Financial Evaluation for Toll Road Projects Considering Traffic Volume and Serviceability Interactions

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Abstract: The rapid increase in both financial demands and the need for large and comprehensive highway infrastructure systems necessitates public authorities to muster support from the private sector. Public-private partnerships (PPP) have been increasingly adopted and cited as one of the most effective project delivery systems, which bring balance to risks and rewards between involved project participants. However, a number of PPP infrastructure projects around the world have been reported to have operating deficits and difficulties in debt-servicing. One of the major reasons for these difficulties is the unrealistic and inaccurate prediction of project investment performance during the initial stages of project viability and profitability analysis. Therefore, the research reported in this paper presents a formulation of a comprehensive framework that evaluates financial viability of PPP toll road projects. The framework utilizes a modified user-equilibrium traffic-assignment algorithm to estimate toll road traffic volume considering critical demand-influencing factors, which include travel time, pavement serviceability, and out-of-pocket user trip expenses. The proposed framework also considers the effects of the rehabilitation maintenance activities on the equilibrium flow pattern and project financial viability. This makes possible an estimation of the maintenance costs and frequency as well as an evaluation of the effects of rehabilitation programs on the traffic volume. The research reported in this paper also demonstrates the difference in traffic-flow patterns with and without interactive changes in pavement performance and traffic volume to demonstrate the need for incorporation of pavement performance and network levels of service into PPP highway project evaluation. **DOI: 10.1061/(ASCE)IS.1943-555X.0000175.**

Author keywords: Highway financing; Public private partnerships; Toll roads; Network equilibrium; Pavement serviceability; Traffic volume.

Background

In the past, the financial and organizational resources of public authorities played a vital role in financing highway infrastructure projects. However, the rapid increase in both financial demands and the need for large and comprehensive highway infrastructure systems necessitates these public authorities to muster support from the private sector. In doing so, public-private partnerships (PPP) have been increasingly adopted and cited as one of the most effective project-financing systems, which brings balance to risks and rewards between involved project participants. In a typical PPP project, a concessionaire is responsible for finance, construction, operation, and maintenance of a highway infrastructure facility in return for the right to collect usage tolls from the public using the facility. For this reason, PPP project-delivery systems provide promising private investment opportunities and fulfill the public objectives in expanding infrastructure facilities. Despite this potential synergy, a number of PPP infrastructure projects around the world have been reported to have operating deficits and difficulties in debt-servicing (Schaufelberger 2005). One of the major reasons for these difficulties is the unrealistic and inaccurate prediction of project-investment performance during the initial stage of project viability and profitability analysis. As a consequence, strenuous efforts for improving PPP project-evaluation methods are prevalent in the literature. These investment evaluation methods for public infrastructure projects require critical decisions to be assessed regarding contract terms and the project financial and capital structures with limited information. Qualitative and quantitative frameworks have been developed and utilized for the selection of the main PPP decision parameters while considering the associated risks and rewards (Bi and Wang 2009). Despite the significant contributions of these frameworks, their implementation may encounter a number of limitations, which include the following: (1) their limited ability to account for critical PPP risks, (2) their inability to consider the impact of important factors influencing traffic demand, and (3) their reliance on current traffic-demand estimation models that fail to account for the effects of rehabilitation activities on project profitability and viability.

Previous research efforts have identified almost 100 distinct risk factors associated with a typical PPP project (Thomas et al. 2003; Schaufelberger 2005; Xenidis and Angelides 2005a, b; Iyer and Sagheer 2010). Considering all risks factors in project evaluation is not only impractical but also not necessary due to diversity and dissimilarity of projects in their nature, size, type, participants, and location. For highway infrastructure projects in particular, traffic-demand risk and risk factors associated with project revenue are considered extremely critical because project revenue from traffic volume is almost the only source for recovery of investments and making profits (Thomas et al. 2003; Chiara and Garvin 2007).

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Although the criticality of the traffic-demand risk is in consensus, estimating its magnitude and uncertainties is challenging because socioeconomic characteristics and service attributes of individual PPP projects vary temporally and geographically. Several techniques for predicting traffic volume and demand risks were used in estimating the revenue generating capacity of highway facilities. These techniques include the following: (1) applications of statistical distributions (Zhang 2005; Shen and Wu 2005; Cheah and Liu 2006), (2) use of statistical projections from similar facilities (Ng et al. 2007; Wang et al. 2009), (3) applications of Wiener processes from option theory (Chiara and Garvin 2007; Chiara et al. 2007; Brandao and Saraiva 2008), (4) applications of utility functions and the stated-preference approach (Aziz and Russell 2006; Gousios et al. 2007), and (5) use of the network-equilibrium concept that determines the facility demand based on traveler expenses (Chen et al. 2003, 2006; Chen and Subprasom 2007; Subprasom and Chen 2007). Although these studies have made significant contributions in this field, none of them estimated the operating revenue by considering the long-term and simultaneous interactions among the critical demand parameters (i.e., the user's route choice, user expenses, and facility's levels of service).

A number of quantitative project evaluation approaches have been previously used in making viable investment decisions. These approaches include (1) applications of data-mining techniques (Ock et al. 2005; Yun and Caldas 2009), (2) optimization of concession periods (Shen and Wu 2005; Ng et al. 2007; Wang et al. 2009), (3) optimization of the toll rates and traffic capacity (Chen et al. 2003, 2006; Chen and Subprasom 2007; Subprasom and Chen 2007), (4) valuation of government support (Cheah and Liu 2006; Chiara et al. 2007; Chiara and Garvin 2007; Brandao and Saraiva 2008; Liu and Cheah 2009), and (5) optimization of capital structures and financial variables (Chang and Chen 2001; Bakatjan et al. 2003; Zhang 2005). From a project evaluation point-of-view, these approaches successfully addressed demand risks and uncertainties and included some of the critical demand-influencing factors. However, these approaches did not consider the effects of rehabilitation and maintenance activities on short-term and long-term traffic demand in the evaluation of the project's financial viability. This also illustrates a clear need to create a more comprehensive framework that evaluates financial viability of PPP toll road projects with more accuracy and reliability.

