Balancing Private and Public Interests in Public–Private Partnership Contracts Through Optimization of Equity Capital Structure

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Capital structure and revenue-sharing agreements lie in the essence of balancing public and private interests in public–private partnership (PPP) contracts. In the United States, many PPP projects may not be fully self-financed through tolls or other user fees because of insufficient revenue streams. With a limited debt capacity secured by toll revenues, most PPP projects must be supported by both private equity investments and public funds. The equity structure is critical in a PPP contract because it implies risk and profit sharing and therefore provides a mechanism for private incentive and protection of the public interest. This paper presents a structured approach to determining the debt–equity investment in PPP projects. Scenarios are generated by using linear programming and probability programming models to reach the optimal equity structure under risk and uncertainty. The I-10 connector project is used as a case study to demonstrate the optimization process. The model is especially useful for public agencies to (*a*) estimate the range of private equity investment, (*b*) determine the target equity structure, and (*c*) document the benefits and costs of private financing for a successful PPP contract.

Transportation infrastructure is widely recognized as an essential feature of economic vitality and national security. The United States, as with many other countries, finds itself with an aging infrastructure and funding that significantly lags current maintenance and future growth. New development and upgrading of transportation infrastructure typically needs significant upfront investments, which formerly were funded by gasoline tax revenues. Because of the shrinkage of tax revenues and the recent financial crisis, the federal and state governments find themselves in a distressed condition and cannot fund enough projects for the maintenance and upkeep of the existing infrastructure. Moreover, transportation infrastructure projects are often large and complex and involve coordination of many project entities. Thus, management of infrastructure projects has become much more challenging for transportation agencies. Therefore, since the early 1990s, there has been an increasing trend for many projects to be delivered through public–private partnerships (PPPs) to address the funding shortfall and to improve project performance.

A PPP can be broadly defined as a long-term agreement between public and private sectors for mutual benefit (*1*). This agreement seeks to involve the private sector in the nontraditional areas of a project with the risks and rewards being shared in new ways (*2*). For example, a public agency may provide right-of-way and the right to collect user fees while a private firm provides financing, technological innovation, and ongoing service. Researchers and practitioners identify many contractual arrangements as PPPs, such as fee-based contract services, design–build, design–build–operate–maintain, design–build–finance–operate, build–own–operate, and long-term leases (*3–5*). In the United States, most partnerships require the private sector to be responsible for acquiring the majority of the necessary financing (*6*). The United Kingdom and Australia are widely recognized as pioneers in PPPs, which have been used in various sectors of facility delivery since the 1980s (*3*). As reported by the Public–Private Infrastructure Advisor Facility and the World Bank, PPP programs in the United Kingdom and Australia have been successful and few PPP projects performed inefficiently or failed to meet their objectives (*7*). In the United States, transportation projects such as the Interstate highway system have been built based on a public–public partnership between the federal and state governments. Adding a private partner to this mix can be challenging.

Delivery of PPP projects primarily depends on properly formulated PPP agreements that both attract private capital and preserve public interests (*6, 8*). However, PPPs are still relatively new in the United States. Most state transportation agencies have not established best practices and guidelines for PPP projects, with resultant strong public resistance from serious concerns about the protection of public interests in PPP contracts. The Texas Department of Transportation (DOT), as a national leader in PPP pursuits, has had to slow down its efforts (*9*). In 2008, the U.S. Government Accountability Office (GAO) conducted a study to evaluate PPP projects in relation to protecting public interests. As GAO pointed out, because the public sector in essence gives up control over a future stream of toll revenues in exchange for upfront payment concession, PPPs might not be warranted when the uncertainties of traffic on these toll roads are considered. It may happen that the net present worth of the exchanged future stream of toll revenues will become much larger than the upfront concession received (*10*). GAO recommended that transportation agencies develop and conduct upfront financial analyses to determine the benefits and costs of PPP agreements and to better deliver transportation infrastructure projects.

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Transportation Research Record: Journal of the Transportation Research Board, No. 2151, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 60–66.
DOI: 10.3141/2151-08

This paper discusses the issue of public and private interests from the standpoint of capital structure optimization. It begins with a review of related literature. Next, it discusses the public, private, and investors' interests in a PPP contract. Third, it outlines financial mechanisms in PPP projects and presents a probability programming model for optimizing the capital structure. The final section illustrates the application of the optimization model.

