Risk-Neutral Pricing Approach for Evaluating BOT Highway Projects with Government Minimum Revenue Guarantee Options

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Abstract: Build-operate-transfer (BOT) is a public-private partnership (PPP) project delivery system for the financing, development, and operations of highway projects around the world. Uncertainty about future traffic demands is one of the most important risk factors in the operations phase of a BOT project. There is a considerable amount of evidence indicating that the improper consideration of this uncertainty contributes to the financial failure of BOT projects. The inherent limitation of conventional economic analysis methods contributes to this uncertainty; most notably the net present value (NPV) approach that is typically used in the economic valuation of BOT projects. In addition, the NPV approach is insufficient to determine the correct market value of minimum revenue guarantee (MRG) options. The government offers MRG options to the concessionaire as a revenue risk-sharing strategy in BOT projects. The authors apply the real options theory from finance/decision science to explicitly price MRG options in BOT projects. This real options model has several prominent attributes that make it different from NPV models. It uses a market-based option pricing approach called risk-neutral valuation method to determine the correct value of MRG options. Unlike the other models, this approach treats the risk of underestimating future traffic demands internally and adjusts for the traffic market risk in the valuation of MRG options. The authors' approach also describes a procedure for characterizing the concessionaire's economic risk profile under uncertainty about future traffic demands. In addition, it uses real options analysis to price MRG and traffic revenue cap (TRC) options as compound options and determines their effects on the concessionaire's economic risk profile. The probability distributions of when the concessionaire may request MRG and when the public sector may receive additional revenues as TRC options are also presented. Further, the distributions of the number of times that the concessionaire may request the MRG option and the number of times that the public sector may receive additional revenue are characterized. Finally, this model identifies the probability distributions of the present value of MRG options and the present value of total additional revenues recalled by the public sector. The proposed model can help public and private sectors better analyze and understand the economic risk of BOT projects under uncertainty about future traffic demands. The private sector can use this proposed model to make better entry decisions to BOT highway projects considering the level of support provided by the government. The government can also use this proposed model to identify the appropriate MRG levels to encourage private investments without comprising future budgetary strength. **DOI: 10.1061/(ASCE)CO.1943-7862.0000447.**

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Introduction

Highway systems across the United States are aging and need major improvements. According to the Report Card for America's Infrastructure (ASCE 2009), 33% of America's major roads are in poor or mediocre condition and 36% of the nation's major urban highways are congested. As a result, more than 4.2 billion hours a year are wasted in traffic, at a cost of \$78.2 billion per year. The federal Department of Transportation (DOT) and state DOTs are facing rising expectations to support economic growth and social welfare by maintaining, modernizing, and expanding highway systems, which, in turn, requires a substantial amount of irreversible investment. State DOTs are unable to keep up with these rapidly rising expectations and cannot deliver required highway projects in a timely manner with the limited financial resources available through federal and state budgets.

Public-private partnership (PPP) is a project delivery system that can help address these rising expectations. The National Council for Public-Private Partnerships defines PPP as "a contractual agreement between a public agency (federal, state or local) and

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a private sector entity." Through this agreement, the skills and assets of each sector (public and private) are shared to deliver the service or facility to the public. In addition to resources, each party shares the inherent risks of PPP projects. A common form of implementing PPP is the build-operate-transfer (BOT) method, which is also known as build-own-operate-transfer (BOOT) in Canada, Australia, and New Zealand. From 2001 to 2006, BOTs made two-thirds of private highway investments ($18 billion) in developing countries (Queiroz and Izaguirre 2008). The major aim of BOT is to utilize the private sector's financing resources and operations expertise in the delivery of public services. The private investors recover initial investments from revenues generated by infrastructure assets.

In a BOT project delivery system, the private partner, generally referred to as the "concessionaire," is responsible and financially liable for performing all or a significant number of functions related to the project. The concessionaire is typically a consortium of private companies with expertise in different functions, including design, construction, financing, operations, and maintenance (Federal Highway Administration 2008). The concessionaire operates the facility for a specified period of time according to the concession contract and then transfers the facility to the agency at the end of the concession lifetime (United States General Accounting Office 1999).

Despite the promising features of the BOT project delivery system for highway development, its implementation has not been without trouble. There is a considerable amount of evidence indicating that the improper consideration of uncertainty about future traffic demands in BOT projects contributes to the financial failure of these projects. The most infamous cases of failure have occurred in Mexico, where the Mexican government had to take over 23 troubled BOT toll road projects. The Mexican government also paid approximately $5 billion in outstanding debt to Mexican banks and approximately $2.6 billion to construction companies (Hodges 2006). Similar instances have occurred in countries such as Hungary and Thailand (Cuttaree 2008). The financial failure of many BOT projects during the operations phase is generally attributed to two major issues (Queiroz 2007; Cutaree 2008):

1. Poor and/or unrealistic assumptions in estimating toll revenues, which are used in the BOT financial analysis; and
2. Inefficient revenue risk-sharing mechanisms between the public and private sectors.

These issues can be traced to the methods used for the economic evaluation of BOT projects. Traditionally, discounted cash flow (DCF) techniques and most notably the deterministic net present value (NPV) analysis have been used to evaluate highway PPP projects (Cheah and Garvin 2009). These conventional methods are inadequate to properly evaluate BOT projects since they do not explicitly capture and treat uncertainty about future traffic demands, which has been identified by numerous researchers as the significant source of revenue uncertainty during the operations phase of BOT projects (Ho and Liu 2002; Zhao et al. 2004; Garvin and Cheah 2004; Chiara et al. 2007; Brandao and Saraiva 2008; Cuttaree 2008). There are increasing concerns about the validity of results and the reliability of using a conventional NPV analysis approach for economic evaluation of PPP highway projects. If the NPV approach was used as a basis of decision-making for a BOT project, the financial solvency of the project and creditworthiness of the concessionaire could results in project failure. Hence, Kaka and AlSharif (2009) indicate a pressing need for developing nondeterministic methods for the proper valuation of BOT projects.

In addition, a 2005 survey of international toll roads, bridges and tunnels revealed that traffic forecasts are typically optimistic and are on average approximately 23% higher than actual traffic demands (Bain 2009). Considering the uncertainty of forecasted future traffic demands, the private sector often requests government support to share the financial risk of overestimating project revenues. One of the most common forms of government support instruments is minimum revenue guarantee (MRG). The government can provide this support to the private sector when the actual toll revenues are lower than anticipated (Mandri-Perrott 2006). Hence, MRG is a mechanism for sharing the revenue risk between the concessionaire and government. A similar mechanism can be applied to share the surplus revenue. This mechanism is often referred to as toll revenue cap (TRC). The NPV approach is not able to address the impact of these risk- and opportunity-sharing options on the financial valuation of BOT projects. Further, the NPV approach is unable to determine the correct market value of these government support options. Decision-makers need a proper valuation method to avoid under- and over-investments in infrastructure highway projects. Investors also need a better valuation method to determine the correct market value of government support options.

The described limitations of the NPV approach can be overcome by using a different approach to evaluate investments with underlying uncertainties. The real options analysis is a financial engineering methodology that provides an integrated formwork to evaluate investment opportunities under dynamic market uncertainty (Dixit and Pindyck 1994). The authors' research objective is to apply the real options theory from finance/decision science to explicitly price MRG options in BOT projects. To achieve this objective, the authors present a real options model that utilizes a market-based option pricing approach called risk-neutral valuation method to determine the correct value of MRG options. Unlike the other models, this approach treats the risk of overestimating future traffic demands internally and adjusts the valuation process to calculate the value of MRG options in BOT projects.

Section 2 of this paper provides the current state of knowledge in real options analysis for investment valuation of highway projects. Section 3 describes the authors'real options model and the unique features of our model that differentiate it from existing models. Section 4 applies the authors' model to a highway project in Korea to illustrate valuation processes and provides a summary of results and Section 5 presents conclusions and future work.

Research Background

Conventional NPV Analysis

Traditionally, a concessionaire evaluates a BOT project using the deterministic NPV analysis approach. The first step in this approach is to outline the concessionaire's cash inflows and outflows. Table 1 shows an example of the concessionaire's cash flows over the investment lifetime of a BOT project. The concessionaire's cash outflows consist of different project cost components including construction costs, operations, maintenance, and rehabilitation costs, and a debt payment plan. Construction costs are the initial expenses to build a BOT project. Operations, maintenance, and capital improvement costs are annual expenses required to keep the highway project within the acceptable service level. The debt payment plan summarizes the principal and interest payments of construction-related loans or other costs related to financing such as public bonds. The annual concessionaire's cash inflows start after the project is completed and the highway opens for traffic. The forecasted concessionaire's operating revenue is primarily based on the tolls collected from the traffic. The toll rates for various kinds of vehicles are predetermined in the initial concession agreement and may be subject to revision thereafter. The annual

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Table 1. Example of Concessionaire's Cash Flow Table Over Investment Lifetime of BOT Project

Cash flow	1995	1996	1997	1998	1999	….	2030
Financing activities inflows	34.9	209.7	385.4	351.7	240.1	….	
Equity	34.9	209.7	131.9			….	
Debt			253.6	351.7	240.1	….	
Financing activities outflows							
Construction cost	−34.9	−209.7	−385.4	−351.7	−240.1	….	
Operations revenue						….	882.5
Operations and maintenance						….	−373.7
Investor's net cash flow	−34.9	−209.7	−131.9	0.0	0.0	….	508.8

concessionaire's net cash flows are computed as the net difference between the annual cash inflows and outflows over the project lifetime. The project net cash flows are shown in Table 1.