To overcome the limitations of existing project-evaluation tools, the writers propose a comprehensive quantitative financial-viability evaluation framework for a toll road project. The proposed framework applies traffic-demand estimation techniques, pavement serviceability concepts, and cash-flow analysis methods in evaluating quantitative decision-support parameters used by project stakeholders. The framework consists of four major components, as follows: (1) demand-estimation model, (2) pavement performance and rehabilitation model, (3) cash-flow calculation model, and (4) performance-metrics calculation model. The subsequent sections describe the details of these models.

Demand-Estimation Model

The proposed demand-estimation model is developed based on the standard deterministic user-equilibrium (UE). As shown in Eqs. (1) and (2a)–(2d), a solution to the UE traffic assignment can be obtained from solving a minimization program (Sheffi 1985; Ukkusuri and Waller 2006; Ukkusuri et al. 2012). The traditional user-equilibrium approach is expanded to overcome two main drawbacks of previous demand models, as follows: (1) important demand-influencing factors will be introduced to the link performance function, and (2) the traditional solution algorithm is modified to handle network link flows that consist of multiple vehicle types. Therefore, given an origin-destination (OD) matrix, the traffic volume in a network with a toll facility can now be determined and take into consideration the interactions between traffic demand, user trip expenses, and pavement serviceability. The subsequent subsections describe the formulation of the proposed demand-estimation model in more detail

$$\min\ z(x,q)\sum_{a\in A}\int_0^{x_a} t_a(w)dw - \sum_{w\in W}\int_0^{q_w} D_w^{-1}(w)dw \tag{1}$$

subject to

$$q_w = \sum_{r\in R_w} f_r^w \quad \forall\ w\in W \tag{2a}$$

$$x_a = \sum_{w\in W}\sum_{r\in R_w} f_r^w \delta_{ar}^w \quad \forall\ a\in A \tag{2b}$$

$$f_r^w \geq 0 \quad \forall\ r\in R_w, \quad \forall\ w\in W \tag{2c}$$

$$q_w \geq 0 \quad \forall\ w\in W \tag{2d}$$

where A = set of the network links; W = set of the network OD pairs; R_w = set of the routes connecting OD pair w; x_a = flow on link a; f_r^w = flow on route r between OD pair w; q_w = demand of OD pair w; δ_{ar}^w = incidence value of link a on route r connecting OD pair w; $t_a(x)$ = equivalent travel-time of the link; and $D_w^{-1}(q)$ = inverse-demand function of an OD pair w.

Modification to Link-Performance Function

The link performance function used in previous work is modified to take into account important demand-influencing factors, which include travel time, value of travel-time, vehicle operating costs, and pavement roughness (Chen et al. 2003, 2006; Chen and Subprasom 2007; Subprasom and Chen 2007). A new term is introduced to represent comprehensive user out-of-pocket costs, which are transformed into a time-equivalent unit using the value of time for each vehicle type. This new term is composed of multiple weighted costs for different vehicle types that are proportional to their percentage of the traffic mix on a particular link

$$\begin{aligned} t_a(x) = t_0\left[1 + 0.15\left(\frac{x_a}{c_a}\right)^4\right] &+ \beta_c[\mathrm{toll}_c + (m\cdot \mathrm{VOC}_c)](1 - tp_a) \\ &+ \beta_t[\mathrm{toll}_t + (m\cdot \mathrm{VOC}_t)]tp_a \end{aligned} \tag{3}$$

where t_0 = free-flow travel time on link a; c_a = capacity of link a; toll = toll applied to link a; m is a vehicle operating cost (VOC) adjustment multiplier; tp_a = truck percentage on link a; β is a parameter that transforms the cost into an equivalent time-unit; c stands for passenger cars; and t stands for trucks. The VOC adjustment multiplier is a parameter that establishes the relation between the VOC and pavement serviceability or roughness, the international roughness index (IRI), in accordance with Sinha and Labi (2007)

$$m = 0.001\left[\frac{(\mathrm{IRI} - 80)^2}{10}\right] + 0.018\left[\frac{(\mathrm{IRI} - 80)}{10}\right] + 0.9991 \tag{4}$$

Initialization

Steps 1–3 are as follows:

1. Identify the shortest route connecting each and every OD pair in accordance with

$$c_r^w = \sum_{a \in A} t_a^0 \delta_{a,r}^w \quad \forall\ r \in R_w, \quad \forall\ w \in W \tag{5}$$

2. Based on the initial travel time c_r^w, assign the entire potential demand of each OD pair to its shortest route m (identified in step 1) and no flows to the other routes r between each OD pair

$$f_m^{w^t} = \bar{q}_{w^t}, \qquad f_r^{w^t} = 0 \quad \forall\ r \neq m \tag{6a}$$

$$f_m^{w^c} = \bar{q}_{w^c}, \qquad f_r^{w^c} = 0 \quad \forall\ r \neq m \tag{6b}$$

$$\bar{q}_{w^t} = \bar{q}_w \cdot tp_w \tag{6c}$$

$$\bar{q}_{w^c} = \bar{q}_w \cdot (1 - tp_w) \tag{6d}$$

3. Determine the feasible flow patterns consisting of a set of link flows$\{x_a^n\}$ and a set of OD pair demands $\{q_w^n\}$ from Eqs. (7*a*)–(7*e*) and calculate the link truck percentages

$$q_w = \bar{q}_w \quad \forall\ w \in W \tag{7a}$$

$$x_a^t = \sum_{r \in R_w} f_r^{w^t} \delta_{ar}^w \quad \forall\ a \in A \tag{7b}$$

$$x_a^c = \sum_{r \in R_w} f_r^{w^c} \delta_{ar}^w \quad \forall\ a \in A \tag{7c}$$

$$x_a = x_a^c + x_a^t \quad \forall\ a \in A \tag{7d}$$

$$tp_a = \frac{x_a^t}{x_a^c + x_a^t} \quad \forall\ a \in A \tag{7e}$$

Update Travel Time and Inverse Demand

Steps 1–2 are as follows:

1. Calculate link performance functions $t_a(x_a^n)$ for all links using Eq. (3), and x_a and tp_a calculated in step 1 of initialization; and
2. Calculate inverse demand functions $D_w^{-1}(q_w^n)$ for all OD pairs using Eq. (8) and q_w determined in step 3 of initialization, where γ = demand elasticity (Chen et al. 2003)

$$D_w^{-1}(q) = \frac{\ln q_w - \ln D_w}{\gamma} \quad \forall\ w \in W \tag{8}$$

Move-Direction Finding

Steps 1–3 are as follows:

1. Compute the travel time c_m^w of the shortest route m connecting OD pair w based on $\{t_a(x_a^n)\}$ calculated in step 1 of updating travel time and inverse demand;
2. Execute the assignment rules to determine the auxiliary route flow $\{g_r\}$

$$\begin{aligned} &\text{If } c_m^{w^n} < D_w^{-1}(q_w^n), && \text{set } g_m^{w^t} = q_w^{-t}, \\ &g_m^{w^c} = \bar{q}_{w^c}, \quad \text{and} && g_r = 0 \quad \forall\ r \neq m \\ &\text{If } c_m^{w^n} \geq D_w^{-1}(q_w^n), && \text{set } g_r = 0 \quad \forall\ r \end{aligned} \tag{9}$$

3. Compute an auxiliary link flow $\{y_a^n\}$ and auxiliary OD pair demand $\{v_w^n\}$

$$y_a^t = \sum_{w \in W} \sum_{r \in R_w} g_r^{w^t} \delta_{ar}^w \quad \forall\ a \in A \tag{10a}$$

$$y_a^c = \sum_{w \in W} \sum_{r \in R_w} g_r^{w^c} \delta_{ar}^w \quad \forall\ a \in A \tag{10b}$$

$$g_r^w = g_r^{w^t} + g_r^{w^c} \quad \forall\ r \in R_w, \quad \forall\ w \in W \tag{10c}$$

$$y_a = y_a^t + y_a^c \quad \forall\ r \in R_w \tag{10d}$$

$$v_w = \sum_{r \in R_w} g_r^w \quad \forall\ w \in W \tag{10e}$$

Move-Size Calculation

Use an interval reduction method to find a number between 0 and 1 (α_n) that minimizes the one-dimensional minimization program

$$\begin{aligned} &\min z(x,q) \sum_{a \in A} \int_0^{x_a + \alpha(y_a - x_a)} \left\{ t_0 \left[1 + 0.15 \left(\frac{x_a}{c_a} \right)^4 \right] + \right. \\ &\left. \times \beta_c(\text{toll}_c + m \cdot \text{VOC}_c)(1 - tp_a) + \beta_t(\text{toll}_t + m \cdot \text{VOC}_t) tp_a \right\} dw \\ &- \sum_{w \in W} \int_0^{q_w + \alpha(v_w - q_w)} \left[\frac{\ln q_w - \ln \bar{q}_w}{\gamma} \right] dq \end{aligned} \tag{11}$$

subject to

$$0 \leq \alpha \leq 1 \tag{12}$$

Flow Update

Calculate $\{x_a^{n+1}\}$, $\{q_{rs}^{n+1}\}$, and tp_a^{n+1} in accordance with

$$x_a^{t^{n+1}} = x_a^{t^n} + \alpha_n (y_a^{t^n} - x_a^{t^n}) \quad \forall\ a \in A \tag{13a}$$

$$x_a^{c^{n+1}} = x_a^{c^n} + \alpha_n (y_a^{c^n} - x_a^{c^n}) \quad \forall\ a \in A \tag{13b}$$

$$x_a^{n+1} = x_a^{t^{n+1}} + x_a^{c^{n+1}} \quad \forall\ a \in A \tag{13c}$$

$$tp_a^{n+1} = \frac{x_a^{t^{n+1}}}{x_a^{t^{n+1}} + x_a^{c^{n+1}}} \quad \forall\ a \in A \tag{13d}$$

$$q_w^{n+1} = q_w^n + a_n (y_w^n - q_w^n) \quad \forall\ w \in W \tag{13e}$$

Convergence Criterion

Check the convergence of the solution and terminate if the criterion K holds; otherwise, set iteration = $n + 1$ and proceed as in update travel time and inverse demand. The magnitude of the criterion depends on a required level of the solution's fineness, which typically ranges from 10^{-6} to 10^{-4} (Sheffi 1985)

$$\sum_{w \in W} \frac{|D_w^{-1}(q_w^n) - c_w^n|}{c_w^n} + \sum_{w \in W} \frac{|c_w^n - c_w^{n-1}|}{c_w^n} \leq K \tag{14}$$

Modification to UE Traffic-Assignment Algorithm

The standard UE solution algorithm is modified to incorporate the new link performance function and account for unequal out-of-pocket costs incurred by different types of vehicles (Sheffi 1985). The steps of the modified algorithm are described as follows:

Pavement Performance and Rehabilitaton Model

Highway network levels of service can be evaluated by examining traffic-flow patterns, pavement deterioration, and maintenance and rehabilitation activities, which change over time. These levels of service affect traffic-demand patterns in the network and can be used to identify financial requirements for maintenance activities in a systematic manner. Therefore, the pavement performance and rehabilitation model serves as a connection between the highway network traffic activities, maintenance and rehabilitation activities, and the project financial viability evaluation model. Hence, the model is composed of three modules that are specifically designed to do the following: (1) evaluate pavement deterioration in a highway network caused by an equilibrium traffic-flow pattern, (2) estimate the frequency and financial requirements of pavement maintenance and rehabilitation activities, and (3) enable consideration of the impacts of the maintenance and rehabilitation activities on network performance.