EARLIER RESEARCH ON PPPs

The PPP delivery method for transportation infrastructure is believed to bring benefits compared with other project delivery systems (*3, 11, 12*). In the United States, PPPs originated from educational programs and became increasingly used in urban renewal projects in the 1960s (*13*). Since the 1990s, there has been an increasing trend of applying PPPs to the transportation sector because of funding shortages in many states. Without strong political and public support, the use of PPPs in many states is limited compared with their use in such pioneers as the United Kingdom and Australia. A lack of well-established procedures, guidelines, and analysis tools for PPP projects further hinders transportation agencies from delivering transportation infrastructure with PPP contracts.

Zhang (*14*) investigated PPP practices in European and Asian countries and identified barriers to successful implementation of PPPs in transportation infrastructure development. Zhang recommended that the best-value procurement should be used on PPP projects, which would improve the efficiency of project delivery. The best-value approach requires public agencies to evaluate bids with a set of predetermined criteria in a two-stage procurement process. During the first stage, private partners are required to submit an application for prequalification. Then, in the second stage, shortlisted private firms send in their bids. The sponsoring agency awards the work to the bidder that offers the best value, sometimes leaving aside the bid with the lowest cost. This process ensures that the public agency gets the best value in relation to cost, time, quality, safety, and so on (*15*). Best-value procurement could also incorporate value-for-money analysis that is typically conducted in the United Kingdom and Australia. The value-for-money analysis compares the PPP procurement with alternative traditional procurement methods under uncertain conditions. Because projects would proceed through PPP projects only when PPP provides the better value compared with a more traditional procurement method, the value for money analysis ensures that PPP procurement achieves the best value for public agencies (*16, 17*).

Researchers also investigated the financial aspects of PPP projects. Gross and Garvin (*18*) presented an approach to structuring concession lengths and toll rates. Zhang (*19*) used an optimization model to facilitate the analysis of financial viability of private and public sectors to determine an optimal debt and equity structure. Chiara and Garvin (*20*) used the Martingale variance model and the general variance model as alternative modeling tools for build–operate–transfer risk evaluation. Brandao and Saraiva (*21*) viewed the minimum traffic guarantee as an option and developed a model to evaluate government outlays in PPPs. Similarly, Liu and Cheah (*22*) used the real options theory to model the PPP structure in wastewater treatment plants. Abdel (*3*) described implementation principles in PPP projects on the basis of analysis of concession agreements and the successful experience in the United Kingdom and British Columbia. Zhang (*23*) reported the primary financial criteria for selecting the right private partners in PPP contracts. These criteria included net present value, internal rate of return (IRR), and total investment schedule. A great number of studies have been conducted in other countries; however, no convincing work has been conducted in the United States. The GAO has called for the development of upfront analysis tools for PPP projects to better protect public interests (*10*). This paper provides a prompt for the allocation of capital, particularly for equity investments, between public and private partners.

PPP FINANCING AND PUBLIC–PRIVATE INTERESTS

Effective partnerships develop from shared interests, responsibilities, resources, and reorganization. One must admit that there is potential for conflicts of interests in a PPP project. Public interests infrequently align perfectly with those of private partners and other project stakeholders. While a public agency aims at maximizing social welfare benefits from a PPP project, the private partner and other stakeholders must make economic profits. The economic profits in a PPP project are obtained from tolls or other user fees. Therefore, private economic interests often conflict with prevailing public opinion on public transportation services. Because both public and private interests should be served in a PPP contract, careful attention must be paid to balancing public interests and private economic interests when a PPP contract is being designed.