These net cash flows are discounted back to the beginning of the project to calculate the concessionaire's NPV. The choice of discount rate in the NPV analysis approach is often subjective and, therefore, challenging in the BOT project valuation. The discount rate represents the rate of return that the concessionaire expects from investing in the BOT project, i.e., the discount rate is the risk-adjusted cost of capital for the concessionaire. The weighted average cost of capital (WACC) and the Capital asset pricing model (CAPM) are two methods which have been frequently used in the identification of the discount rate for BOT projects. Ellingham and Fawcett (2006) and de Neufville (1990) provide a thorough discussion about the choice of discount rate in the conventional valuation of infrastructure projects. Using the concessionaire's choice of discount rate and the BOT project net cash flows, the NPV analysis can be conducted according to the following formulation

$$\mathrm{NPV} = -\sum_{i=0}^{n} \frac{CC_i}{(1+\rho)^i} + \sum_{j=n+1}^{N} \frac{(PR_j - OC_j)}{(1+\rho)^j} \tag{1}$$

where n = length of construction period in years; N = total concession length in years from the initial construction to the return of the highway asset to the government; CC_i (where $i = 1, 2, \ldots, n$) = annual construction costs from the beginning of the project until the end of construction period; OC_j $j = n+1, n+2, \ldots, N$) = annual operations, maintenance, and rehabilitation costs from the first year after the project is completed until the end of concession period; PR_j (where $j = n+1, n+2, \ldots, N$) = forecasted annual toll revenues from the first year after the project is completed until the end of concession period; and ρ = discount rate.

Limitations of NPV Analysis Approach

As described previously, the conventional NPV analysis approach is not difficult to implement but it is subject to two major limitations for the proper evaluation of BOT projects: (1) the improper treatment of traffic uncertainty in the evaluation procedure; and (2) the choice of the subjective discount rate. The NPV analysis approach does not explicitly capture and treat uncertainty about future traffic demands, which in turn, determine the concessionaire's revenue cash inflows. The concession length is often several decades, which makes it impractical to accurately forecast future traffic demands for the BOT project. This is noted as the demand risk in BOT projects, which is due to the inability of the concessionaire to determine the behavior of actual traffic demands compared to forecasted traffic demands (TRANSYT 2007). The BOT project is then subject to the risk of underestimating future traffic demands and may not earn sufficient revenues to recover the operations expenses and debt payments or leave an adequate return for investors (Chiara et al. 2007). Researchers concur that uncertainty about future traffic demands is one of the most significant risks in the operations phase of BOT projects (Ho and Liu 2002; Zhao et al. 2004; Garvin and Cheah 2004; Chiara et al. 2007; Brandao and Saraiva 2008).

There is no standard systematic approach in the conventional NPV analysis to describe how the discount rate should be adjusted to reflect the risk of underestimating future traffic demands. The choice of an exogenous discount rate is critical for the proper evaluation of BOT projects because the project NPV is very sensitive to changes in the value of discount rate. Therefore, if the NPV approach is used as a basis of decision-making for a BOT project, the financial solvency of the project and creditworthiness of the concessionaire could be inadequate and my result in project failure.

Considering the great uncertainty about future traffic demands, the private sector often requests government supports to share the financial risk of overestimating project revenues. This has created a growing pressure on the government to provide incentives to guarantee the financial viability of BOT projects and attract private investors. If the government fails to address this private sector's concern, it would reduce the participation of private investors in high-risk BOT projects and contribute to the project failure. For instance, the poor risk management assumptions of the Mexican and Hungarian governments were central in the financial collapse of several BOT projects in these countries (Cuttaree 2008).

Irwin (2003) summarizes several public support instruments applicable to BOT projects: output-based cash subsidies; in-kind grants; tax breaks; capital contributions; guarantees of risks under the government's control; and guarantees of risks not under the government's control. These support instruments are intended to enhance the concessionaire's ability to develop, operate, and maintain the BOT highway project at the satisfactory service level and maintain the road toll at an affordable level.

One of the most common forms of government support instruments is an MRG. The government will provide an MRG to the private sector when the actual toll revenue falls shorter than the forecasted revenues (Mandri-Perrott 2006). Hence, MRG is a mechanism for sharing the revenue risk—over which neither the government nor the private sector has control—in a BOT project. A similar mechanism can be applied to share the surplus revenue between the concessionaire and government. This mechanism is often referred to as TRC. The poor choice of an MRG threshold and a TRC may lead to the inappropriate risk-sharing between public and private sectors. The poor risk-sharing mechanism also impacts the BOT project credit rating and reduces the government's flexibility to invest in other required transportation projects. The conventional NPV approach is unable to address the impact of risk-sharing mechanisms on the financial evaluation of investments

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in BOT projects. To overcome the limitations of the conventional NPV analysis method, the authors propose an alternative approach for evaluating investments under uncertainty—real options analysis.

Real Options Analysis

The term "real options" was first introduced by Myers (1977). It referred to the application of options pricing in finance and banking, such as Black and Scholes formula (1973), to the assessment of nonfinancial or "real" investment opportunities. The real options analysis is the state-of-the-art financial engineering methodology that provides an integrated formwork to evaluate investment opportunities under dynamic market uncertainty (Dixit and Pindyck 1994). The field of real options analysis has gone through a transition from a topic of a modest academic interest in 1980s and 1990s to one that now receives considerable, active academic and industry attention (Borison 2005). The real options methodology has been applied in several different industries, such as technology assessment (Shishko et al. 2004), research and development (Bodner and Rouse 2007), retail (Ashuri et al. 2008), mining (Mayer and Kazakidis 2007), manufacturing (Bengtsson 2001), healthcare (de Neufville et al. 2008), corporate real estate (Ashuri 2010), architecture (Greden and Glicksman 2005), building technology (Greden et al. 2006), construction engineering and management (Ford et al. 2002).

The body of knowledge on the application of real options in infrastructure management is still growing. Prior research has focused on the definition and analysis of various kinds of options on highway projects. Ho and Liu (2002) present an option pricing model for evaluating the impact of the government's guarantee and the developer's negotiation option on the financial viability of privatized infrastructure projects. Zhao et al. (2004) developed a multistage stochastic model for decision-making in highway development, operations, and rehabilitation, which considers three sources of uncertainty, namely, future traffic demands, land price, and highway deterioration, and their interdependencies. Garvin and Cheah (2004) used an option pricing model to capture the strategic value of project deferment for The Dulles Greenway project. Cheah and Liu (2006) used Monte Carlo simulation methodology to evaluate government guarantees and subsidies as real options and apply it to the case of the Malaysia-Singapore Second Crossing. Huang and Chou (2006) developed a compound option pricing formula for the Taiwan High-Speed Rail Project. Minimum revenue guarantee options combined with the option to abandon in the preconstruction phase are evaluated as a series of European-style call options in their work. Chiara et al. (2007) modeled governmental guarantees on BOT projects as one of three discrete-exercise real options: European, Bermudan, and simple multiple-exercise (Australian) options, and expanded the least-squares Monte Carlo technique to value these guarantees. Brandao and Saraiva (2008) present a real options model for evaluating highway projects with minimum traffic guarantees, and applied it to the 1000 mi BR-163 toll road project that links the Brazilian Midwest to the Amazon River.

This study builds upon and contributes to this body of knowledge. This study's real options model has several attributes which make it different from the previous models. It uses a market-based option pricing approach called the risk-neutral valuation method to determine the correct value of MRG options. Unlike the other models, this approach treats the risk of overestimating future traffic demands internally and adjusts for the traffic market risk in the valuation of MRG options. This is done through developing a procedure for estimating the project volatility that will be used to determine the market price of revenue risk.

In addition, this model offers several important features which have not been discussed in previous models. It determines the concessionaire's economic risk profile under uncertainty about future traffic demands in a BOT project. A combination of MRG and TRC options is evaluated as a compound option in this valuation model. The impact of MRG and TRC options on the concessionaire's economic risk profile is also shown in this valuation approach. The model provides the probability distribution of when the concessionaire requests MRG and when the public sector receives additional revenue as TRC options. Further, this study characterizes the distribution of the number of times that the concessionaire requests the MRG option, and the number of times that the public sector receives additional revenue. Finally, this model identifies the distribution of the present value of MRG options, and the present value of total additional revenues recalled by the public sector. The government can benefit from this market-based valuation framework to avoid conferring substantial subsidies and undervaluing investment opportunities in BOT projects. The concessionaire can use this valuation model to determine the correct market value and the economic risk profile of an investment opportunity in a BOT project. This study's real options model is described in the next section.