Performance-Prediction Module

Pavement serviceability has a strong correlation with pavement deterioration factors such as traffic-loading, environmental conditions, and the age of a particular pavement section (Irfan et al. 2009; Khurshid et al. 2011). This correlation can be represented in the form of a mathematical expression between the IRI and the previously mentioned deterioration factors

$$\mathrm{IRI} = \exp[\alpha + (\beta \cdot \mathrm{AMTA} \times t) + (\gamma \cdot \mathrm{AMDX} \times t)] \quad (15)$$

where IRI is in units of meter/kilometer; accumulated truck-traffic (AMTA) is in units of millions; average freezing index (AMDX) is in units of °F-day; t = time (years since the rehabilitation treatment); and α, β, and γ are regression coefficients (Irfan et al. 2009; Khurshid et al. 2011).

Rehabilitation-Requirement Module

The second module helps estimate the frequency and financial requirements of pavement rehabilitation projects. The module is designed to monitor changes in pavement performance of network links and compare them to a predefined threshold-serviceability level. If the pavement performance deteriorates and falls below the threshold value, financial and physical rehabilitation requirements can be anticipated. Another important feature of this module is the duration of rehabilitation projects. Rehabilitation projects involve a number of construction activities that cause temporary delays and a reduction of network performance due to decreased capacity and operating speed. Therefore, the duration during which these activities take place and affect the network performance must be considered.

Rehabilitation-Impact Module

As mentioned in the previous section, rehabilitation projects and construction activities cause significant reductions in network performance and change the equilibrium flow pattern, but also cause pavement performance improvements after their completion. For this reason, the rehabilitation impact module considers both the negative and positive impacts of rehabilitation programs.

Negative Impacts from Rehabilitation

This proposed framework considers two main negative impacts resulting from a rehabilitation project, which include (1) reduction in operating capacity due to closed lanes, and (2) reduced speed limits in work zones. While under rehabilitation, these negative impacts can be reflected as changes in the link performance function used in the demand-estimation model, in which the capacity of particular links will be decreased and their free-flow speed will be decreased. After the completion of the rehabilitation project, the road section will go back to operating at normal capacity and speed.

Positive Impacts from Rehabilitation

After the rehabilitation project is completed and the road section is opened to traffic, an immediate improvement can be realized as a jump in pavement performance. Similarly to the pavement performance model, this jump can be predicted using a mathematical relationship between the performance improvement and an initial pavement condition (Irfan et al. 2009; Khurshid et al. 2011). The performance jump PJ or the sudden drop in IRI values is a function of the initial condition of the pavement

$$PJ = a \cdot \ln(\mathrm{INI}) + b \quad (16)$$

where INI_a = initial IRI just before the treatments (m/km of link a); and a and b are regression coefficients (Irfan et al. 2009; Khurshid et al. 2011).

Cash-Flow Calculation Model

The objective of this model is to calculate cash flow components associated with all activities in the concession based on the outcome of the first two models. To determine the project financial performance indicators, cash flow variables need to be calculated. The demand-estimation model and pavement performance and rehabilitation model provide quantitative input for the cash-flow calculation model. The number of vehicles of different types and toll rates are essential to determination of the project revenue in each year of its operation, whereas the frequency and locations of the rehabilitation treatments indicate the maintenance and rehabilitation expenses. For reasons of brevity, only cash flow variables derived from the model outputs will be presented. The complete details of all cash flow variables can be found in Jeerangsuwan (2011) and Jeerangsuwan and Kandil (2012).

Annual net after-tax cash inflows (NATCI) is the net available cash in each year of the operation of the facility in current dollars

$$\mathrm{NATCI}_j = \mathrm{PBIT}_j + \mathrm{DE}_j - \mathrm{DI}_j - \mathrm{TAX}_j, \quad j = 1, 2, \ldots, n \quad (17)$$

where TAX_j = income tax; j = operation period; DE = depreciation, which refers to general depreciation; DI = debt repayment, the debt-servicing payment made to the lenders for the construction loan; and PBIT_j = profit before tax and interest, the net profit from the operation of the facility. The latter is simply the difference between the total annual revenue and all operation and maintenance expenditure as well as depreciation losses

$$\mathrm{PBIT}_j = \mathrm{RE}_j - \mathrm{OM}_j - \mathrm{DE}_j, \quad j = 1, 2, \ldots, n \quad (18)$$

where OM_j = operation and maintenance cost, the expenditure that comes from the operation, maintenance and preservation of the facility; and RE_j = annual revenue, the total revenue in one year of the operation of the facility. In this context, the annual revenue is calculated directly from the product of the annual number of vehicles and their respective toll rates

$$\mathrm{RE}_j = \sum_{v=1}^{V} \sum_{a=1}^{A} (\mathrm{toll}_a^v)(x_a^v), \quad j = 1, 2, \ldots, n \quad (19)$$

where toll_a^v = toll rate applied to the Type v vehicles traversing on link a; and x_a^v = number of the Type v vehicles traversing on link a obtained from the demand-estimation model. The OM_J cash flow variable is composed of three elements, as follows: (1) operation cost (OC), the cost incurred from the general operations (utility bills, overhead cost, and so on) of the facility; (2) annual maintenance cost (AMC), the cost for funding routine maintenance activities on an annual basis to maintain the physical conditions of the facility; and (3) rehabilitation maintenance cost (RM), the cost for funding relatively large scale maintenance and rehabilitation treatments, which depends on the types of required treatments

$$\text{OM}_j = \text{OC}_j + \text{AMC}_j + \text{RM}_j \tag{20}$$

The amount of the debt installment depends on the financial and debt structure of the initial investment. Tax is applied at the end of every fiscal year to the project revenue.

