Study on Toll-Pricing Strategies for Managing Transportation Facilities in Design-Build-Finance-Operate Partnerships

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ABSTRACT

In recent years, transportation planning has been challenged by increasing need for infrastructure development, a shortfall of revenue from the public sector, and political trending towards deregulation of transportation infrastructure development. These factors have led to increased interest in the privatization of transportation infrastructure and the development of public-private partnerships, such as Design Build-Finance-Operate (DBFO). Although the overall goal of a transportation infrastructure project is to provide safe, reliable transportation systems for the public, the parties involved in public-private partnerships take different roles and responsibilities. The public sector leads in laying out the terms and standards to regulate the obligations between the State DOTs and private entities. The private sector makes capital investment to provide agreed services as well as to assume various investment risks, including project operational and financial risks. Toll pricing strategies are a key component for the public sector to regulate operation of a PPP facility and for the private sector to control investment risks. This paper investigates the applicability of deterministic dynamic optimization models for determining toll-pricing strategies that can help improve mobility, secure the public interest, and attract the investment from the private sector. A case study of a DBFO project was carried out. The results showed that the proposed model provides a useful tool for both public and private sectors to make more informed decisions, including the study of optimal strategies to seek the investment return and the determination of the predefined contract regulations.

INTRODUCTION

While the existing transportation infrastructure is aging, travel demand is continually increasing. The traditional funding sources for transportation projects are unable to keep up with the growing demands on the nation's highway infrastructure. Transportation acts, such as ISTEA, TEA-21, and SAFETEA-LU allowed for innovative financing tools, which provided flexibility for implementation of tolling and also encouraged the states to pursue private participation in the development and operation of transportation infrastructure (*1*). Several alternative approaches have been explored for infrastructure development in order to serve increasing travel demands and facilitate economic growth. Public-private partnerships (PPPs) have emerged as one such mechanism through which public transportation agencies partner with private entities to develop and manage capital intensive transportation projects (*2*).

Three key economic objectives behind toll roads have been cited by planners: the improved efficiency and effectiveness in infrastructure management through private sector participation, the ability to finance infrastructure independent of public investment, and the pursuit of an 'economic optimum' (*3*) in infrastructure operation and maintenance. Based on the degree of risk shared by the public and private entities involved, different partnership structures have evolved over the years. One such model that is increasingly gaining popularity and acceptance is the Design Build-Finance-Operate (DBFO) model. DBFO business model is a form of concession, in which the private entity obtains a contract to design, finance, build, operate, and collect tolls on the road for a specified time period, following which ownership of the facility is restored to the public sector. The three parties involved in a typical DBFO project—governmental highway agency or state Department of Transportation (DOT), private sector developers, and road users—all take different roles and responsibilities

Role of the Public Sector

A PPP changes the traditional role the DOTs play in the development, operation and management of the highway infrastructure. The DOTs, whose primary objective is social and economic welfare through the provision of safe, comfortable roads and reliable transportation means, traditionally assume the leading role in the operation and maintenance of highways. In a PPP, the contractual agreement creates and defines the obligations between the State DOTs and private entities and lays out the terms and standards that should be met by the concessionaire. The State DOT involved is responsible for the approval of tolls to be charged to the road users and the maintenance of a certain level of condition of the highway infrastructure.

The users of toll roads are primarily interested in minimizing travel time and costs while maintaining a comfortable and safe ride. The highway agency manages costs and the level of roadway conditions through stipulations in the contract agreement specifying tolling policies and a minimum acceptable condition of the roadway system.

Role of the Private Sector

The private sector makes capital investment to provide agreed highway management service through all the design, build, and finance and operate phases. One of the drivers for the private sector to be involved in a PPP project is to achieve a return on investment on the equity invested and to control investment risks. Toll-pricing strategies are the most important tool for the private parties to achieve their financial goals. Simply setting toll rates to the highest allowed value according to the specification of tolling policies in the contract agreement is not always the wisest strategy for the private sector to operate the highway facility in the long term. Although higher tolls usually increase revenues at the very beginning, they would also result in reduced users and thereby reduce toll revenues. On the other hand, very low toll rates or no cost may attract more traffic at first, but such a strategy can lead to traffic jams and thus increase the overall cost for motorists. In addition, number of vehicles using the toll road would accelerate the pavement deterioration process, increase maintenance and rehabilitation costs and, in turn, lead to reduced profit. As described above, traffic volume on a tolled highway—known as the demand function—responds to toll pricing changes and is dynamic in nature.