Real Options Model

Fig. 1 shows an overview of the proposed real options model consisting of the following steps:

1. Specify required input data (e.g., cost data related to the BOT project) the concessionaire's capital structure, and future traffic demands;
2. Develop a binomial lattice model to characterize uncertainty about future traffic demands;
3. Generate random future paths for future traffic demands using Monte Carlo simulation technique;
4. Conduct life cycle cost and revenue analysis for the BOT project under each random traffic path and characterize the concessionaire's economic risk profile; and
5. Adjust the binomial lattice model of future traffic demands based on the risk-neutral option valuation approach and repeat

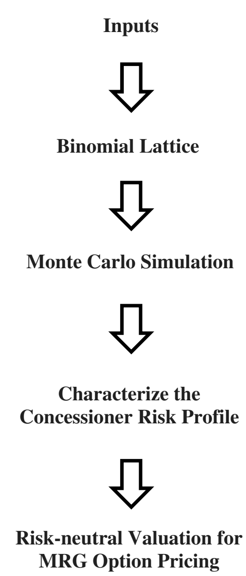

Fig. 1. Overview of the proposed real options analysis model

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Steps 3 and 4 to characterize the concessionaire's economic risk profile with MRG and TRC options.

Inputs

Certain data are required as inputs to the proposed model. The first dataset is the BOT project life cycle costs, including construction costs, operations, maintenance, and capital improvement costs over the concession lifetime, as described in Table 1. The second dataset is the concessionaire's capital structure consisting of the a debt payment plan and the concessionaire's cost of capital. The debt payment plan is a series of principal and interest payments, as summarized in Table 1. The cost of capital is the minimum rate of return that the concessionaire needs to compensate for bearing risks and waiting for returns. This rate is specific to the concessionaire and will be used as the discount rate in this analysis.

The third dataset is used for characterizing uncertainty about future traffic demands and consequently, uncertainty about future project revenues. Traffic study is typically conducted for all major BOT projects by special consultant groups. A typical traffic study summarizes the annual average daily traffic (AADT) values over the concession lifetime. Annual average daily traffic is the total volume of vehicles passing through a highway in a year divided by 365 days. Traffic study often contains three Annual average daily traffic projections as optimistic, most-likely, and pessimistic forecasts. This is a simple approach to address uncertainty about future traffic demands. However, in this approach the authors treat uncertainty about future traffic demands in a stochastic manner. The authors use the traffic study report to determine three forecasts of the initial traffic demand for the BOT project. Also, the authors use the traffic study report to determine the expected annual growth rate of AADT. This expected annual growth rate may change over the project lifetime depending on the traffic study assumptions. Suppose AADT_j (where $j = n+1, n+2, \ldots, N$) are the most-likely forecasts of AADT from the first year after the project is completed $(n+1)$ until the end of concession lifetime (N). The authors will use these $N-n$ data points in time, spanning over $N-(n+1)$ periods, to compute the expected annual growth rate of AADT—denoted by α—as follows (Luenberger 1998)

$$\alpha = \frac{1}{N-(n+1)} \ln\left[\frac{\text{AADT}_N}{\text{AADT}_{n+1}}\right] \tag{2}$$

The expected annual growth rate of AADT is not sufficient to characterize uncertainty about future traffic demands. The authors also need to know the annual volatility of AADT to describe uncertainty about future traffic demands. Annual volatility (or parameter σ) hereafter refers to the standard deviation of the expected annual growth rate of AADT. It is often used to quantify the risk of underestimating/overestimating the future traffic growth over the concession lifetime. The choice of annual volatility of AADT is often not easy since the BOT project is yet to be built. Three ways are suggested to determine σ in BOT projects: (1) use historical AADT data of similar existing highway projects to estimate the volatility of the new BOT project (Irwin 2003); (2) use the forecasted annual volatility of gross domestic product (GDP) of the region where the BOT project is built (Banister 2005)—available from an appropriate economic research source—as a surrogate measure for the annual volatility of AADT; and (3) refer to the subject matter experts' opinions to estimate the annual volatility of the new BOT project (Brandao and Saraiva 2008). The authors assume that the concessionaire can use one of the previously mentioned approaches to provide an appropriate estimate for σ. Sensitivity analysis should, however, be conducted to account for the risk of improper estimation for the volatility of AADT.

Binomial Lattice

The authors use a binomial lattice model (Hull 2008) to characterize uncertainty about future values of AADT. A binomial lattice model is a simple, discrete random walk model that has been used by several researchers (e.g., Ho and Liu 2002; Garvin and Cheah 2004) to characterize uncertainty about future traffic demands. The modeling choice of binomial lattice is consistent with the general body of knowledge in real options analysis (e.g., Hull 2008; Luenberger 1998). In economics and finance, the binomial lattice is an appropriate random walk model to capture uncertainty about a variable that grows over time plus random noise (Dixit and Pindyck 1994; Copeland and Antikarov 2001). A basic period length of one month is considered to define a binomial lattice for future traffic demands, i.e., $\Delta t = 1$ month $= 1/12$ year. According to the model formulation, the current traffic demand AADT_0 is known. In the proposed model, it is assumed that AADT_0 is chosen randomly from a triangular distribution whose lowest, most-likely, and highest parameters are the pessimistic, most-likely, and optimistic forecasts of the initial traffic demand, respectively. These forecasts are specified in the traffic study report as described in Step 1. Then, the AADT at the beginning of the following month is assumed to take just one of the two multiples of the AADT at the current period: a multiple (u) for the upward movement and a multiple (d) for the downward movement where both u and d are positive values with $u > 1$ and $d < 1$. The probabilities of upward and downward movements are $0 \le p \le 1$ and $0 \le 1-p \le 1$, respectively. These binomial lattice parameters can be determined using the expected annual growth rate of AADT, α, and the annual volatility of AADT, σ, as formulated in Eq. (3) (Hull 2008) as follows:

$$u = e^{\sigma\sqrt{\Delta t}} \qquad d = e^{-\sigma\sqrt{\Delta t}} \qquad p = \frac{e^{\alpha \Delta t} - d}{u - d} \tag{3}$$

Fig. 2(a) shows the binomial lattice for future values of AADT. The initial AADT is AADT_0, which is the AADT at the beginning of the first year after the project is completed. The AADT at the beginning of the second month will be either $u \times \text{AADT}_0$ with probability p or $d \times \text{AADT}_0$ with probability $1-p$. This variation pattern continues for subsequent months until the end of the concession lifetime. The probability of upward movement from any node in this lattice is p and the probability of downward movement from any node is $1-p$. An upward movement followed by a downward movement is identical to a downward movement followed by an upward movement in the binomial lattice. A slight modification in this binomial lattice model is necessary to ensure that infeasible, large future traffic demands are not generated for AADT. A highway is operationally adequate for providing satisfactory services to a specific maximum number of vehicles (Transportation Research Board 2000). The authors use this maximum capacity as the cap for AADT values in this binomial lattice. Any AADT values over this cap will be changed to the maximum AADT in the proposed binomial lattice model.

A lattice model is a simple, yet powerful, model to capture the dynamic uncertainty about future traffic demands in an approximate fashion. Particularly, if the period length is relatively small (e.g., 1 month), many AADT values are possible after several short time steps (Hull 2008; Luenberger 1998). This AADT binomial lattice will be used as a basis to generate random paths for future traffic demands in the BOT project as described in the next section.

Monte Carlo Simulation

The authors use the Monte Carlo simulation technique to generate several random paths for AADT along the binomial lattice from the

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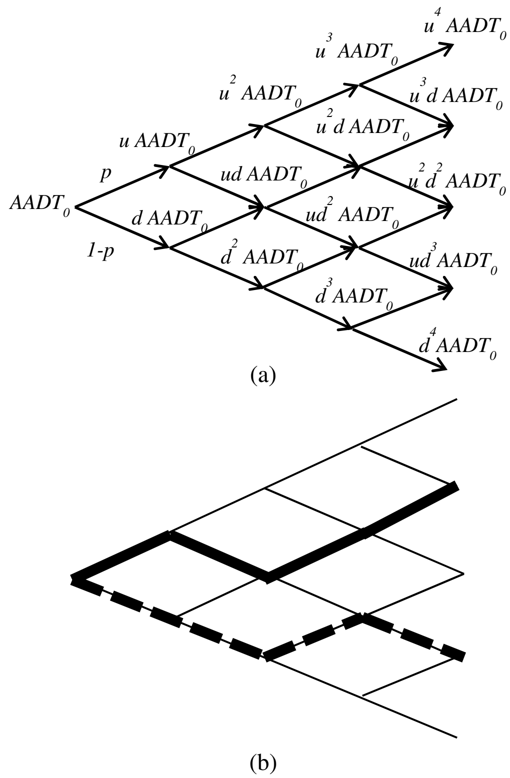

Fig. 2. (a) Binomial lattice to model AADT uncertainty; (b) randomly generated traffic demand paths along the binomial lattice

first year after the project is completed until the end of the concession lifetime. Considering the binomial lattice formulation, AADT at the beginning of the j year $j = n+1, n+2, \ldots, N$ is a random variable that follows a discrete binomial distribution. There are several upward and downward movements that are needed to reach any node in this lattice from the root. The initial AADT at the beginning of the $(n+1)$ year is AADT_0, which represents the respective AADT value of the root node in the authors' binomial lattice model. The possible values of AADT at the beginning of the $(n+2)$ year, $(n+3)$ year, …, (N) year are summarized in the binomial lattice nodes of the 12th month, 24th month, …, $(12 \times (N - (n+1)))$ month, respectively.