Public and private interests are served differently in a PPP contract. The protection and reflection of stakeholders' interests are associated with the project's capital structure and revenue sharing agreement. The project's capital structure refers to the way a project is financed through some combination of debt, equity, and other instruments. Typically, debt financing represents debt holders' interests. Equity, including private equity and public funds, reflects the project ownership of the private partners and the public sector. Although debt holders are guaranteed repayments of principle with interest, debts are not risk free. Should project revenues face unexpected decline and are not enough for debt services, debt holders will suffer a loss and may not get a return on their initial investments. Two safeguard mechanisms are used in PPP project financing to protect debt holders, namely interest rate and debt service coverage ratio (DSCR). In addition to debt investment return, the interest rate includes a risk premium that is determined and applied on the basis of evaluation of project risk, revenue stability, and debt rating. DSCR, in contrast, is used to compute debt capacity of a PPP project. DSCR is usually larger than 1.2. Therefore, the debt capacity is always lower than the expected project revenue (*24*).

PPP projects are financed on the basis of expected revenues from project operations. If a project is expected to yield large revenues, sufficient debt financing from the financial market can be obtained. When the expected revenues fall short, debt financing may not cover total project costs and thus may create a financial gap. The financial gap needs to be closed with funds from either the public or the private sector. Equity holders take the entire downside risk and get repaid after debt service. First, private partners are willing to invest in PPP projects only when they anticipate a high rate of return or minimum IRR from the investments. If the project is not sufficiently profitable, private partners will not spend a penny or take the risk. Therefore, public agencies may have to give away a significant share from the total profit to attract private investments, even if equity investments may be just a small percentage of the financial gap.

Second, public agencies must protect their interests and ensure that private partners do not abandon projects when those partners obtain sufficient profits from PPP projects earlier than expected. An earlier exit from PPP projects may benefit private partners because they could reduce their operation, maintenance, or rehabilitation costs. Private partners are thus required to guarantee a minimum amount of investment to reduce the public agencies' risk. Third, strong public resistance to high private profit in PPP projects pushes many public agencies to limit the rate of return for private investments. Therefore, the amount of private equity, or the allocation of private equity and public funds in a PPP contract, remains a major subject of PPP financing.

MODEL FOR OPTIMIZATION OF PPP CAPITAL STRUCTURE

Enhanced Linear Programming Model

Division of equity financing between private partners and public agencies determines the sharing of project profit streams and affects the successful delivery of PPP projects. An enhanced linear programming (ELP) model is developed to help public agencies accomplish their objectives while keeping those objectives attractive to private investments.

First, it is assumed that a PPP project spans T years. Funding is secured, and the project starts at time $t = 0$. The following model notations are used in the remainder of this paper:

C = construction cost,
D = debt,
E_1 = private equity,
E_2 = public funds,
i_A = rate of return for public agency,
i_B = rate of return for debt holders,
i_P = rate of return for private partner,
γ = public opportunity-loss coefficient,
R_t = revenue at time t,
DS_t = debt service at time t,
OM_t = operation and maintenance costs at time t,
DSR_t = debt service reserve payment at time t,
$P_{1(t)}$ = profit sharing for private partner at time t,
$P_{2(t)}$ = profit sharing for public agency at time t, and
DSCR = debt service coverage ratio.

$$\max\left(D-\sum_{t=0}^{T}\frac{\mathrm{DS}_t}{(1+i_A)^t}\right)+\left(E_1-\sum_{t=0}^{T}\frac{P_{1(t)}}{(1+i_A)^t}\right)-\gamma * E_2$$

(maximizing public interests)

subject to

$$D * \mathrm{DSCR}-\sum_{t=0}^{T}\frac{\mathrm{DS}_t}{(1+i_B)^t}\leq 0$$

(debt capacity constraint – debt holder interests)

$$\mathrm{DS}_t * \mathrm{DSCR}-\left(R_t+\mathrm{DSR}_t-\mathrm{OM}_t\right)\leq 0$$

