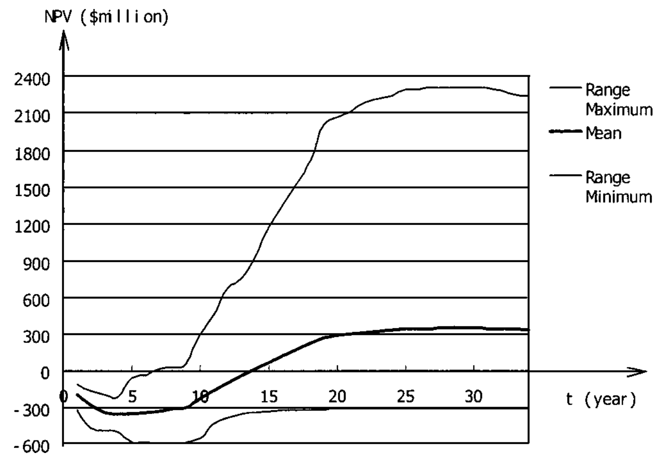


**Fig. 10.** Estimation zone for net present value across project life cycle

$$\begin{aligned} I^{\beta_P} &\leqslant \mathrm{NPV}^{\beta_P}(T_{c\_L}^{\beta_P}) \\ \mathrm{NPV}^{\beta_G}(T_{c\_U}^{\beta_G}) &\leqslant \mathrm{NPV}^{\beta_G}(T_f) \\ I^{\beta_P} &= \left| \operatorname*{Min}_{t=1}^{T_f} \{\mathrm{NPV}^{\beta_P}(t)\} \right| \end{aligned} \tag{13}$$

## Application of Risk Concession Model

The application of BOTCcM-R to the three scenarios is demonstrated by referring to the following discussions relating to the Sanchuan Bridge.

### *Scenario 1:* $\beta_P = \beta_G = \beta$

When $\beta_P = \beta_G = \beta$ (namely, the private investor and the concerned government agree to a common risk confidence level), $\beta = 0$ is adopted for the simplicity of demonstration. Referring to the criterion in model BOTCcM-R, the values of various parameters in the model will be found by referring to the simulation results presented in Table 4.

The capital investment ($I^{\beta_P}$) obtained from Table 4 is

$$I^{\beta_P} = \left| \operatorname*{Min}_{t=1}^{T_f=34} \{\mathrm{NPV}^{\beta_P=0}(t)\} \right| = 357$$

If the investor aims for a 10% return, i.e., $R = 10\%$, the investor's expected investment return will be $I^{\beta_P}R = I^{(0)}R = 357 \times 0.1 = 35.7$.

To find the lower limit of concession interval, $T_{c\_L}^{\beta_P}$, the criterion in the model BOTCcM-R, $\mathrm{NPV}^{\beta_P}(T_{c\_L}^{\beta_P}) \geqslant I^{\beta_P}R$, is used, where $\beta_P = 0$ and $I^{\beta_P}R = 35.7$. The value $\mathrm{NPV}^{(0)}(15) = 73$ is obtained from Table 4. Thus, the lower limit, $T_{c\_L}^{(\beta_P)} = T_{c\_L}^{(0)} = 15$ is found as $\mathrm{NPV}^{\beta_P}(T_{c\_L}^{\beta_P}) = \mathrm{NPV}^{(0)}(15) \geqslant I^{\beta_P}R$.

On the other hand, in order to find the upper limit of concession interval, $T_{c\_U}^{(\beta_G)}$, the criterion in model BOTCcM-R, $\mathrm{NPV}^{\beta_G}(T_{c\_U}^{\beta_G}) \leqslant \mathrm{NPV}^{\beta_G}(T_f)$, is used, where $\beta_G = 0$, and $T_f = 34$. The values $\mathrm{NPV}^{\beta_G}(T_f) = \mathrm{NPV}^{(0)}(34) = 334$ and $\mathrm{NPV}^{(0)}(24) = 334$ are found from Table 4. Thus, the upper limit of the concession interval, $T_{c\_U}^{(0)} = 24$, is found as $\mathrm{NPV}^{\beta_G}(T_{c\_U}^{\beta_G}) = \mathrm{NPV}^{(0)}(24) \leqslant \mathrm{NPV}^{\beta_G}(T_f) = \mathrm{NPV}^{(0)}(34)$.