Performance-Metrics Calculation Model

In general, concessionaires and private investors focus on a level at which the initial investment pays off in terms of returns and profits (Bakatjan et al. 2003). However, lenders pay much attention to the steadiness and robustness of the project cash-flow (Finnerty 2007). The performance-metrics calculation model provides quantitative indicators for the economic efficiency and financial performance of a PPP highway project from the perspective of concessionaires

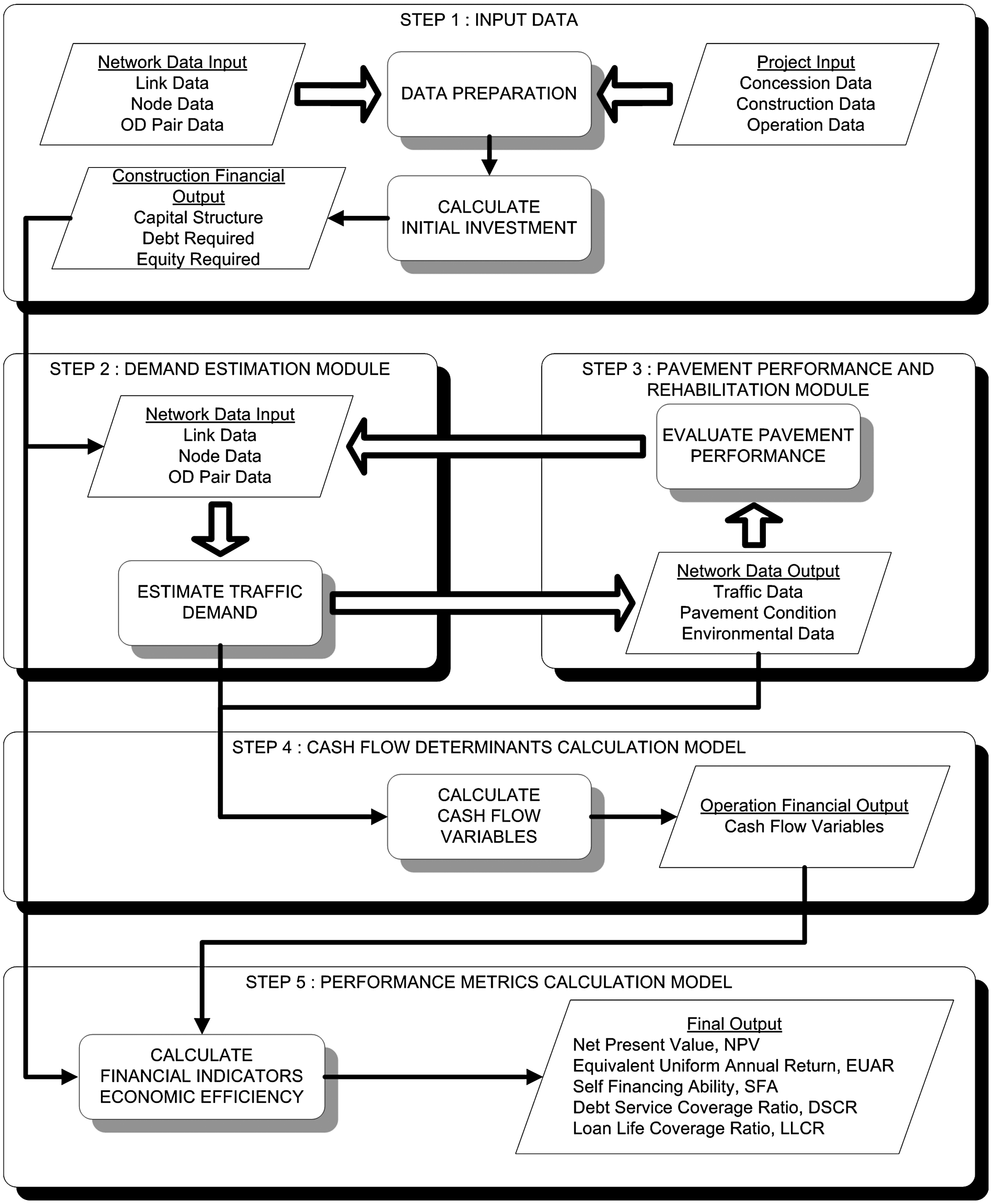

Fig. 1. Financial viability evaluation framework

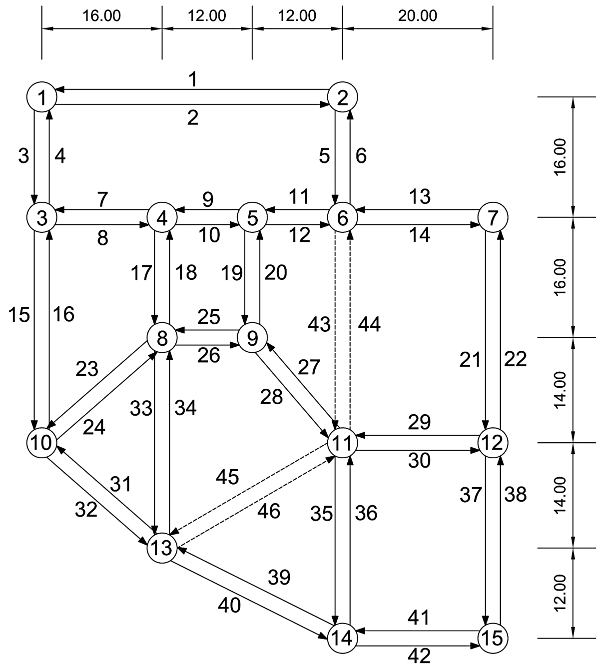

Fig. 2. Highway network (in miles)

and lenders. That is, the model simply determines the subsequent decision-support indicators, which are derived from the cash flow variables.