Take any node in month $l = 12, 24, \ldots, 12 \times (N - (n+1))$. This node can be reached from the root node by $0 \le k \le l$ upside and $0 \le l - k \le l$ downside movements along the lattice. The AADT at this node, then, becomes $\text{AADT}_0 \times u^k d^{l-k}$, which has the following binomial distribution

$$\Pr(\text{AADT at the Beginning of the } (l) \text{ month} = \text{AADT}_0 \times u^k d^{1-k}) = \begin{bmatrix} 1 \\ k \end{bmatrix} p^k (1-p)^{1-k} \quad (4)$$

This binomial distribution is used to generate random binomial variables as AADT values over the project lifetime. The Monte Carlo simulation engine for binomial random variables is then applied to generate a large number of random AADT paths across the binomial lattice as shown in Fig. 2(b). This simplicity is a powerful feature of the proposed model model for characterizing uncertainty about future traffic demands, which will be used to determine random revenue streams for the concessionaire, as discussed in the next section.

Life Cycle Cost and Revenue Analysis under AADT Uncertainty

Each generated random AADT path represents a possible revenue stream for the concessionaire. The annual operating toll revenue from the first year after the project is completed until the end of concession lifetime—OR_j $j = n+1, n+2, \ldots, N$—can be calculated for each generated random AADT path as follows:

$$OR_j = \text{AADT}_j \times 365 \times \text{Scheduled Toll Rate}_j \quad j = n+1, n+2, \ldots, N \quad (5)$$

Thus, the authors generate random cash inflows as the concessionaire's future revenues through each simulation run. These randomly generated revenue streams will then be used to calculate the concessionaire's NPV based on Eq. (1). The concessionaire's cost of capital is used as the discount rate (ρ) in this equation. A sufficiently large number of simulation runs should be conducted to calculate all possible NPVs, in addition to their respective likelihoods. The cumulative distribution function (CDF) can be identified for the concessionaire's NPV in this toll road project. Therefore, the proposed model expands the conventional NPV analysis approach by the systematic treatment of uncertainty about future traffic demands.

The CDF of the concessionaire's NPV can be used to calculate the probability of the event that the NPV of investing in the BOT project is negative. Investors can use this probability and decide whether investing in the BOT concession stays within the appropriate confidence level in their portfolio. The risk-neutral option pricing method can be used to determine how the concessionaire's economic risk profile changes considering risk- and revenue-sharing options.

Risk Neutral Valuation

Uncertainty about future traffic demands causes the private sector to request government supports in order to share the financial risk of overestimating project revenues. In this paper, the authors study MRG, one of the most common forms of government support instruments. An MRG option is a discrete-exercise real option in infrastructure finance (Chiara et al. 2007). The concessionaire or the MRG holder has the right but not the obligation to use this guarantee at prespecified points of time over the concession lifetime. The authors assume that the concessionaire has this MRG option for every year after the project is completed (i.e., year j where $j = n+1, n+2, \ldots, N$).

The authors also assume that MRG options are provided free-of-charge to the concessionaire as a motivation to attract private investments in public infrastructure assets. However, it is necessary for both the concessionaire and the government to determine the correct market value of MRG options. The concessionaire needs to determine the impact of MRG options on the economic risk profile while the government needs to evaluate the correct cost of MRG options for the tax payers. The concessionaire should use a market-based approach to properly account for the investment risk in the evaluation of the BOT project. The authors propose a risk-neutral valuation approach (Hull 2008) for this purpose as described subsequently.

Suppose PR_j is the forecasted toll road revenue in year $j = n+1, n+2, \ldots, N$; PR_j is computed based on the most -likely value of future traffic demands—which are specified in the traffic study—as follows:

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$$PR_j = \text{Most Likely Estimated AADT}_j \times 365 \times \text{Scheduled Toll Rate}_j \quad j = n+1, n+2, \ldots, N \tag{6}$$

In any year, the government offers an MRG if the actual toll revenue (i.e., $OR_j\, j = n+1, n+2, \ldots, N\nabla$) falls shorter than the respective, prespecified toll revenue (i.e., $PR_j\, j = n+1, n+2, \ldots, N$). The MRG is offered as an $X_j\, j = n+1, n+2, \ldots, N$ percentage of this difference to cover the revenue shortfall in any year as follows:

$$MRG_j = \text{Max}\{0, X_j \times (PR_j - OR_j)\} \qquad j = n+1, n+2, \ldots, N \tag{7}$$

where MRG_j (where $j = n+1, n+2, \ldots, N$) = additional revenue in year j if the actual revenue falls shorter than the prespecified revenue in year j. The additional revenue is the concessionaire's option payoff that changes the concessionaire's economic risk profile in the BOT project. The conventional NPV analysis approach is not a correct method to evaluate investment opportunities with embedded real options, such as BOT projects with government MRG options. The risk-neutral valuation approach should be used as a correct options pricing method to determine the correct market value of MRG options in BOT projects.

The risk-neutral valuation approach is developed in mathematical finance to price options and derivatives by revising the probability measures of underlying assets (Luenberger 1998; Hull 2008). The price of an option depends on the risk of the underlying asset. Investors are typically risk-averse and demand returns for bearing uncertainty about the underlying asset. Therefore, option payoffs should be discounted at an appropriate risk-adjusted rate to compute the option price.

Under the condition of the absence of arbitrage opportunity in the market, there is an alternative equivalent method to do this calculation. Instead of first taking the expectation and then discounting for the risk, the probabilities of future asset values can first be adjusted to incorporate the risk effects, the expectation under these risk-adjusted probabilities can be calculated, and then, the expected future option payoffs at the risk-free rate can be discounted. These revised probabilities are just mathematical artifacts and are therefore counterfactual, i.e., they do not exist in the real world. These probabilities are called risk-neural probabilities and this option pricing method is referred to as risk-neutral valuation approach. The option value using the risk-neutral valuation approach is equivalent to the option value using the former direct approach. The major benefit of risk-neutral valuation approach is that once the risk-neutral probabilities of the underlying asset are found, the expected option payoffs will be discounted at the risk-free rate. Correctly implemented, the risk-neutral valuation approach produces the correct option price.

An MRG option should be evaluated as a derivative whose underlying asset is future traffic demand. Therefore, the authors need to revise the probabilities of future traffic demands to find the value of MRG options. The authors adopt and manipulate a method developed by Hull (2008) for adjusting the probabilities of AADT binomial lattice in Section 3.2. The modification of the AADT binomial lattice for applying the risk-neutral valuation approach is described subsequently.

First, the authors need to substitute the actual expected growth rate of AADT, α, in Eq. (3) with the risk-neutral expected growth rate of AADT—denoted by $\alpha - \lambda\sigma$. Then, the authors compute the risk-neutral probabilities of upward and downward movements using this revised expected growth rate. In this adjustment, σ is the volatility of AADT and λ is the market price of traffic demand risk; λ is also called the Sharpe ratio or reward-to-variability ratio. It is a measure of the excess return or risk premium per unit of risk of the underlying asset. Using the Sharpe's definition (1994), the risk premium of future traffic demands is described as follows:

$$\lambda = \frac{R - r_f}{\sigma} \tag{8}$$

where R = asset return; r_f = risk-free rate of return; and σ = volatility of future traffic demands. The future traffic demand is not a traded asset in the financial market and, therefore, the authors cannot observe and find the excess return $R - r_f$ that investors require to bear the risk of the underlying asset. Since the revenue risk in the operations phase of the project stems from uncertainty about future traffic demands, the risk premium of investment in the BOT project—denoted by λ_p—must be identical to the risk premium of future traffic demands (i.e., $\lambda = \lambda_p$). The concessionaire's risk premium in the project λ_p, conversely, can be computed.

The concessionaire's excess return—denoted by $R_p - r_f$—is the excess return that the concessionaire wants to invest in this project. The concessionaire's return (R_p) is the cost of capital (ρ) that has been used as the discount rate in the NPV calculation. Thus, the concessionaire's excess return in the project is $\rho - r_f$. In addition, Copeland and Antikarov (2001) describe an approach for computing the project volatility (σ_p). This approach is based on the fact that the concessionaire's NPV without any options is an unbiased indicator of the project market value. Hence, the return on the project NPV can be used to compute the project volatility. The return on the project NPV is the log-ratio of the concessionaire's first-year present value to the concessionaire's initial, forecasted present value [i.e., $\ln(PV_1/PV_0)$]. The initial investment costs to construct the project should be excluded in the concessionaire's present value calculation. The initial forecasted present value (PV_0) is constant and is based on the most-likely forecasts of future traffic demands. The first-year present value (PV_1) is variable and is computed based on generated random paths of future traffic demands. The standard deviation of the log-return present value distribution [i.e., the standard deviation of $\ln(PV_1/PV_0)$ distribution] is the project volatility (σ_p). Thus, the risk premium of future traffic demands (λ) or the risk premium of the BOT project (λ_p) can be calculated as follows:

$$\lambda = \lambda_p = \frac{R_p - r_f}{\sigma_p} = \frac{\rho - r_f}{\sigma_p} \tag{9}$$

The valuation of the BOT project with MRG options will be conducted using the risk-neutral binomial lattice of AADT. The concessionaire's economic risk profile with MRG options can be characterized using the same evaluation steps described in Sections 3.3 and 3.4. The Monte Carlo technique will be used to generate random AADT paths along the risk-neutral binomial lattice. Then, $\text{MRG}_j j = n+1, n+2, \ldots, N$ will be considered as additional revenues along each random AADT path when the actual traffic demand falls shorter than the forecasted traffic demand. The entire project cash flows will then be discounted at risk-free rate (r_f) to compute the concessionaire's NPV for each random AADT path. Therefore, the CDF will be created for the concessionaire's investment value in this toll road project considering (possible) additional MRG options. The concessionaire can apply the described risk-neutral option pricing approach to update the economic risk profile in the toll road investment with MRG options. The market value (or option premium) of MRG is the difference between the concessionaire's investment value with MRG options and the concessionaire's investment value without any MRG option. This difference will be computed for each random AADT path to create the CDF of MRG option value.