**Table 4.** Simulation Results of Net Present Value (NPV) for 34 Years

| | | | NPV estimation using different β | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *t* | μ | σ | −1.645 | −1 | −0.674 | 0 | 0.674 | 1 | 1.645 |
| 1 | −194 | 29 | −242 | −223 | −214 | −194 | −174 | −165 | −146 |
| 2 | −280 | 42 | −349 | −322 | −308 | −280 | −252 | −238 | −211 |
| 3 | −345 | 44 | −417 | −389 | −375 | −345 | −315 | −301 | −273 |
| 4 | −357 | 42 | −426 | −399 | −385 | **−357** | **−329** | −315 | −288 |
| 5 | −352 | 52 | −438 | −404 | **−387** | −352 | −317 | −300 | −266 |
| 6 | −343 | 55 | −433 | −398 | −380 | −343 | −306 | −288 | −253 |
| 7 | −331 | 57 | −425 | −388 | −369 | −331 | −293 | −274 | −237 |
| 8 | −315 | 58 | −410 | −373 | −354 | −315 | −276 | −257 | −220 |
| 9 | −298 | 60 | −397 | −358 | −338 | −298 | −258 | −238 | −199 |
| 10 | −231 | 70 | −346 | −301 | −278 | −231 | −184 | −161 | −116 |
| 11 | −165 | 89 | −311 | −254 | −225 | −165 | −105 | −76 | −19 |
| 12 | −102 | 112 | −286 | −214 | −177 | −102 | −27 | 10 | 82 |
| **13** | −42 | 139 | −271 | −181 | −136 | −42 | **52** | 97 | 187 |
| 14 | 17 | 168 | −259 | −151 | −96 | 17 | 130 | 185 | 293 |
| **15** | 73 | 198 | −253 | −125 | −60 | **73** | 206 | 271 | 399 |
| 16 | 126 | 230 | −252 | −104 | −29 | 126 | 281 | 356 | 504 |
| 17 | 177 | 262 | −254 | −85 | 0 | 177 | 354 | 439 | 608 |
| 18 | 226 | 295 | −259 | −69 | 27 | 226 | 425 | 521 | 711 |
| **19** | 272 | 328 | −268 | −56 | **51** | 272 | 493 | 600 | 812 |
| 20 | 286 | 339 | −272 | −53 | 58 | 286 | 514 | 625 | 844 |
| 21 | 299 | 349 | −275 | −50 | 64 | 299 | 534 | 648 | 873 |
| 22 | 312 | 360 | −280 | −48 | 69 | 312 | 555 | 672 | 904 |
| 23 | 323 | 370 | −286 | −47 | 74 | 323 | 572 | 693 | 932 |
| **24** | 334 | 379 | −289 | −45 | 79 | **334** | 589 | 713 | 957 |
| 25 | 340 | 384 | −292 | −44 | 81 | 340 | 599 | 724 | 972 |
| 26 | 344 | 389 | −296 | −45 | 82 | 344 | 606 | 733 | 984 |
| 27 | 348 | 393 | −298 | −45 | 83 | 348 | 613 | 741 | 994 |
| 28 | 351 | 396 | −300 | −45 | 84 | 351 | 618 | 747 | 1,002 |
| 29 | 353 | 398 | −302 | −45 | 85 | 353 | 621 | 751 | 1,008 |
| 30 | 351 | 396 | −300 | −45 | 84 | 351 | 618 | 747 | 1,002 |
| 31 | 348 | 392 | −297 | −44 | 84 | 348 | 612 | 740 | 993 |
| 32 | 344 | 388 | −294 | −44 | 82 | 344 | 606 | 732 | 982 |
| 33 | 340 | 383 | −290 | −43 | 82 | 340 | 598 | 723 | 970 |
| **34** | 334 | 376 | −285 | −42 | 81 | **334** | 587 | 710 | 953 |

The above discussion leads to the establishment of the concession interval as $(T_{c\_L}^{(0)}, T_{c\_U}^{(0)}) = (15, 24)$. This indicates that when the private investor and the concerned government have a common risk confidence level ($\beta = 0$), the basic interests of both sides can be protected if the concession period is arranged between 15 and 24 years in this BOT project.