(debt service constraint – debt holder interests)

$$C-\left(D+E_1+E_2\right)\leq 0 \quad \text{(minimal project funds constraint)}$$

$$E_1-\sum_{t=0}^{T}\frac{P_{1(t)}}{\left(1+i_{P(\min)}\right)^t}\leq 0$$

(project attractiveness constraint – private interests)

$$\sum_{t=0}^{T}\frac{P_{1(t)}}{\left(1+i_{P(\max)}\right)^t}-E_1\leq 0$$

(capping private equity return – public and private interests)

$$P_{1(t)}\leq R_t-\mathrm{OM}_t-\mathrm{DS}_t \quad \text{(payment priority constraint)}$$

$$D,\mathrm{DS},E_1,E_2,P_1,P_2\geq 0 \quad \text{(nonnegative constraint).}$$

The objective of the optimization is to maximize the benefits from PPP financing for the public agency. Three components are included in the objective function, namely debt financing benefits (costs), private equity financing benefits (costs), and opportunity costs associated with public funds. The model must satisfy several constraints. First, the debt capacity constraint defines the maximal amount of debt that a PPP project can secure. Financial rating companies (e.g., Fitch and Standard and Poors) rate project debts in accordance with associated project risk and profitability. The bond rating for similar projects could be used to determine the DSCR, which, along with the projected project revenue stream, determines the debt capacity of the project. Second, the debt holders require that the debt service be secured with higher priority from net revenue. A reserve fund may also be created to pay debt service. The reserve fund would be from either (*a*) initial public or private investments or (*b*) operation profit reserves from earlier years. Third, PPP financing must be able to cover project costs. Fourth, the rate of return for private partners must be large enough to attract private investments, yet small enough to protect public interests. The factors $i_{P(\min)}$ and $i_{P(\max)}$ indicate the low and high boundaries of the rate of return for private equities. Furthermore, profits to private partners must be paid after debt services and reserve.

Simplified Linear Programming Model

In most cases, the ELP model involves many variables and equations that cause computation complexity. To simplify the calculation, an alternative simplified linear programming (SLP) model is developed and presented below. The objective function is defined to minimize costs to reflect a public agency's not-for-profit status. All values are discounted back to the decision time point ($t=0$). R, DS, P_1, and OM are the present worth of cash flows R_t, DS_t, $P_{1(t)}$, and OM_t. Coefficients α and β are used to convert values at the discount rates i_B and i_P. The model constants then could be obtained by dividing the present worth of cash flows at i_A by the present worth of the same cash flows at i_B or i_P. Capital structure variables D, E_1, E_2 and profit-sharing variables P_1 and P_2 remain as the decision variables.

$$\min\left(\mathrm{DS}-D\right)+\left(P_1-E_1\right)+\gamma * E_2$$

subject to

$$D * \mathrm{DSCR}-R\leq 0$$

$$\mathrm{DS}=\alpha * D$$

$$D+E_1+E_2\leq 0\ C$$

$$P_1 \geq \beta_{min} * E_1 \quad \text{(SLP)}$$

$$P_1 \leq \beta_{max} * E_1$$

$$P_1 \leq R - \text{OM} - \text{DS}$$

$$\text{DS}, D, P_1, E_1, E_2 \geq 0$$

Three types of financing mechanisms in PPP projects are debt, private equity, and public funds. The difference between debt service and debt represents the public costs through debt financing. If the expected revenue is less, then the debt capacity available from banks will decrease. This decrease occurs because banks that accept debt take DSCR into consideration when calculating the amount of a debt. The DSCR is calculated as revenue available for debt service over debt service. In such cases, the finance gap is arranged through equity financing, which is costlier than the debts. In return for equity investments, private partners take a large share of project profits, which translates into high rates of return. Hence, public agencies need to fill the financial gap with private capital in the meantime to ensure that the return to private partners is not unexpectedly high. $(P_1 - E_1)$ represents the cost of private equity financing.

A reduction in upfront public investments may be beneficial to public agencies. These reduced upfront investments leave more money in hand to be used for other new or renovation jobs. By using public funds in a PPP project, a public agency essentially gives up the opportunity to build other infrastructure that could bring economic and social benefits to the public. In the ELP and SLP models, a public opportunity-loss coefficient γ is used to calculate the opportunity loss due to the use of public funds in PPP projects. Profit sharing for the public agency should also be incorporated into coefficient γ. When $\gamma = 1$, the amount of benefit from PPP project operations derived from funds invested in the PPP project by the public will equal the cost of opportunity lost from alternative infrastructure development. The inequality $\gamma < 1$ indicates that opportunity cost is less than the benefits from the PPP projects. The opposite is true when $\gamma > 1$. The higher the γ is, the larger the opportunity loss is. In both models, $\gamma * E_2$ represents the total opportunity cost of public funds in a PPP project.