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The expected value of this distribution is the expected value or the expected premium of MRG options.

The described risk-neutral valuation approach can also be used to evaluate BOT projects with government TRC options. Traffic revenue cap options are revenue-sharing mechanisms where the concessionaire shares a percentage of the excess revenue with the government once the actual revenue exceeds the pre specified ceiling level (Mandri-Perrott 2006). Minimum revenue guarantee options are intended to provide government supports for the uncontrollable risk of overestimating future traffic demands. Conversely, TRC options provide the right for the government to claim a portion of excess revenues when the actual traffic demand is higher than the revenue ceiling.

Suppose both MRG and TRC options are available in a BOT project. The combined impact of these options will be considered through appropriate adjustments in the concessionaire's revenue streams. The revised concessionaire's revenue in realm of TRC options in year j (i.e., ROR_j $j = n+1, n+2, \ldots, N$) follows, as shown in Eq. (10)

$$ROR_j = \mathrm{Min}\{(OR_j + MRG_j), (((1+K_j) \times PR_j) + AR_j)\} \quad (10)$$

where K_j (where $j = n+1, n+2, \ldots, N$) = maximum portion of revenue that the concessionaire can entirely claim above the projected revenue PR_j $j = n+1, n+2, \ldots, N$ in year j (K_j will be specified in the BOT agreement between the government and the concessionaire); AR_j (where $j = n+1, n+2, \ldots, N$) = additional revenue that the concessionaire can claim above $(1+K_j) \times PR_j j = n+1, n+2, \ldots, N$ in year j as identified subsequently

$$AR_j = \mathrm{Max}\{0, ((OR_j - ((1+K_j) \times PR_j) \times T_j))\} \quad (11)$$

where T_j (where $j = n+1, n+2, \ldots, N$) = portion of revenue that the concessionaire can claim above $(1+K_j) \times PR_j j = n+1,$ $n+2, \ldots, N$ in year j (T_j will be specified in the BOT agreement between the government and the concessionaire). The MRG and TRC options, together, form a specific case of compound options on the BOT project. The same described risk-neutral valuation approach will then be used to characterize the concessionaire's economic risk profile under the combined impact of MRG and TRC options. The authors will apply the proposed real options model to the IIAH highway project in Korea as an example to illustrate the proposed valuation process.

Example

The IIAH project is a 36.6 km highway connecting Korea's Incheon International Airport to the capital city of Seoul. This is the first privately financed highway project in Korea. The construction began in 1995 and the highway was open to traffic by 2000. The concessionaire is New Airport Highway Corporation (NAHC), a consortium of 10 companies that were involved in the highway's construction. The NAHC has the operating rights on this BOT project for 30 years from the date the construction was finished (Lee 2007). The total financing amount needed for the construction of this project was \$1.7 billion, which was raised between 1995 and 2000. The concessionaire's capital is \$434 million in private equity (25% of the total financing amount) and \$1.3 billion in syndicated loans (75% of the total financing amount). Table 1 partially summarizes the concessionaire's cash flow in the IIAH project. The concessionaire's annual cash outflows consist of construction costs, operations, maintenance, capital improvement costs, and debt payments. The concessionaire's cash inflows are anticipated annual toll revenues based on the most-likely forecasts of future traffic demands. The risk-free rate of return and the concessionaire's cost of capital are specified in the project agreement between the concessionaire and the government. According to Lee (2007 Section 7, pp. 18), "through negotiation between the parties in the consortium, it was decided that the concessionaire's cost of capital was the sum of risk-free interest $r_f = 12.56\%$ and a 0.5% spread." Hence, the concessionaire's discount rate is $\rho = 12.56 + 0.5 = 13.06\%$ per year.

The values of several other input variables in the proposed model are retrieved from the project documents and the traffic study report which were conducted by the Ministry of Construction and Transportation in Korea (1996). The traffic study report specifies that the value of annual expected growth rate of AADT or parameter α is 9.8% from 2001–2005, 5.3% from 2006–2010, and 3.1% from 2011–2020. The traffic study forecasts the most-likely initial AADT to be 100,720. In addition, the traffic study identifies 80,576 and 120,864 as pessimistic and optimistic forecasts for the initial AADT respectively. Further, the capacity cap for future traffic demands is assumed to be 20% above the maximum forecasted, optimistic AADT.

In addition to the previous parameter values, the authors assume that the annual volatility of AADT is $\sigma = 10\%$ to characterize uncertainty about future traffic demands over the project lifetime. The authors also try 5%, 20%, and 30% as other possible values for traffic volatility when sensitivity analysis is conducted on the results. These expected growth rates and volatilities are then used to compute the AADT binomial lattice parameters—u, d, and p—as described in Eq. (3).

The authors assume that the Korean Ministry of Construction and Transportation agreed to pay the concessionaire a percent of the difference between the actual and forecasted revenue if the actual toll revenue falls shorter than the forecasted revenue. These MRG options are available in any year after the project is completed until 15 years after the project completion date, i.e., from 2000–2014. This percent is 90% from 2000–2004, 80% from 2005–2009, and 70% from 2010–2014. The MRG options are completely terminated after 2,014. In addition, the government and the concessionaire agreed to equally split additional revenues beyond 110% of forecasted revenues. These TRC options are available in any year after the project is completed until 20 years after the project is built, i.e., from 2000–2019. The authors will apply the proposed real options model on this example to characterize the concessionaire's economic risk profile in this BOT project. The summary of results is presented in the next section.

Summary of Results

First, the authors conduct conventional NPV analysis for the IIAH project. The deterministic NPV—which is calculated according to Eq. (1)—is \$35.37 million. This indicates that the concessionaire should invest in this BOT project. However, as previously discussed, the conventional NPV does not capture the concessionaire's economic risk under revenue uncertainty. The authors' model can be used to characterize the concessionaire's economic risk profile under uncertainty about future traffic demands. Fig. 3(a) shows the probability distribution of the concessionaire's NPV in this project. This distribution shows all possible project NPVs and the probability of their occurrences. Fig. 3(b) depicts the probability distribution of the concessionaire's log-return present value, i.e., the probability distribution of $\ln(PV_1/PV_0)$. The standard deviation of this log-return present value distribution is 78.64% per year. This is the project volatility, i.e., $\sigma_P = 78.64\%$ per year. Fig. 3(c) shows the concessionaire's CDF in this project. The riskiness of the IIAH project is highlighted in Fig. 3(c). There is an approximately 42.5% chance that the concessionaire's NPV becomes negative. Although

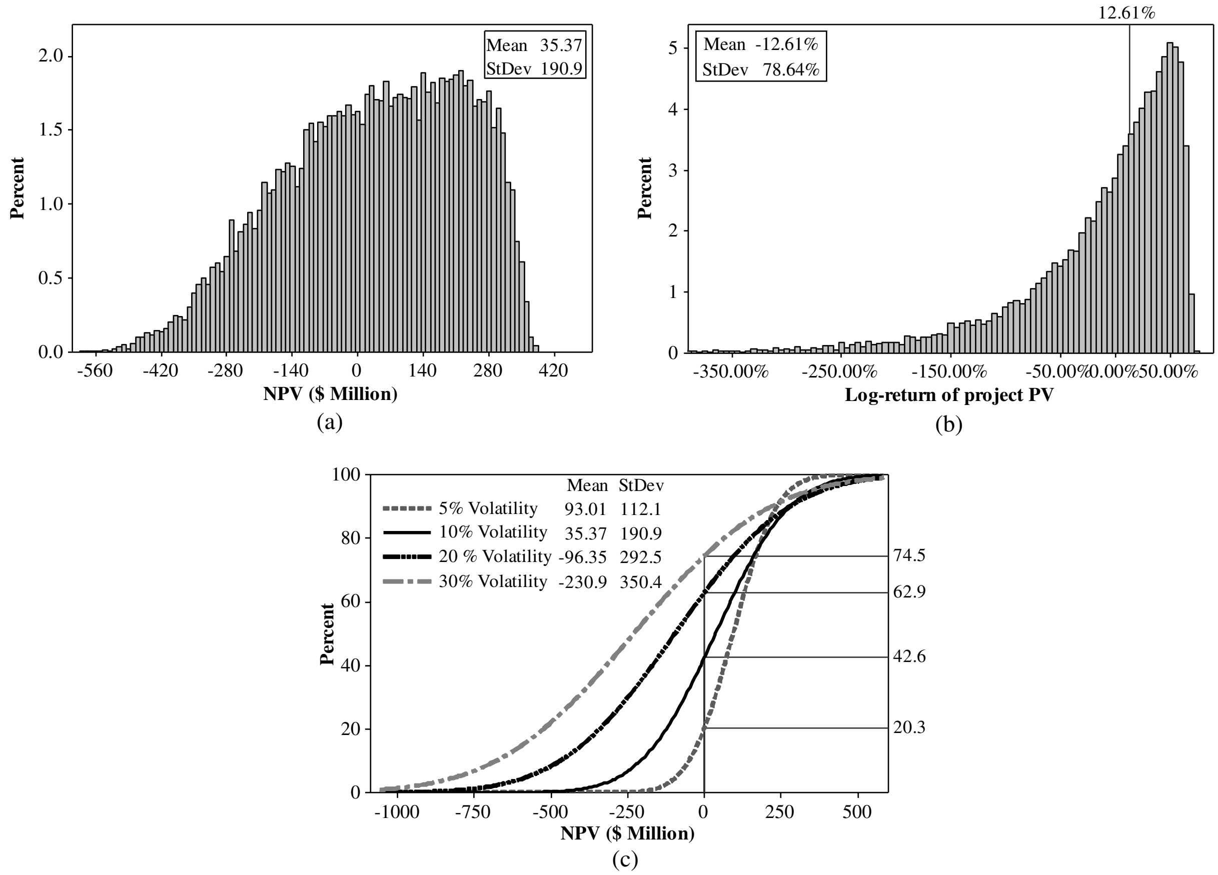

Fig. 3. (a) Probability distribution of the concessionaire's NPV; (b) probability distribution of the concessionaire's log-return present value (PV); (c) impact of changes in the annual traffic demand volatility on the concessionaire's CDF