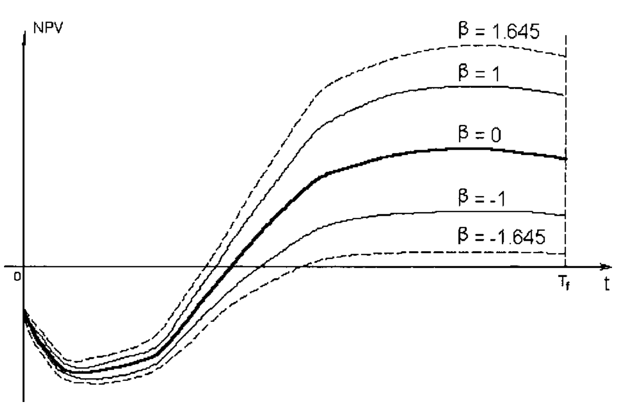


**Fig. 11.** Five particular net present value curves

### *Scenario 2:* $\beta_P < \beta_G$ ($\beta_P = -0.674, \beta_G = 0$)

When $\beta_P < \beta_G$, i.e., the private investor is less confident of the project future than the government concerned, $\beta_P = -0.674$ and $\beta_G = 0$ are adopted for simplicity within the following demonstration.

When $\beta_P = -0.674$, the simulated capital investment is obtained from Table 4:

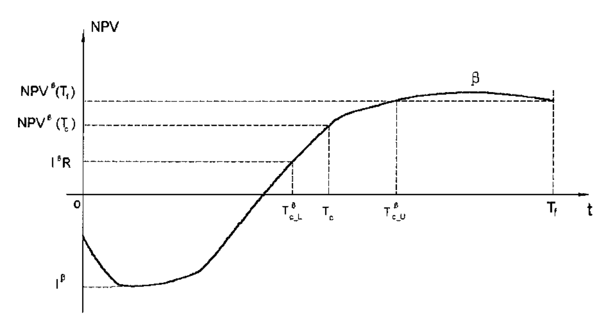


**Fig. 12.** Risk concession period of build–operate–transfer

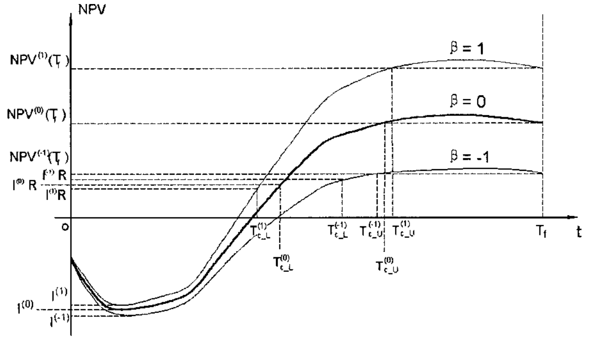


**Fig. 13.** Different concession when different risk levels are considered

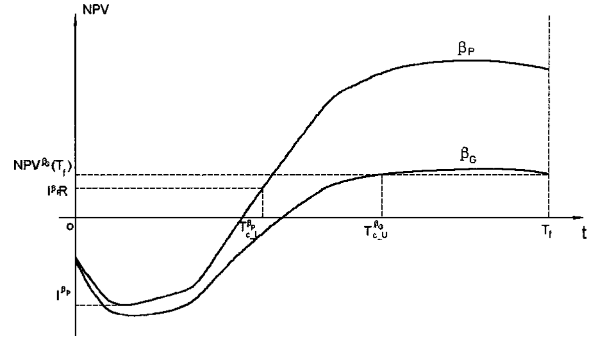


**Fig. 15.** Net present value profile with different perceptions by government and the investor $(\beta_P > \beta_G)$

$$I^{\beta_P} = \left| \operatorname*{Min}_{t=1}^{T_f}\{\mathrm{NPV}^{\beta_P}(t)\} \right| = \left| \operatorname*{Min}_{t=1}^{T_f}\{\mathrm{NPV}^{(-0.674)}(t)\} \right| = 387$$

With a 10% return rate $(R)$, the investor's expected return on investment will be $I^{\beta_P}R = I^{(-0.674)}R = 387 \times 0.1 = 38.7$.