Net Present Value

Net present value (NPV) is considered to be one of the most practical and effective performance indicators for project economic efficiency (Bakatjan et al. 2003; Zhang 2005; Sinha and Labi 2007; Jeerangsuwan 2011; Jeerangsuwan and Kandil 2012). The NPV is, by definition, the difference between income and expense over an analysis period discounted to the present (Sinha and Labi 2007). In the model, NPV and be calculated in accordance with Zhang (2005)

$$\mathrm{NPV} = \sum_{j=1}^{n} \frac{\mathrm{NATCI}_j}{(1+r)^{j+m}} - \sum_{j=1}^{m} \frac{E_i}{(1+r)^{i-1}} \tag{21}$$

where m = construction duration; E_i = equity drawing at the beginning of the ith year of the construction period; and r = discount rate.

Self-Financing Ability

Self-financing ability (SFA) indicates the percentage of the total construction cost that can be recovered by the net operating profit. A project with a higher SFA would be considered to have more revenue-generating capability than a low-SFA project (Chang and Chen 2001)

$$\mathrm{SFA} = \frac{\mathrm{NPV}_R}{\mathrm{NFV}_C} \times 100\% \tag{22}$$

where NPV_R = present value of the net revenue during the operation period discounted to the end of the construction; and NFV_C = future value of the construction cost at the end of the construction period.

Debt-Service Coverage Ratio

Debt-service coverage ratio (DSCR) measures the stability and robustness of the cash flow stream. It can be calculated from the

Table 1. Node Types and Potential Demand between Nodes

City type	Node	Potential demand (vehicles/h) Main	Major	Minor
Main districts	4, 5, 8, and 9	1,000	800	600
Major suburb cities	1, 2, 3, 6, 10, 11, and 13	800	600	400
Minor suburb cities	7, 12, 14, and 15	600	400	200

Table 2. Link Attributes

Link	Length [km (mi)]	Speed [km/h (mi/h)] Free-flow	Work-zone	Lanes Full capacity	Work-zone	Capacity (vehicles/lane/h)
1	64.000 (40.00)	112 (70)	72 (45)	3	2	2,400
2	64.000 (40.00)	112 (70)	72 (45)	3	2	2,400
3	25.600 (16.00)	112 (70)	72 (45)	3	2	2,400
4	25.600 (16.00)	112 (70)	72 (45)	3	2	2,400
5	25.600 (16.00)	112 (70)	72 (45)	3	2	2,400
6	25.600 (16.00)	112 (70)	72 (45)	3	2	2,400
7	25.600 (16.00)	88 (55)	64 (40)	3	2	2,100
8	25.600 (16.00)	88 (55)	64 (40)	3	2	2,100
9	19.200 (12.00)	72 (45)	32 (20)	3	2	1,900
10	19.200 (12.00)	72 (45)	32 (20)	3	2	1,900
11	19.200 (12.00)	88 (55)	64 (40)	3	2	2,100
12	19.200 (12.00)	88 (55)	64 (40)	3	2	2,100
13	32.000 (20.00)	88 (55)	64 (40)	2	1	2,250
14	32.000 (20.00)	88 (55)	64 (40)	2	1	2,250
15	48.000 (30.00)	112 (70)	72 (45)	3	2	2,400
16	48.000 (30.00)	112 (70)	72 (45)	3	2	2,400
17	25.600 (16.00)	72 (45)	32 (20)	3	2	1,900
18	25.600 (16.00)	72 (45)	32 (20)	3	2	1,900
19	25.600 (16.00)	72 (45)	32 (20)	3	2	1,900
20	25.600 (16.00)	72 (45)	32 (20)	3	2	1,900
21	48.000 (30.00)	88 (55)	64 (40)	2	1	2,250
22	48.000 (30.00)	88 (55)	64 (40)	2	1	2,250
23	34.016 (21.26)	88 (55)	64 (40)	3	2	2,100
24	34.016 (21.26)	88 (55)	64 (40)	3	2	2,100
25	19.200 (12.00)	72 (45)	32 (20)	3	2	1,900
26	19.200 (12.00)	72 (45)	32 (20)	3	2	1,900
27	29.503 (18.439)	88 (55)	64 (40)	3	2	2,100
28	29.503 (18.439)	88 (55)	64 (40)	3	2	2,100
29	32.000 (20.000)	88 (55)	64 (40)	2	1	2,250
30	32.000 (20.000)	88 (55)	64 (40)	2	1	2,250
31	34.016 (21.260)	112 (70)	72 (45)	3	2	2,400
32	34.016 (21.260)	112 (70)	72 (45)	3	2	2,400
33	44.800 (28.000)	88 (55)	64 (40)	3	2	2,100
34	44.800 (28.000)	88 (55)	64 (40)	3	2	2,100
35	41.600 (26.000)	88 (55)	64 (40)	2	1	2,250
36	41.600 (26.000)	88 (55)	64 (40)	2	1	2,250
37	41.600 (26.000)	88 (55)	64 (40)	2	1	2,250
38	41.600 (26.000)	88 (55)	64 (40)	2	1	2,250
39	42.933 (26.833)	88 (55)	64 (40)	2	1	2,250
40	42.933 (26.833)	88 (55)	64 (40)	2	1	2,250
41	32.000 (20.000)	88 (55)	64 (40)	2	1	2,250
42	32.000 (20.000)	88 (55)	64 (40)	2	1	2,250
43	48.000 (30.000)	112 (70)	72 (45)	3	2	2,400
44	48.000 (30.000)	112 (70)	72 (45)	3	2	2,400
45	44.456 (27.785)	112 (70)	72 (45)	3	2	2,400
46	44.456 (27.785)	112 (70)	72 (45)	3	2	2,400

ratio of total annual cash available for debt repayment over the annual debt in a particular year. A high DSCR shows high debt-carrying capacity (Zhang 2005)

$$\mathrm{DSCR}_j = \frac{\mathrm{PBIT}_j + \mathrm{DE}_j - \mathrm{TAX}_j}{D_j}, \quad j = 1, 2, \ldots, n \tag{23}$$