the concessionaire's expected NPV is much greater than zero [i.e., $E(NPV) = \$35.81$ million] there is a considerable amount of uncertainty about this NPV. The standard deviation of the concessionaire's NPV distribution is \$189.8 million because of the uncertainty about future traffic demands, which makes the investment in this project volatile. Fig. 3(c) also shows how the concessionaire's CDF changes as the annual traffic demand volatility changes from 5% to 10%, 20%, and 30%. As the traffic volatility increases, the risk of underestimating future traffic demands increases and, consequently, uncertainty about the project's future revenues increases. Thus, it becomes more likely that the project underperforms and the concessionaire's NPV becomes negative. This is shown in Fig. 3(c). This great exposure to the risk of underestimating future traffic demands is the primary motivation that the Korean government offers MRG options.

The details of MRG options offered by the government are previously specified. The authors will apply the proposed real options model to characterize the concessionaire's economic risk profile with MRG options. The authors revise the expected growth rate of AADT to create a risk-neutral binomial lattice. According to Eq. (9), the risk premium of the concessionaire's investment in this project (λ_p), which is equal to the risk premium of future traffic

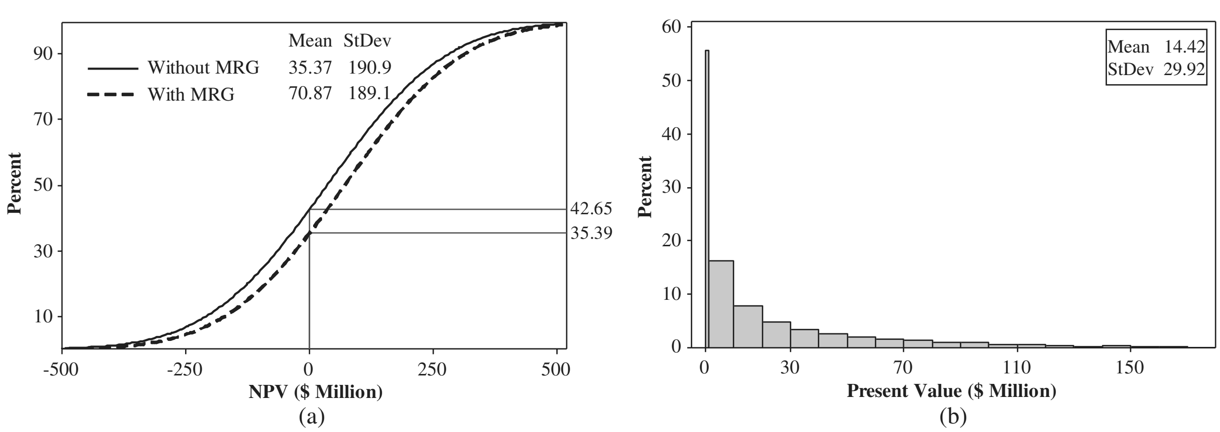

Fig. 4. (a) CDF of the concessionaire's investment value with and without MRG options; (b) probability distribution of the value of MRG options

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demands (λ), is 0.5% per year. Thus, $\sigma\lambda = 0.1272\%$ per year, which will be subtracted from α to create the risk-neutral binomial lattice. Fig. 4(a) shows the CDF of the concessionaire's investment value in this project with MRG options and compares it with the CDF of the concessionaire's investment value in this project without MRG options. The (possible) additional revenues of MRG options increase the concessionaire's expected investment value from \$35.81 million to \$70.87 million. Also, the chance that the concessionaire's investment value becomes negative reduces from 42.52% to 35.39%. Hence, the concessionaire's economic risk profile shifts to the right when MRG options are added to the agreement. In addition, Fig. 4(b) shows the probability distribution of the value of MRG options in this project. This value is computed as the difference between the concessionaire's investment values with and without MRG option. The expected value of this distribution is the expected premium of MRG options, i.e., \$14.42 million. This is the market-based premium, which the government implicitly offers to the concessionaire in this BOT project through considering MRG options.

It is important to study the significance of MRG options from the government standpoint. Fig. 4(b) can also be considered as the probability distribution of the present value of MRG options paid by the government over the concession lifetime. It can be noticed that there is an approximate 56% chance that the present value of MRG options become zero. This occurs when actual traffic demands are higher than forecasted traffic demands and therefore, the concessionaire never requests MRG options. The distribution of the MRG present value depends on the number of times that the concessionaire actually requests support. Fig. 5(a) shows the probability distribution of the number of times that the concessionaire may request MRG options in the first 15 years of the concession lifetime. The number of times that the concessionaire may request MRG from the government is variable and can take any values from 0 to 15. There is an approximate 56% chance that the concessionaire never requests MRG options and, therefore, the present value of MRG options becomes zero. This probability drops sharply to approximately 10% for one MRG exercise and continues to decrease until 15 possible MRG option exercises.

The government also needs information on how likely it is that the concessionaire requests MRG in any year after the project is completed. Fig. 5(b) shows how likely it is that the concessionaire requests MRG in 2000, 2001, …, 2014. This likelihood drops twice in 2005 and 2010 because of the structural changes in the percentage of revenue shortfalls for calculating MRG options (i.e., the initial 90% MRG coverage rate will be reduced to 80% and 70% in 2005 and 2010, respectively). Conversely, the probability that the concessionaire requests MRG increases from 2000–2004, 2005–2009, and 2010–2014. In any of these three distinct periods, forecasted future traffic demands increase rapidly based on the traffic study report. However, this report does not address the volatility of future AADTs. The rising AADT forecasts combined with the volatility of future traffic demands increase the probability that actual AADTs become smaller than forecasted AADTs. Fig. 5(b) shows how the risk of underestimating the AADT grows as the