To find the lower limit of concession interval, $T_{c\_L}^{\beta_P}$, the criterion in the model BOTCcM-R, $\mathrm{NPV}^{\beta_P}(T_{c\_L}^{\beta_P}) \geq I^{\beta_P}R$, is used, where $\beta_P = -0.674$, and $I^{\beta_P}R = 38.7$. The value $\mathrm{NPV}^{(-0.674)}(19) = 51$ is obtained from Table 4. Thus, the lower limit, $T_{c\_L}^{(\beta_P)} = T_{c\_L}^{(-0.674)} = 19$, is found as $\mathrm{NPV}^{\beta_P}(T_{c\_L}^{\beta_P}) = \mathrm{NPV}^{(-0.674)}(19) > I^{\beta_P}R$. The upper limit, $T_{c\_U}^{(\beta_G)}$, has been found when $\beta_G = 0$ in Scenario 1, namely, $T_{c\_U}^{(0)} = 24$.

Therefore, the concession interval $(T_{c\_L}^{(\beta_P)}, T_{c\_U}^{(\beta_G)})$ is formulated as (19,24) when the private investor is less confident than the government concerned, i.e., $\beta_P = -0.674$, and $\beta_G = 0$. In other words, if the concession period is arranged between 19 and 24 years, the basic interests of both sides can be protected whilst the private investor has a smaller confidence level that the government concerned.

On the basis of the analysis in scenarios 1 and 2, it can be noted that the concession interval is narrower when the private investor tends to be risk conservative in comparing to the situation where both the private investor and the government concerned have the same risk confidence. This indicates that the alternative concession periods are reduced for negotiation between the two sides if the private investor is reluctant to assume risks.

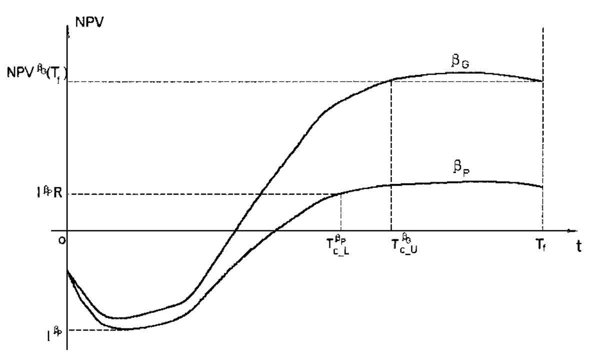


**Fig. 14.** Net present value (NPV) profile with different perceptions by government and the investor $(\beta_P < \beta_G)$

***Scenario 3:* $\beta_P > \beta_G$ $(\beta_P = 0.674, \beta_G = 0)$**

When $\beta_P > \beta_G$, i.e., the private investor's risk seeking attitude is increased, and he is more confident of the project future than the government concerned, $\beta_P = 0.674$ and $\beta_G = 0$ are adopted for the simplicity of the following demonstration.

When $\beta_P = 0.674$, the simulated capital investment obtained from Table 4 is as follows:

$$I^{\beta_P} = \left| \operatorname*{Min}_{t=1}^{T_f}\{\mathrm{NPV}^{\beta_P}(t)\} \right| = \left| \operatorname*{Min}_{t=1}^{T_f}\{\mathrm{NPV}^{(0.674)}(t)\} \right| = 329$$

With a 10% return rate, the investor's expected investment return will be $I^{\beta_P}R = I^{(0.674)}R = 329 \times 0.1 = 32.9$.

The lower limit of concession interval, $T_{c-L}{}^{\beta_P}$, can be identified by using the criterion $\mathrm{NPV}^{\beta_P}(T_{c\_L}^{\beta_P}) \geq I^{\beta_P}R$, where $\beta_P = 0.674$, and $I^{\beta_P}R = 32.9$. From Table 4, the value $\mathrm{NPV}^{(0.674)}(13) = 52$ is obtained. Thus, the lower limit, $T_{c-L}{}^{\beta_P} = T_{c-L}{}^{(0.674)} = 13$, is found as $\mathrm{NPV}^{\beta_P}(T_{c\_L}^{\beta_P}) = \mathrm{NPV}^{(0.674)}(13) > I^{\beta_P}R$.

The above scenario indicates that, when $\beta_G = 0$, the upper limit of concession interval, $T_{c\_U}^{(\beta_G)} = T_{c\_U}^{(0)} = 24$.

The above discussion indicates that the concession interval $(T_{c\_L}^{(\beta_P)}, T_{c\_U}^{(\beta_G)})$ is (13,24) when the risk seeking attitude of the private investor increases, i.e., $\beta_P = 0.674$ and $\beta_G = 0$. If the concession period is arranged between 13 and 24 years, the basic interests of both sides can be protected.