Loan-Life Coverage Ratio

The loan life coverage ratio (LLCR) is also used to evaluate the credit quality and debt-carrying capacity of a portfolio. The LLCR is the ratio between the present value of all available cash in every year of the facility operation period until debt maturity and the present value of the remaining debt of the project (Zhang 2005)

$$\mathrm{LLCR}_k = \frac{\sum_{j=k}^{N} \frac{\mathrm{PBIT}_j + \mathrm{DE}_j - \mathrm{TAX}_j}{(1+r)^{j-k+1}}}{\sum_{j=k}^{N} \frac{D_j}{(1+r)^{j-k+1}}} \tag{24}$$

Application of Financial Viability Evaluation

In previous sections the formulation of the components of the framework as well as theories relevant to that formulation were presented. This section presents the integrated framework and detailed procedures for evaluating financial viability of a toll road project (Fig. 1)

Input Data

Two types of data are needed for the proposed framework (general project attributes and highway network attributes), as follows:

1. Project attributes define the physical and financial structure of a toll road project. This type of data includes the following:
   - Construction costs and the schedule of the project, including maintenance and rehabilitation schemes;
   - Financial and debt structure, including equity level, loan term, interest, debt maturity, rate of return, concession period, and so on; and
   - Economic environment parameters such as inflation rate and minimum attractive rate of return.
2. Network attributes relate to technical attributes that define a highway transportation network. These network attributes entail a collection of nodes and links with capacity and location, an origin-destination demand matrix, and so on.

Demand-Estimation Model

This model utilizes the modified standard user-equilibrium traffic-assignment algorithm to determine the number of vehicles of different types on particular links in the highway network.

Pavement Performance and Rehabilitation Model

Given a traffic-flow pattern from the demand-estimation model, pavement performance and rehabilitation requirements could be predicted. That is, the pavement performance and network attributes would change in accordance with pavement deterioration and rehabilitation activities, and would also affect the traffic-flow pattern continually. The first two models function together in a cyclic fashion. In this case, the length of the debt-payment cycles could be used.

Table 3. Summary of Input Variables

Input variables	Values
Project information	
Equity level (%)	24
Minimum attractive rate of return (%)	10
Operation period (years)	30
Toll rates (US$)	6.00 for cars, 12.00 for trucks
Capacity (vehicles/h)	7,200 for all tolled links
Construction period (years)	4
Construction cost schedule (%)	Table 3
Discrete inflation rate (%)	Table 3
Debt interest (%)	10
Debt maturity (years)	Operation period
Tax rate (%)	7
Design life (years)	Operation period
Annual operation cost (US$/year)	2 million
Rehabilitation maintenance cost [2007US$/(lane-km)]	375,101
Network attributes	
Truck percentage in each OD pair (%)	20
Demand elasticity in each OD pair	1.33
Travel-time value ($/h)	38.75 for cars, 43.24 for trucks
Average VOC {US$/(vehicle-km) [US$/(vehicle-mi)]}	14.37 (22.99) for cars, 31.16 (49.85) for trucks
Coefficients for performance prediction module	
α, HMA overlay structural	−0.638
β, HMA overlay structural	0.111
γ, HMA overlay structural	0.151
Coefficients for rehabilitation impact module	
α, HMA overlay structural	1.843
β, HMA overlay structural	−0.144
Rehabilitation threshold	
Toll link, interstate (m/km)	2.35
Free links, noninterstate NSH (m/km)	2.46
Annual freeze index (°F-day)	4,530

Cash-Flow Calculation

After each debt-payment cycle is completed, the cumulative number of vehicles will be used to calculate the cash flow variables as well as the incurred costs for rehabilitation and maintenance, if required. The next step continues until the concession period ends.

Performance-Metrics Calculation

At the end of the concession period, project performance indicators are calculated from the cash flow variables determined over the construction and operation periods. These project performance indicators could be used to evaluate the financial viability of a toll road project and to help in investment decision-making.

Table 4. Construction Cost Schedule and Inflation Rates

Construction year	Inflation rate (%)	Construction cost schedule (%)
1	0.00	20
2	1.10	30
3	1.30	30
4	1.50	20