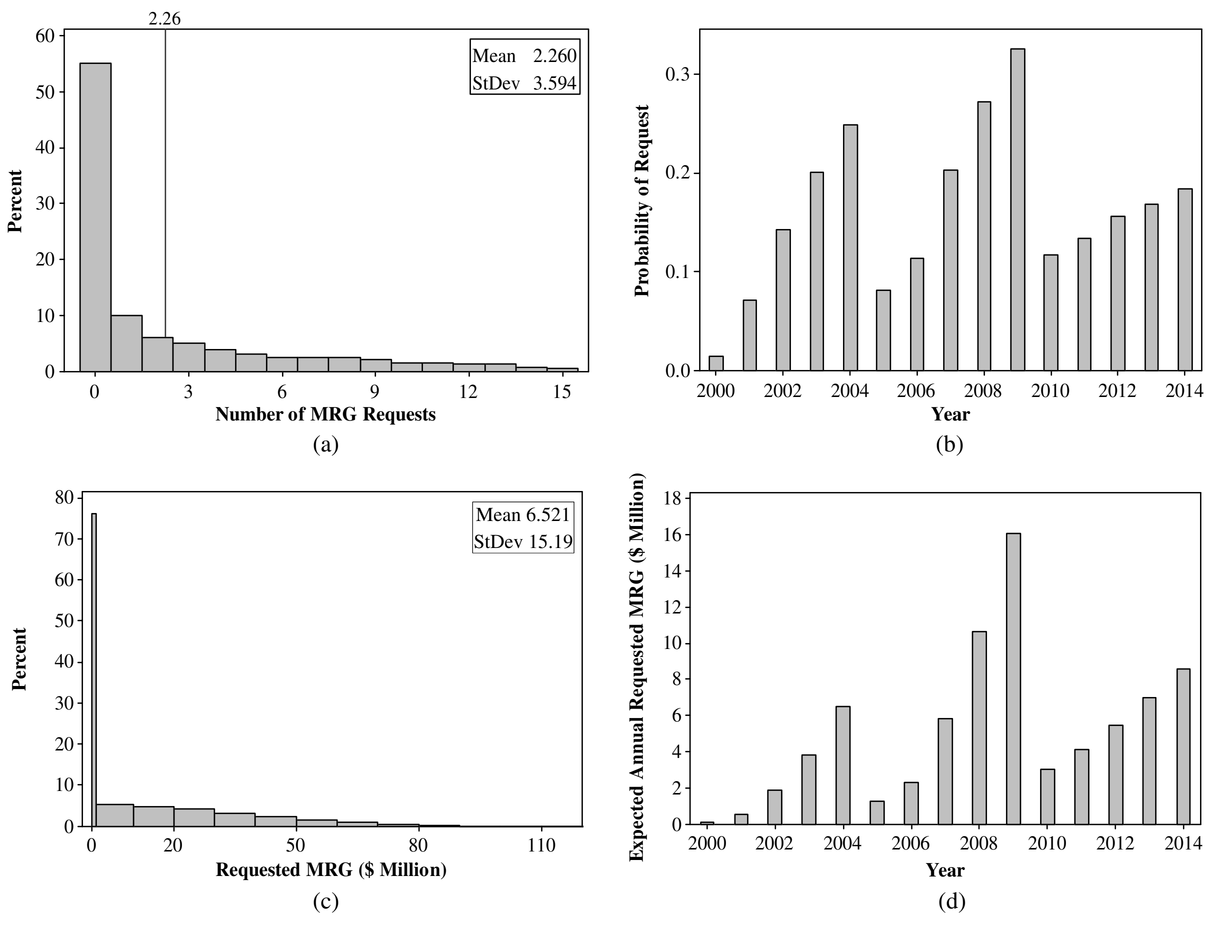

Fig. 5. (a) Probability distribution of the number of times that the concessionaire may request MRG options; (b) likelihood that the concessionaire requests MRG option in 2000, 2001, ..., 2014; (c) distribution of MRG value requested in 2004; (d) expected value of MRG distributions in 2000, 2001, ..., 2014

BOT project advances. It can be seen that relying on just forecasted future traffic demands can be problematic for the government. As the project advances, the government is more likely to pay MRG options to the concessionaire if it does not consider the volatility of future traffic demands in the project valuation.

The amount of MRG, which is requested by the concessionaire in any year, is also variable. For instance, Fig. 5(c) illustrates the probability distribution of MRG, which is requested from the government in 2004. It is shown that there is a great chance (approximately 76%) that the concessionaire does not request MRG in 2004. The expected value and standard deviation of MRG distribution in 2004 are $6.52 million and $15.19 million, respectively. This distribution shows the inherent uncertainty about the amount of requested MRG in any year. This is a great challenge for the government in terms of financial resource allocation and annual budget preparation when related to the BOT project. Fig. 5(d) summarizes the expected values of MRG distributions in 2000, 2001, …, 2014. This graph shows how much, on average, the government needs to pay the concessionaire as MRG options in 2000, 2001, …, 2014.

The Korean government shares the risk of overestimating future traffic demands with the concessionaire through offering MRG options. The concessionaire also shares the excess revenues with the Korean government through offering TRC options. The details of TRC options requested by the government were previously specified. The authors will apply the proposed real options model to characterize the concessionaire's economic risk profile with combined MRG and TRC options. Fig. 6 shows the CDF of the concessionaire's investment value with both MRG and TRC options compared with the CDF of the concessionaire's investment value with just MRG options and without any options in the IIAH project The concessionaire's access to extremely high revenues will be limited through offering TRC options to the government. Hence, the expected value and standard deviation of the concessionaire's investment value distribution with MRG and TRC options are lower than the expected value and standard deviation of the concessionaire's investment value distribution with just MRG options, respectively. However, the expected value of the concessionaire's investment value distribution with MRG and TRC options is greater than the expected value of the concessionaire's investment value distribution with just MRG options. Also, the probability of the event that the concessionaire's NPV becomes negative is lower when the concessionaire considers both MRG and TRC options compared to the case without any options.

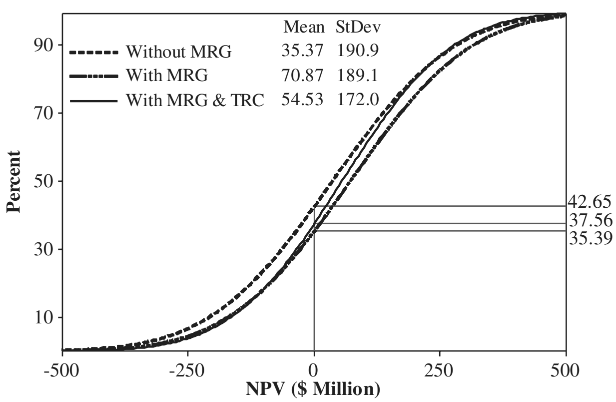

Fig. 6. CDF of the concessionaire's investment value under three circumstances: (1) with MRG and TRC; (2) with MRG options only; and (3) without any options

Further, Fig. 7(a) characterizes the probability distribution of the present value of TRC options. This probability distribution specifies all possible present values of total excess revenues that the Korean government receives under TRC options. The expected value and standard deviation of this distribution are $16.38 million and $21.79 million, respectively. There is approximately a 36% chance that the Korean government does not receive any additional revenues through TRC options. This probability is lower than the 56% chance that the concessionaire never requests MRG. Thus, TRC options are attractive to the government. Excess revenues, if they occur, can be collected and used to pay the concessionaire as MRG options if requested.

Fig. 7(b) characterizes the probability distribution of the government's net present value of TRC and MRG options. This probability distribution specifies all possible net present values of total excess revenues—which the Korean government receives under TRC options—subtracting all MRGs that it pays to the concessionaire over the project lifetime. The expected value and standard deviation of this probability distribution are $1.96 million and $42.66 million, respectively. The asymmetry in the shape of this probability distribution indicates that the above MRG and TRC options will possibly be in the favor of the Korean government. It can be seen that the probability that the government realizes a gain (i.e., the probability of the event that the government's NPV of TRC and MRG options is positive) is approximately 58.1%.

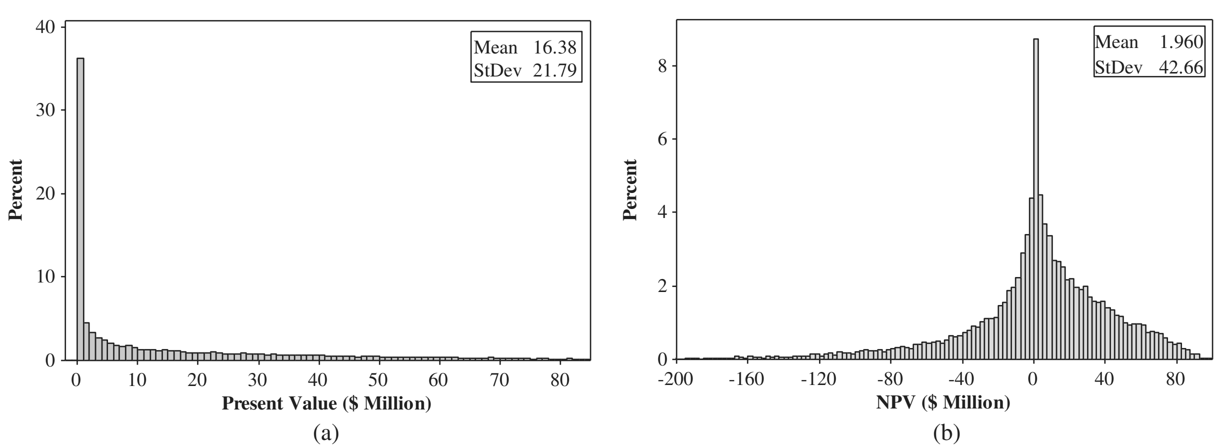

Fig. 7. (a) Probability distribution of the present value of TRC options; (b) probability distribution of the government's NPV of TRC and MRG options

Conclusion and Future Work

The private sector can play a vital role in the delivery of an infrastructure's assets by contributing to the financing, development, and operations of infrastructure projects. As "the interface between the construction industry and the finance and insurance markets" (Angelides and Xenidis 2009, pp. 165), BOT has been used as an innovative project delivery system for infrastructure systems. While the number of BOT projects around the world grew in early 1990s, there has been a considerable decline in the number of PPP projects in the late 1990s. While much of this downward trend is attributed to the major economic crises around the globe, there is a considerable amount of evidence indicating that the improper financial evaluation of BOT projects and inappropriate risk-sharing mechanisms between the private and public sectors contribute to the failure of these projects and hence, the lack of interest from the private sector. Therefore, in this paper, a novel financial model is developed to evaluate BOT projects under uncertainty about future traffic demands, which is considered as one of the most significant sources of uncertainty in these projects.

The proposed model considers the volatility of future traffic demands in the valuation of BOT projects and characterizes the concessionaire's economic risk profile under future traffic uncertainty. It is shown that forecasted future traffic demands are insufficient to capture uncertainty about the financial performance of BOT projects. The proposed model internally treats uncertainty about future traffic demands and describes a procedure to characterize the concessionaire's economic risk profile under the risk of underestimating future traffic demands.

Also, the authors' real options model is able to overcome the inherent limitation of conventional economic analysis methods and most notably the NPV approach. The NPV approach is insufficient to determine the correct market value of MRG options, which the government may offer to the concessionaire as a revenue risk-sharing strategy in a BOT project. The authors apply the real options theory from finance/decision science to explicitly price MRG options in BOT projects.