The focus of this paper to investigate toll pricing that would help improve mobility, secure the public interest reduce the overall cost of motorists and attract private-sector investment in a DBFO partnership. As it was briefly discussed, an optimal toll-pricing plan is contingent upon several factors. It calls for a trade-off that would yield an optimal solution for the system. Additionally, the system is dynamic in nature, as there are lagged dependent variables in the demand function and the pavement deterioration function. One year is used as the unit time interval to study this dynamic process, which means that the toll price is assumed to be fixed for each year, and that it will not fluctuate with traffic congestions in real time. A dynamic toll-pricing model is developed in this study with the use of the General Algebraic Modeling System (GAMS), where the applicability of deterministic dynamic optimization models is examined for determining toll pricing in a DBFO partnership.

The rest of the discussions are organized as follows. In Section 2, a literature review of previous studies on determination of toll pricing strategies is presented. In Section 3, a deterministic dynamic toll-pricing model is present and explained. In section 4, an empirical experiment is presented and the results are discussed. Finally, section 5 presents conclusions and topics for further research.

LITERATURE REVIEW

A number of efforts have been undertaken to study issues regarding toll pricing strategies and regulation policy in PPP projects from different perspectives (*4-12*). While many papers focus on reducing the network congestion by imposing tolls (*4-7*), other papers aim to explore how toll strategies would influence the performances and financial feasibility of a PPP projects (*8-12*). Yang and Meng (*8, 9*) explored the use of bi-level mathematical programming formulations to investigate the feasibility of a candidate build-operate-transfer (BOT) project for a given highway network and to determine the optimal toll rates and capacity of a new highway under various market conditions. Ferrari (*10*) presented a definition of optimal road tolls which aimed to share the costs between motorists and public financial so that social welfare was maximized. In the paper, an optimization model was proposed to calculate the toll rates under the definition of optimal road tolls, and the model was applied to a real case in Italy. The results from the case study indicated that the optimal toll rates were influence heavily by the marginal costs of public funds and motorists' willingness to pay. Chen and Subprasom (*11*) developed a set of road pricing models to determine the optimal pricing strategies in a BOT scheme under demand uncertainty, considering the objectives of the government, the private investors, and the road users. They evaluated seven cases of BOT arrangements using the Ban Pong–Kanchanaburi Motorway (BKM) project in Thailand in the case study, and concluded that different objectives and regulation lead to different toll pricing strategies and financial performance.

Common limitations of these studies include that 1) they did not consider the pavement deterioration process and how it impacts the motorists on their route choice; 2) they did not optimize the pavement maintenance and rehabilitation (M&R) schedule to save costs. To overcome these limitations, this study proposed an optimization model to not only consider the impact of traditional factors (e.g., travel costs) on motorists' choice but also capture the influence of M&R activities on traffic demand. Under such model, the optimal toll strategy is determined along with the optimal toll road M&R schedule.

DYNAMIC OPTIMIZATION MODEL FOR TOLL PRICING STRATEGIES

In this paper, the financial performance of a DBFO project is discussed at the project level. Therefore, the tolls charged, demand function, and the deterioration function are treated as homogenous for the entire stretch of a toll roadway section being analyzed.

Profit

For any private sector involved in the DBFO partnership, the primary concern is profit maximization. The annual profit for a private party can be expressed as the difference between the revenue generated through the toll road operation and the costs incurred:

$$P_n = R_n - C_n$$

where P_n = profit in year *n*,
R_n= revenue generated in year *n*, and
C_n = total costs incurred as a result of operating the toll road in year *n*.

Revenue function

The annual revenue generated from operating the toll road can be expressed as the product of the number of road users patronizing the toll road and the toll charge:

$$R_n = \delta V_n \pi_n$$

where V_n = average daily traffic volume in year *n*, and
π_n = toll charged to a road user.

More specifically, V_n is measured in terms of the annual average daily traffic (AADT), a parameter that describes the traffic volume. The vehicle configurations are assumed to remain consistent for the duration of the project. The parameter δ converts daily traffic volume into annual traffic volume In some PPP projects, the project concession agreements may address the upper limits for tolls that can be charged to a road user, and this can be considered in the model by the following constraint:

$$\pi_n \leq \varphi$$

where, φ is the maximum toll rate that can be charged to a road user.