By comparing Scenario 3 to other two scenarios, it can be noted that the concession interval becomes wider when the private investor tends to be more risk seeking. This provides more alternatives for negotiation between the two sides. In the example, the private investor's confidence level is chosen as 0.674. It is a modest level, indicating that the investor is not very risk seeking. Therefore, the difference in concession interval between Scenario 3 where the investor is more risk seeking and Scenario 1 where the investor and government have the same risk confidence is not significant, only by two years. Nevertheless, for all the three scenarios, a feasible concession period lies within an interval. The actual decision on a specific concession period can be negotiated between the two sides, which may be more favorable to either investor or the government, but will certainly protect the basic interests of both sides and reduce the risks perceived by both sides.

Concerning this demonstrative example, an alternative analysis without performing the simulation can be conducted by using the mean values of the distributions. The calculation results of NPV are obtained by using mean values, as shown in Table 5, or shown graphically in Fig. 16. It can be noted that the NPV estimation across the project life cycle is given with a deterministic

**Table 5.** Net Present Value (NPV) Calculation by Using Mean Values of Variable Distributions

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *t* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| NPV | −192 | −278 | −357 | −357 | −354 | −346 | −335 | −321 | −305 | −242 | −182 | −124 | −69 | −18 | 30 | 76 | 119 |
| *t* | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| NPV | 158 | 195 | 207 | 217 | 226 | 234 | 242 | 246 | 249 | 251 | 253 | 254 | 252 | 251 | 248 | 246 | 243 |

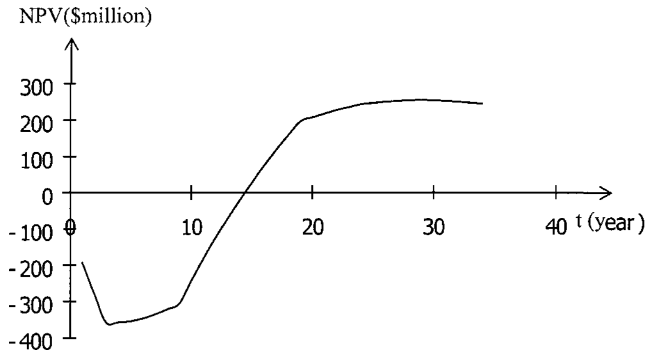


**Fig. 16.** Net present value (NPV) profile by using mean values of variable distributions

value, and the concern interval is found as (16,24). This concession interval cannot incorporate the variations of risk confidence between the investor and the government concerned.

It is considered that the simulation results are more realistic and useful as they provide a likely range of outcomes of NPV in operating the BOT project. They will enable both the investor and the government concerned to assess the level of risk involved in a BOT project, and to forecast the likelihood of the results that investor or the government might expect.

## Conclusions

The key factor of a BOT project is the agreement on the length of concession period. The establishment of this agreement is usually based on the analysis on project cash flow measured by NPV. Traditionally, this cash flow is described as a deterministic flow, and agreed upon by both sides. Shen et al. (2002) adopted the traditional cash flow approach and presented a methodology for determining a concession period which may protect the basic interests of both sides. This paper argues that various risks exist in the process of implementing a BOT project, and that they have significant impacts to project cash flow. It is therefore considered more proper to describe the project NPV with a distribution of estimates and consider risk impacts. Based on a simulated case with the adoption of the Monte Carlo simulation technique, the distribution of NPV value at a specific time point within the project process can be reasonably described with a normal probability distribution.

This paper extends the concession model by Shen et al. (2002) to incorporating risks impacts, leading to the development of a risk concession model. The application of the risk concession model to a simulated case in the paper indicates that there will be a wider interval for agreeing upon a concession period between the private investor and the concerned government if the private investor is prepared to accept a higher risk that that of the government. On the other hand, an acceptable concession period to both sides will be subject to a narrow feasible interval if the private investor is more risk conservative. In some extreme cases, a feasible concession period may not be available if both sides are too risk conservative. The adoption of the concession period derived from the risk concession model is expected to reduce the impact of the risk to the parties who may perceive risks differently. Furthermore, the simulation results of NPV value across the project life provide a wide range of information for decision making.

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