Simplified Probability Programming Model

When one considers that most PPP projects span a few decades, uncertainty exists and should be incorporated into the model. The randomness of project revenue is primarily investigated in this research. Three major techniques—robust optimization, stochastic programming, and probabilistic programming—are available for uncertainty modeling. Probabilistic constraints are obviously the best method to model the uncertainty issue of PPP capital structure for the following reasons. First, the robust optimization method requires that none of the constraints can be violated, and therefore that method is overly pessimistic because it chooses the worst-case scenario. Second, the stochastic programming approach assumes that the distributional information is known. However, this approach is overly optimistic for realistic cases. Third, the probabilistic constraints model controls the overall probability of constraints. More importantly, the probabilistic programming model measures the risk quantitatively.

There are three techniques to solve the probabilistic programming: scenario optimization, sample average approximation, and polynomial approximation. The first two methods will provide a feasible solution rather than the optimal solution. The reason is obvious in that the general probabilistic constraints are usually nonconvex. A polynomial approximation approach was used to transform the original model into a convex optimization with polynomial constraints. The resulting model is solvable by most interior-point solvers. The polynomial approximation approach is fundamentally based on the properties of the Bernstein polynomial. A detailed discussion on the Bernstein polynomial appears in Philips (*25*). Then, the SLP can be modified to the simplified probability programming (SPP) model as follows:

$$\min(\alpha - 1)D + (P_1 - E_1) + \gamma * E_2$$

subject to

$$\Pr(D * \text{DSCR} - R \leq 0) \geq p$$

$$D + E_1 + E_2 = C$$

$$P_1 \geq \beta_{min} * E_1$$

$$P_1 \leq \beta_{max} * E_1 \quad \text{(SPP)}$$

$$\Pr(P_1 \leq R - \text{OM} - \text{DS}) \geq p$$

$$\text{DS}, D, P_1, E_1, E_2 \geq 0$$

$$D, E_1, E_2 \leq C$$

where p is the probability. The two constraints with random parameter R are modified as a probability function. Given a p value of 95%, this probability constraint requires that the equation must be held at a 95% confidence level.

CASE STUDY

The Alabama Department of Transportation (ADOT) received an unsolicited proposal to build a 23-mi highway, named US-231–I-10 connector, to run between the Alabama–Florida border to Dothan, Alabama. This highway was proposed to provide a safer and a more efficient road network to relieve traffic congestion. Dothan, also known as the Hub of the Wiregrass, is located about 100 mi from Montgomery, Alabama, and about 200 mi from the Alabama cities of Birmingham and Mobile. The proposed highway will connect Dothan with these major population centers, which are currently served by the Interstate system. The proposed connector is to start at US-231 in Dale County, northwest of Dothan, and will follow a southerly direction, pass through Geneva County, and finally merge with US-231 near the Alabama–Florida border. This alignment will allow traffic to bypass Dothan and thus help to relieve current congestion in the city. If this connector is extended another 20 mi, it would connect to I-10 in Florida. The connector could be part of the corridor that was proposed by private developers to connect Montgomery, Alabama, and Panama City, Florida. Figure 1 shows the alignment proposed for the connector. The preliminary traffic and revenue study report estimated the cost of construction of the connector highway to be $100 million (the numbers have been adjusted within reasonable limits to maintain the confidentiality of actual numbers associated with the project). It also estimated the expected revenue streams obtained from each of two traffic patterns: a base case and an external–external (EE) boosted-trip-table case.