Demand function

The traffic volume on a tolled highway depends on many influencing factors, including the toll charged, the ride quality of the toll way experienced by the road users, ride quality offered by alternative routes and modes, current gas price, the level of economic activity during the period, and other factors (*14*). A linear model was used to describe the relationship between traffic volume and toll rate as well as those other factors discussed:

$$V_n = \alpha_1 V_{n-1} + \alpha_2(\pi_n - \pi^d)/\pi^d + \alpha_3(S_n - S^d)/S^d + E_n$$

where V_n and V_{n-1} = average daily traffic volumes in a year *n* and its previous year,
S_n = state variable that describes the prevailing pavement condition,
E_n = an exogenous variable for the overall impact of economic factors (i.e., gas price) and level of economic activity,
π^d = original designed toll rate, and
S^d = desired pavement conditions.

The parameter α_1 denotes a constant rate of the increase in traffic volume over N years. The term $\alpha_1 V_{n-1}$in the model is included to take into account the consistency in travel behaviors of road users. The specification of the initial value V_0 can reflect the origin-destination (O-D) characteristics for a particular project. The term $\alpha_2(\pi_n - \pi^d)/\pi^d$ describes the phenomena that some travelers would switch to alternative routes if the toll rates were increased. The term $\alpha_3(S_n - S^d)/S^d$ indicates the impact that the factors such as pavement condition and ride quality have on the choices that road users make. By such a definition, the demand function reflects the motorists' responses on their overall travel cost which takes estimated travel time values, tolls, travel experience, and gas expenditure into consideration.

Several sources discuss the demand elasticity on tolled highways and various models have been developed to describe the demand function. Since the primary objective for this study was to assess how optimal control theory can be used to evaluate optimal pricing in a DBFO project, a linear function in system equations was used.

Cost function

The annual costs incurred in a DBFO project primarily consisting of the construction costs, maintenance costs, and operation costs can be expressed as:

$$C_n = Cons_n + (\beta_0 + \beta_1 \mu_n) + (\beta_2 + \beta_3 \delta V_n \pi_n)$$

where $Cons_n$ is the sum of the nominal construction costs for the toll road. For example, assuming that the toll road opened in FY 2009 and it took four years to build the toll road before the opening year, $Cons_0$ will denote the sum total of all nominal construction costs from FY 2005 to FY 2008.

$\beta_0 + \beta_1 \mu_n$ denotes the annual M&R costs incurred as a result of applying M&R treatments to the pavement. This cost usually comprises of two parts: the fixed costs incurred as a result of mobilizing machines, personnel, and materials; and the variable costs that depend on the intensity and effectiveness of the M&R treatments. The parameter μ_n reflects the amount of maintenance applied onto the pavement (*15*). As an example, if we consider overlay as the M&R treatment, μ_n can represent the thickness of the new layer. Similar to π_n (the toll charged) that is a control variable, the parameter μ_n is also a control variable in the model to reflect the amount of maintenance treatment being applied. The parameters β_0 and β_1 are infrastructure-dependent parameters.

The term $\beta_2 + \beta_3 \delta \upsilon_n \pi_n$ represents operation costs which consists of two parts: the fixed costs due to activities such as routine maintenance, patrolling for the toll collection system, administration and overheads, advisors, and others; and variable costs related to toll collection costs such as $0.15/transaction.

Because a highway cannot carry traffic more than its capacity,, an upper limit of the demand is defined such that the demand would not exceed the capacity:

$$V_n \leq \eta$$

where η = design capacity.

Pavement deterioration function

Pavement condition is a function of the pavement deterioration process which is continuous in the intervals between subsequent M&R activities. Different indices are used to reflect the pavement condition from different aspects (*16-18*). This study adopts an index that measures the pavement condition by its roughness. Since roughness directly affects the ride quality experienced by road users, it is a good indicator for measuring pavement condition and has been widely used both in the U.S. and internationally (*19-21*). Based on a previous study (*22*) a linearized deterioration was adopted:

$$S_n = \gamma_0 + \gamma_1 S_{n-1} + \gamma_2 \mu_{n-1} + \gamma_3 V_n$$

where S_n = roughness of the pavement of the facility in year n, and

μ_{n-1} = maintenance activities in the previous year.

S_n is measured in a new set of units - Quarter car Index (QI), where QI =13×IRI (*23*). IRI is the International Roughness Index, a measurement of pavement roughness in (m/km). Thus, the lower the value of S_n , the better is the pavement condition. In this project, a minimum requirement of the pavement conditions is set as the following:

$$S_n \leq \theta$$

where θ = the maximum limit of the roughness of the pavement..