It is shown that as the traffic volatility increases, the risk of underestimating future traffic demands increases and, consequently, uncertainty about the project's future revenues increases. Thus, it becomes more likely that the project underperforms and the concessionaire's investment value becomes negative. It is also concluded that the risk of underestimating future traffic demands grows as the BOT project advances. It is shown that as the project advances, the government is more likely to pay MRG options to the concessionaire if it does not consider the volatility of future traffic demands in the project valuation.

It is concluded that the expected value and standard deviation of the concessionaire's investment value distribution with MRG and TRC options are lower than the expected value and standard deviation of the concessionaire's investment value distribution with just MRG options, respectively. However, the expected value of the concessionaire's investment value distribution with MRG and TRC options is greater than the expected value of the concessionaire's investment value distribution with just MRG options. Also, the probability of the event that the concessionaire's NPV becomes negative is lower when the concessionaire considers both MRG and TRC options compared to the case without any options.

The proposed model can help public and private sectors better analyze and understand the financial risk of BOT projects. The private sector can use this innovative model to make better entry decisions to BOT highway projects considering the level of support provided by the government. The government can also use this model to identify the appropriate MRG levels to encourage private investments without comprising future budgetary strength. The proper levels of TRC can also be identified as a reward-sharing strategy to enhance the government's spending flexibility in highway projects without hurting the financial success of the concessionaire. It is shown that an appropriate combination of MRG and TRC options is an effective risk- and reward-sharing strategy between the government and the concessionaire in the BOT project. This limits the exposures of both parties to the risk of underestimating or overestimating future traffic demands.

Research should be conducted to incorporate the other sources of risk such as uncertainty about interest and exchange rates and construction costs in BOT project valuation. Extended financial models are required to assess the risk of unexpected changes in interest and exchange rates. Construction-related risks, such as construction cost overruns, schedule delays, and technical difficulties, should also be considered in the comprehensive BOT project valuation. Future work should examine how the combination of economic and construction risks affect the financial stability of BOT highway projects. Future work is required to handle the casual link between toll road pricing and traffic volume. This will allow the concessionaire to study how various toll pricing mechanisms can improve the financial performance of a BOT project. Further, the efficiency and effectiveness of the other government fiscal support instruments, such as tax breaks, should be investigated and compared with MRG options.

References

Angelides, D. C., and Xenidis, Y. (2009). "PPP infrastructure investment: Critical aspects and prospects." *Policy, finance and management for public-private partnership*, A. Akintoye, and M. Beck, eds., Wiley-Blackwell, Chichester, West Sussex, UK.

ASCE. (2009). "Report card for America's infrastructure." ⟨http://www.infrastructurereportcard.org/sites/default/files/RC2009_roads.pdf⟩ (Oct. 10, 2009).

Ashuri, B. (2010). "Valuation of flexible leases for corporate tenants facing uncertainty in their required work space." *Int. J. Strategic Property Manage.*, 14(1), 49–72.

Ashuri, B., Rouse, W. B., and Bodner, D. A. (2008). "A real options approach to investment decisions in competitive, dynamic retail markets." *Proc., 2008 Hawaii Int. Conf. on System Sciences (HICSS-41)*, IEEE Computer Society, Washington, DC.

Bain, R. (2009). "Error and optimism bias in toll road traffic forecasts." *Transp.* 36(5), 469–482.

Banister, D. (2005). *Unsustainable transport: City transport in the new century*, Routledge, London.

Bengtsson, J. (2001). "Manufacturing flexibility and real options: A review." *Int. J. Prod. Econ.*, 74(1–3), 213–224.

Bodner, D. A., and Rouse, W. B. (2007). "Understanding R&D value creation with organizational simulation." *Syst. Eng.*, 10(1), 64–82.

Borison, A. (2005). "Real options analysis: Where are the emperor's clothes?" *J. Appl. Corporate Finance*, 17(2), 17–31.

Brandao, L. E. T., and Saraiva, E. (2008). "The option value of government guarantees in infrastructure projects." *Constr. Manage. Econ.*, 26(11), 1171–1180.

Cheah, C., and Garvin, M. J. (2009). "Application of real options in PPP infrastructure projects: Opportunities and challenges." *Policy, finance and management for public-private partnership*, A. Akintoye, and M. Beck, eds., Wiley-Blackwell, Chichester, West Sussex, UK.

Cheah, C., and Liu, J. (2006). "Valuing governmental support in infrastructure projects as real options using Monte Carlo simulation." *Constr. Manage. Econ*, 24(5), 545–554.

Chiara, N., Garvin, M. J., and Vecer, J. (2007). "Valuing simple multiple-exercise real options in infrastructure projects." *J. Infrastruct. Syst.*, 13 (2), 97–104.

Copeland, T., and Antikarov, V. (2001). *Real options: A practitioners guide*, W. W. Norton & Company, New York.

Cuttaree, V. (2008). "Successes and failures of PPP projects." The World Bank, Washington, DC.

De Neufville, R. (1990). *Applied systems analysis: Engineering planning and technology management*, McGraw-Hill, New York.

De Neufville, R., Lee, Y. S., and Scholtes, S. (2008). "Flexibility in hospital infrastructure design." *Proc., IEEE Conf. on Infrastructure Systems*, IEEE, Washington, DC, 8–10.

Dixit, A. K., and Pindyck, R. S. (1994). *Investment under uncertainty*, Princeton University Press, Princeton, NJ.

Ellingham, I., and Fawcett, W. (2006). *New generation whole-life costing—Property and construction decision-making under uncertainty*. Taylor & Francis, Abingdon, UK.

Federal Highway Administration. (2008). "Glossary of terms." ⟨http://www.fhwa.dot.gov/reports/pppwave/08.htm⟩ (Jun. 4, 2010).

Ford, D. N., Lander, D. M., and Voyer, J. J. (2002). "A real options approach to valuing strategic flexibility in uncertain construction projects." *Constr. Manage. Econ*, 20 (4), 343–351.

Garvin, M. J., and Cheah, C. Y. J. (2004). "Valuation techniques for infrastructure investment decisions." *Constr. Manage. Econ.*, 22(4), 373–383.

Greden, L., and Glicksman, L. (2005). "A real options model for valuing flexible space." *J. Corp. Real Estate*, 7(1), 34–48.

Greden, L., Glicksman, L. R., and Lopez-Betanzos, G. (2006). "A real options methodology for evaluating risk and opportunity of natural ventilation." *J. Sol. Energy Eng.*, 128(2), 204–212.

Ho, S. P., and Liu, L. Y. (2002). "An option pricing-based model for evaluating the financial viability of privatized infrastructure projects." *Constr. Manage. Econ.*, 20(2), 143–156.

Hodges, J. (2006). "PPP highway experiences: Chile and Mexico." The World Bank Regional Workshop on Public-Private Partnership (PPP) in Highways, Belgrade, Serbia.

Huang, Y. L., and Chou, S.-P. (2006). "Valuation of the minimum revenue guarantee and the option to abandon in BOT infrastructure projects." *Constr. Manage. Econ.*, 24(4), 379–389.

Hull, J. C. (2008). *Options, futures, and other derivatives*, Prentice Hall, Upper Saddle River, NJ.

Irwin, T. (2003). "Public money for private infrastructure: Deciding when to offer guarantees, output-based subsidies, and other fiscal support." The World Bank, Washington, DC.

Kaka, A., and Alsharif, F. (2009). "Financial modeling of PPP." *Policy, finance and management for public-private partnership*, A. Akintoye, and M. Beck, eds., Wiley-Blackwell, Chichester, West Sussex, UK.

Lee, S. (2007). "Entry decision for unsolicited build-operate-transfer (BOT) highway projects: Real options approach." Ph.D. thesis, University of Colorado, Boulder, CO.

Luenberger, D. G. (1998). *Investment science*, Oxford University Press, New York.

Mandri-Perrott, C. (2006). "Mobilizing private capital and management into infrastructure development." The World Bank Infrastructure Economics and Finance Dept. (IEF) Workshop, Riga, Latvia.

Mayer, Z., and Kazakidis, V. (2007). "Decision making in flexible mine production system design using real options." *J. Constr. Eng. Manage.*, 133(2), 169–180.

Queiroz, C. (2007). "International experience with transport PPP projects." The World Bank Regional Workshop on Public-Private Partnership (PPP) in Highways, Riga, Latvia.

Queiroz, C., and Izaguirre, A. (2008). "Worldwide trends in private participation in roads: Growing activity, growing government support." PPIAF Gridline Note No. 37. The World Bank, Washington, DC.

Sharpe, W. F. (1994). "The Sharpe ratio." *J. Portf. Manage.*, 21(1), 49–58.

Shishko, R., Ebbeler, D. H., and Fox, G. (2004). "NASA technology assessment using real options valuation." *Syst. Eng.*, 7(1), 1–13.

Transportation Research Board. (2000). "Highway capacity manual." Washington, DC.

TRANSYT. (2007). "Evaluation of demand risk mitigation in PPP projects." *EIB University Research Sponsorship Program*, Transport Research Center.

U.S. General Accounting Office. (1999). "Public-private partnership: Related to building and facility partnerships." ⟨http://www.gao.gov/special.pubs/Gg99071.pdf⟩ (Nov. 15, 2009).

Zhao, T., and Sundararajan, S. K. (2004). "Highway development decision-making under uncertainty: A real options approach." *J. Infrastruct. Syst.*, 10(1), 23–32.

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