Three scenarios were developed from the base case. The worst-case scenario assumed that the toll revenue growth (which incorporated

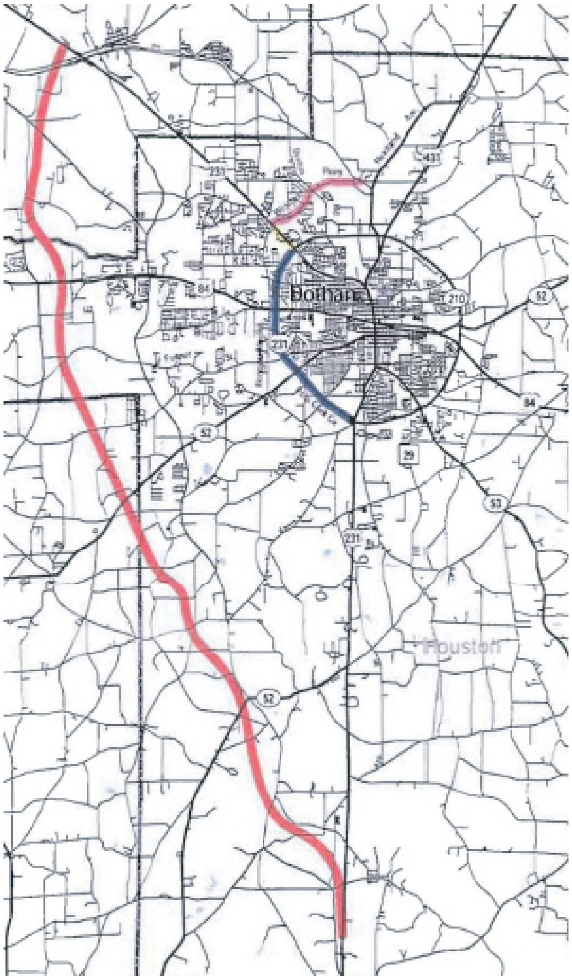

FIGURE 1 Proposed alignment of US-231–I-10 connector. (Source: ADOT.)

traffic growth and toll growth with inflation) would be 4.6% for 30 years. Under the average scenario, the toll revenue growth rate would be 4.6% for the first 10 years, 8% for the next 10 years, and 4.6% for the last 10 years. Under the best case scenario, the toll revenue would grow at 4.6% for the first 10 years and 8% for the next 20 years. Three more scenarios were developed from the EE boosted revenue streams. Under some of these scenarios, however, the toll revenue could not provide enough debt to cover all project costs. Therefore, equity financing would be required for this project. A reasonable distribution of private equity and public funds would remain the major concern to the state agency.

Both the SLP and SPP models were used to determine the optimal allocation of equity investment for the I-10 connector project. Beta distribution was used to calculate the present worth of expected revenue under each scenario. Furthermore, sensitivity analysis was conducted to evaluate the impact of uncertainty in the toll revenue and the opportunity loss coefficient. Data sets used on the base run appear in Table 1. The optimal private equity investments under the base case and the EE boosted case would be $9.55 million and $11.76 million, respectively. Under the SPP optimization model, given revenue R following a normal distribution, the optimal private equity investment would be $10.25 million. Figure 2 shows the impact of various expected revenue on agency cost, debt capacity, private equity, profit sharing to private partner, and public funds when DSCR is 1.5. As the expected revenue increases, the total costs to the state agency decrease gradually until the expected revenue reaches $120 million. When the expected revenue exceeds $140 million, the project becomes self-financed through debt. Then the cost to the public agency remains constant at $20 million to cover the cost of debt. Furthermore, because of a higher agency opportunity cost in this case, the increased revenue is first used to attract more debt and then private equity. Therefore, as demonstrated in Figure 2, the public agency equity decreases at a faster pace than the private equity when the project becomes almost entirely self-financed.

Scenario analysis was also conducted to evaluate the impact of the DSCR value on the equity structure. The DSCR value was set from 1.35 to 1.75. The optimal equity structure was defined as the ratio of public equity (E_2) over private equity (E_1). When higher toll revenues are expected, the expectation of getting higher profits increases. The project then becomes more attractive to private investors and therefore reduces the need for public funds. The equity structure at different DSCR values is shown in Figure 3. Each curve on this graph is an optimal curve and can be used to obtain the values of E_2 and E_1 by projecting the values of expected revenue from the x-axis to the optimal curves and then projecting them to the y-axis. Given the DSCR, the optimal equity structure, described as public fund over private equity (E_2/E_1), can be determined.