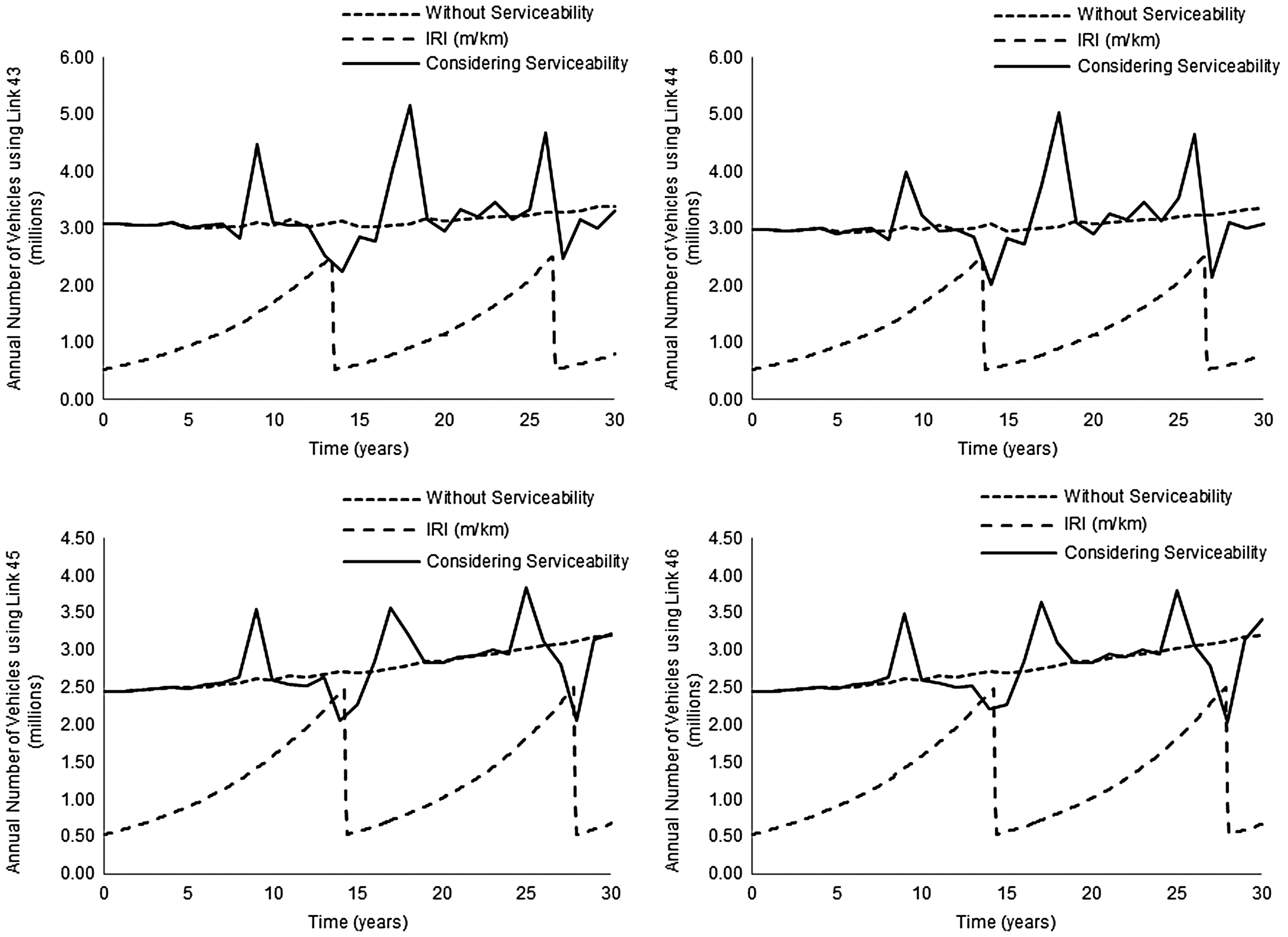

Fig. 3. Comparison of the annual number of vehicles using toll links and IRI (m/km)

Case Study and Results

Overview

A sample highway network was used to test the performance of the framework. The hypothetical network (Fig. 2) consists of 15 nodes, 46 directed links, and 210 OD pairs representing cities and highway corridors connecting them. There are three types of cities, as follows: (1) major districts, (2) major suburb cities, and (3) minor suburb cities. Table 1 summarizes the potential demand between these cities. Table 2 shows detailed information about the attributes of the individual links.

A prospective tolled facility is to be constructed to provide direct connectivity between city 6, 11, and 13 using links 43, 44, 45, and 46. Table 3 summarizes the project-input variables and network attributes. Table 4 shows additional project inputs during the construction period.

Effects of Pavement Serviceability on Estimated Traffic Volume

The proposed framework was used to show the difference in traffic-flow patterns in the highway network with and without the consideration of pavement serviceability. Fig. 3 illustrates the annual number of vehicles on toll road sections with and without pavement-serviceability effects. The IRI of the particular road section is presented. The annual number of vehicles on toll road sections corresponds to the changes in pavement roughness and rehabilitation activities. As pavement roughness increases, the link performance is less attractive to road users, resulting in the shift of the traffic volume to other links. The reductions in link performance become significant during rehabilitation projects around the 15th year of operation. The traffic volume clearly falls because of the reduced capacity and limited operating speed in rehabilitation projects. After the rehabilitations project is completed, resulting in sudden drops in the pavement roughness, the link performance also recovers. The rehabilitation construction activities taking place on the competing links also impact the performance of the toll links. However, the rehabilitation activities on the competing links also cause impacts on traffic volume on the toll links. Between years 8 and 10 in the concession period, a series of rehabilitation activities on link 9, 10, 19, 20, 21, 22, 25, 26, 37, and 38 cause considerable increases in traffic volume on toll facilities. The same shifting patterns could be seen in the 17th and 25th years as well.

Conclusions

The writers' ultimate goal was to develop a comprehensive and realistic financial viability evaluation framework for public-private partnership toll road projects. The framework consists of four computational models, each of which performs distinct tasks and interacts with the other models in determining project financial viability. A network equilibrium approach is used for estimating the project traffic-revenue and the magnitude of potential damage to highway network performance. A modified link-performance function was introduced to incorporate pavement serviceability into road-user route selection. Since truck traffic is a major cause of pavement deterioration, the standard user-equilibrium solution algorithm was modified to support link flows consisting of multiple vehicle types. The resulting network flow patterns, however, could also be used to estimate the damage to pavement serviceability, which affects the route selection simultaneously. Considering the interaction between traffic volume and pavement serviceability, traffic revenue as well as operation and maintenance expenditure could be estimated in a more comprehensive and realistic fashion. A collective set of project financial and economic performance indicators were used to aid the investment decision-making given an initial set of project information and network attributes. The writers also demonstrated the difference in traffic-flow patterns with and without the interactive changes between pavement performance and traffic volume.

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