In a consideration of the deterministic linear program model (SLP), the optimal equity structure for the I-10 connector project would be 3.0 under the base case and 5.8 under the EE boosted case when the DSCR is 1.5. However, if the DSCR is varied over a range of 1.35 to 1.75 while the net revenues are assumed to be $60 million, the equity structure ratio would range from 3.74 to 10.3. A value of zero for E_2:E_1 indicates that the optimal solution should have no investment from the public agency, but that does not mean that E_1 should also be zero. The amount of private equity investment can be determined only from Figure 2.

Figure 3 can be generalized for uncertain DSCR values. When the DSCR is uncertain over a range of low and high values, the upper and lower boundaries of the optimal equity structure would be determined in accordance with the low and high DSCR values. Because of the volatility of expected revenue flows, the left and right boundaries of the optimal equity structure can also be determined. This determination will define an equity structure efficiency area as shown in Figure 4. The area is dependent on DSCR value and expected revenues. If the uncertainty in DSCR is low, the optimal curves would be much closer. Similarly, if the expected revenue ranges within small intervals, then the efficiency space can be reduced. Under an extreme

TABLE 1 Data and Results from SLP and SPP Analysis

Model	C ($ millions)	R ($ millions)	DSCR	α	β (min.)	β (max.)	γ	Optimal Private Equity ($ millions)
SLP								
Base case	100	65	1.50	1.20	1.36	2.10	2.00	9.55
EE boosted	100	80	1.50	1.20	1.36	2.10	2.00	11.76
SPP	100	N(80,25)	1.50	1.20	1.36	2.10	2.00	10.25

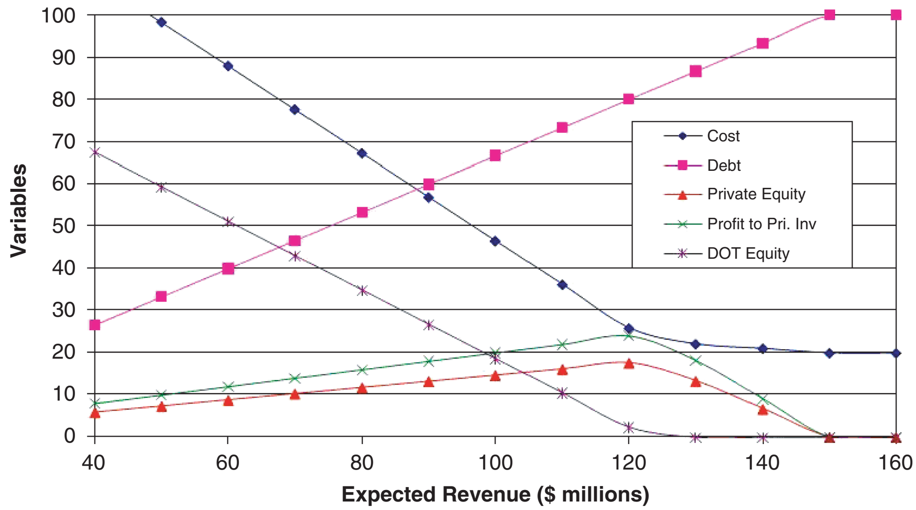

FIGURE 2 Impacts of expected revenue.

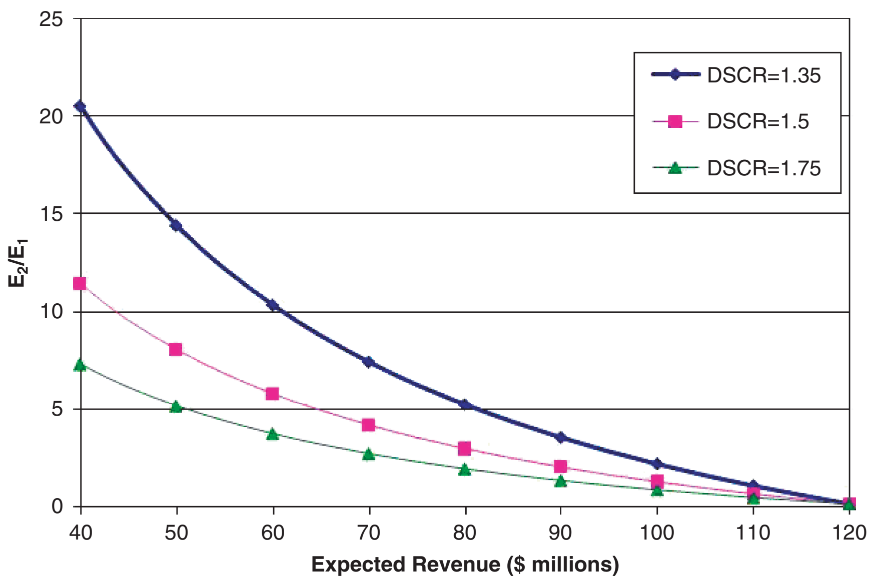

FIGURE 3 Equity structure under diverse DSCRs and expected revenue.

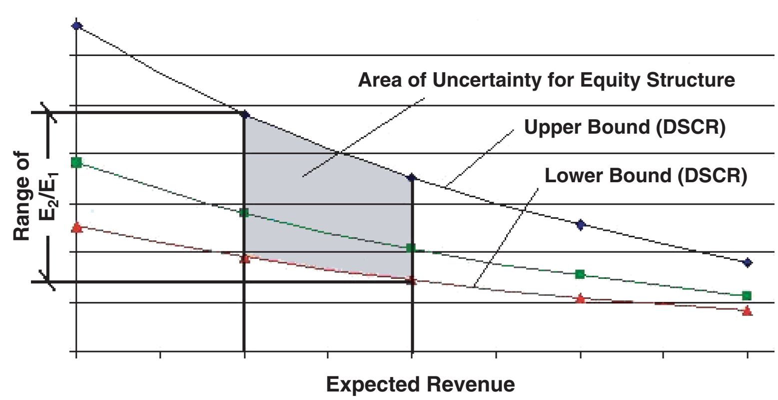

FIGURE 4 Equity structure efficiency area under uncertainty.

case where both DSCR value and revenue flows are deterministic, the equity structure efficiency area will form a single point.

One of the major contributions of the model is the introduction of the opportunity loss coefficient γ, which represents all opportunity costs associated with public investments (e.g., social benefits and transportation network improvement if the public investments are used in other projects). A sensitivity analysis indicates a threshold value of γ that causes the preference of financing methods switching from public funds to private equities. The threshold value indicates that alternative projects or other public works are highly beneficial for society or for the transportation infrastructure network and therefore should be given first priority from the public agency's standpoint. The model presented here demonstrates a methodology that can be adopted by planners for balancing private and public interests in PPP contracts under uncertainty. The use of the public opportunity loss coefficient γ enables the weighing of the social and external benefits of public funds, but the selection of γ requires careful consideration.

CONCLUSION

Equity structure is critical to PPP project financing. In trying to deliver PPP projects successfully, transportation agencies must carefully design the equity structure to simultaneously attract private capital and protect public interests. This paper presents a model to help agencies maximize the benefits from PPP financing. The model includes the benefits and costs from debt and equity financing and allows users to incorporate opportunity loss into the evaluation. The case study discussed here shows that optimal equity structure depends on three factors: expected toll revenue, debt service coverage ratio, and public opportunity loss coefficient. The research suggests that an optimal equity structure space could be defined under uncertainty. The model discussed here is especially useful for public agencies to (*a*) estimate the range of private equity investment, (*b*) identify the negotiation space for PPP contracts, and (*c*) determine the target equity structure in a PPP project.

The model does not include federal grants as a funding source. If earmark funds or federal grants are available for PPP projects, users should consider the grants as a deductible item of total project costs that are financed through state agencies and private investors. Debt and equity financing could be from several sources and require different rates of return, which would make the optimization problem much more complicated. Under this condition, users could either expand the model or consider the weighted average cost of capital. Furthermore, the analysis result is extremely sensitive to the selection of parameters in the model; therefore, users should be cautious in the selection of these parameters when designing the PPP financing plan.

ACKNOWLEDGMENT

The authors thank the Alabama Department of Transportation for providing financial support for this study.

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The opinions and findings are those of the authors alone.

The Project Delivery Methods Committee peer-reviewed this paper.