As traffic volume (V_n) is one of the major factors that impact pavement deterioration process, it is explicitly considered in this pavement deterioration function. γ_3 represents the average impacts based on the vehicle configurations.

Objective function

The objective is to maximize the profit for a concessionaire. The objective function can be expressed as:

$$\text{Maximize } J = \sum_{n=1}^{N} P_n$$

where J = overall profit for the private sector.

Year n = 1 corresponds to the opening year of the project, and year 0 is included for the purpose of initialization. A discount term is not included in the objective function because the dollar value in the opening year of the project is used as the unit for calculating annual profit (P_n). That is, the real value which adjusts for the effect of inflation is adopted. In this way, the toll rate as well as the coefficients in the cost function can be expressed in dollar value of the opening year. As there is no lag in the profit function (i), revenue function (ii), and cost function (iii), using such a unit will generate results similar to those where inflation in each function is considered independently.

Summary on the model

In summary, the toll pricing model can be stated as finding control vectors $(\pi_0, \pi_1, \pi_2, ..., \pi_N)$, $(\mu_0, \mu_1, \mu_2, \ldots, \mu_{N-1})$ to maximize the objective function with defined constraints

$$\text{Maximize} \quad J = \sum_{n=0}^{N-1} P_n$$

$$\text{Such that} \quad P_n = R_n - C_n \qquad \text{(i)}$$

$$R_n = \delta V_n \pi_n \qquad \text{(ii)}$$

$$V_n = \alpha_1 V_{n-1} + \alpha_2(\pi_n - \pi^d)/\pi^d + \alpha_3(S_n - S^d)/S^d + E_n \quad \text{(iii)}$$

$$C_n = Cons_n + (\beta_0 + \beta_1 \mu_n) + (\beta_2 + \beta_3 \delta V_n \pi_n) \quad \text{(iv)}$$

$$S_n = \gamma_0 + \gamma_1 S_{n-1} + \gamma_2 \mu_{n-1} + \gamma_3 V_n \quad \text{(v)}$$

$$V_n \leq \eta \quad \text{(vi)}$$

$$S_n \leq \theta \quad \text{(vii)}$$

$$\pi_n \leq \varphi \quad \text{(viii)}$$

$$V_n, S_n, \pi_n, \mu_n \geq 0 \quad \text{(ix)}$$

$$\text{given } S_0, V_0 \quad \text{(x)}$$

where the endogenous variables are:

P_n= annual profit
R_n=annual revenue
C_n= annual cost
V_n= traffic volume
S_n= pavement condition

Exogenous variables are:

$Cons_n$= construction cost
E_n= economic impact on demand

Control variables are:

π_n= toll rate
μ_n= M&R activities

By solving this model, the private parties can find the toll-pricing strategies and the M&R activity plan to optimize their profit complying with the concession agreement. The public sector can apply the model to study the impact of different regulations on operational and financial phases of the project. Even though the values for some of the variables in the models are pre-determined in practice (e.g., levels of maintenance), the model can help highway agencies to study the impact of different pre-defined values on the overall management of the DBFO project. Therefore, this proposed model provides a useful tool for decision makers in both the public and the private sectors to make more informed decisions, including the study of optimal strategies to seek the investment return and the determination of the pre-defined regulations in the contract.

CASE STUDY

The above model was implemented in GAMS using the nonlinear programming solver (*24*). The model discussed above provides a realistic way of simulating how the toll rates and M&R activities impact the system by taking into account the travel choices and the pavement deterioration process. With the proposed model, the optimal policies that maximize the objective function can also be evaluated. The proposed formulation was applied to a DBFO highway project, State Highway 130 (SH 130) in Texas. SH 130 is a toll road from Interstate 35 (I-35) in

Georgetown to US 183 and SH 45 at Mustang Ridge in Central Texas. It was designed as a bypass for I-35 to share parts of the heavy traffic and reduce the congestions on the I-35 corridor. Several firms in private sectors, including Lone Star Infrastructure and Cintra-Zachry, participated in the SH-130 project (*25*). Most of the data (e.g., construction cost $\mathrm{Cons_n}$ and traffic volume (V_0) used for the case study was from sources of information on the SH 130 project. Data that was not directly available from these sources was derived from other indirect sources of information and common knowledge. For instance, the values for the parameters of the deterioration model and M&R costs were referred from a recent report (*22*).The concession period is 40 years, consisting of 5 years of construction, and 35 years of operational period, N. It was assumed that the toll road convened operation in year 2009. All the costs, revenues and profits through N years are expressed in 2009 dollars. Table 1 summarized the values of all the parameters:

TABLE 1 Summary on Parameters in Numerical Study

Equation	(ii)Revenue function	(iii) Demand function					(iv)Cost function				(v)Deterioration function				(vi)	(vii)
parameter	Δ	α_1	α_2	α_3	π^d	S^d	β_0	β_1	β_2	β_3	γ_0	γ_1	γ_2	γ_3	θ	φ
value	0.000365	1.01	-6000	-3000	10	40	2	5	4	0.15	-3	1.07	-1	0.00016	60	25

In equation (ii), δ was set to 0.000365 (calculated as $365*10^{-6}$). This parameter transforms the daily traffic volumes into annual traffic volumes and also converts the unit of revenue to million dollar amounts.

In equation (iii), annual growth rate of the travel demand was set to 1%, and therefore the value of α_1 was 1.01. Considering the length of this toll road at 40 miles, the designed toll rate π^d was set to \$10. The score for desired pavement condition S^d was set to 40, the roughness score for newly built pavements. Coefficient α_2 which was set to -6000 indicates that a 10-percent increase in toll rate will lead to a decrease of 600 vehicles per day in the traffic demand. Similarly, a 10% deterioration in the prevailing pavement condition will lead to a decrease of 300 vehicle per day in demand with α_2 equal to -3000.

In equation (iv), the construction costs for the 40-mile toll road was estimated by the private investor at 1,000 million dollars. The parameters β_0, β_1, β_2, β_3 are for constant costs or units cost, and was discussed earlier, these are infrastructure dependent variables.

In equation (v), the parameter γ_3 was set as 0.00016 indicating that with an annual average traffic volume (AADT) of 10,000 vehicles per day, the pavement roughness score would increase 1.6 per year. Since vehicles with varying sizes and weight will pose different damages to the pavement, γ_3 only represents the average impacts based on the vehicle configurations for this particular project. The truck percentage is assumed to be 13.5 percent in this case study. As the ratio of cars and trucks changes, the value of this parameter needs to be adjusted accordingly.

In equation (vi) and (vii), the limits for the minimum pavement conditions and the maximum toll were set to be 60 and \$25, respectively. These values can be changed according to concession agreements.

The initial values of the pavement roughness score and traffic volume were set to 40 and 14,000 vehicles per day respectively.

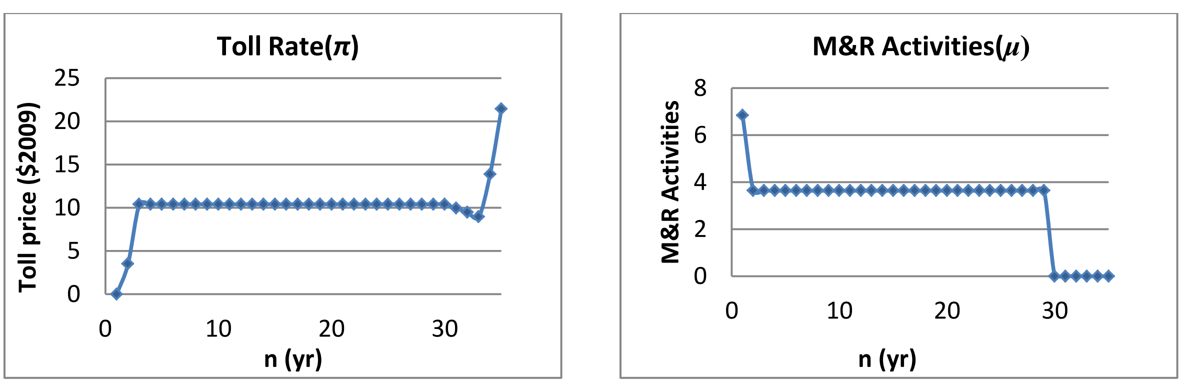
Discussion of numerical results

Figure 1 illustrates the optimal solutions for policy variables. Figure 2 shows the optimal paths for some of the state variables. In Figure 1 and Figure 2 (a) (b) (c), the optimal paths indicate three distinct stages: starting stage, stable stage, and ending stage under different policies scenarios.

In the starting stage (n = 1, 2), low toll rates and well maintained highway can attract a higher number of potential users switching from other alternative routes to the toll road, for not only this stage but also the following years, which contributes to higher revenue. The optimal solution suggests that, for the first year, no tolls should be charged so that a rapid increase in demand can be achieved for the toll road. This observation connects well with the industry practice where several toll roads have used similar strategies in their initial years of operations.

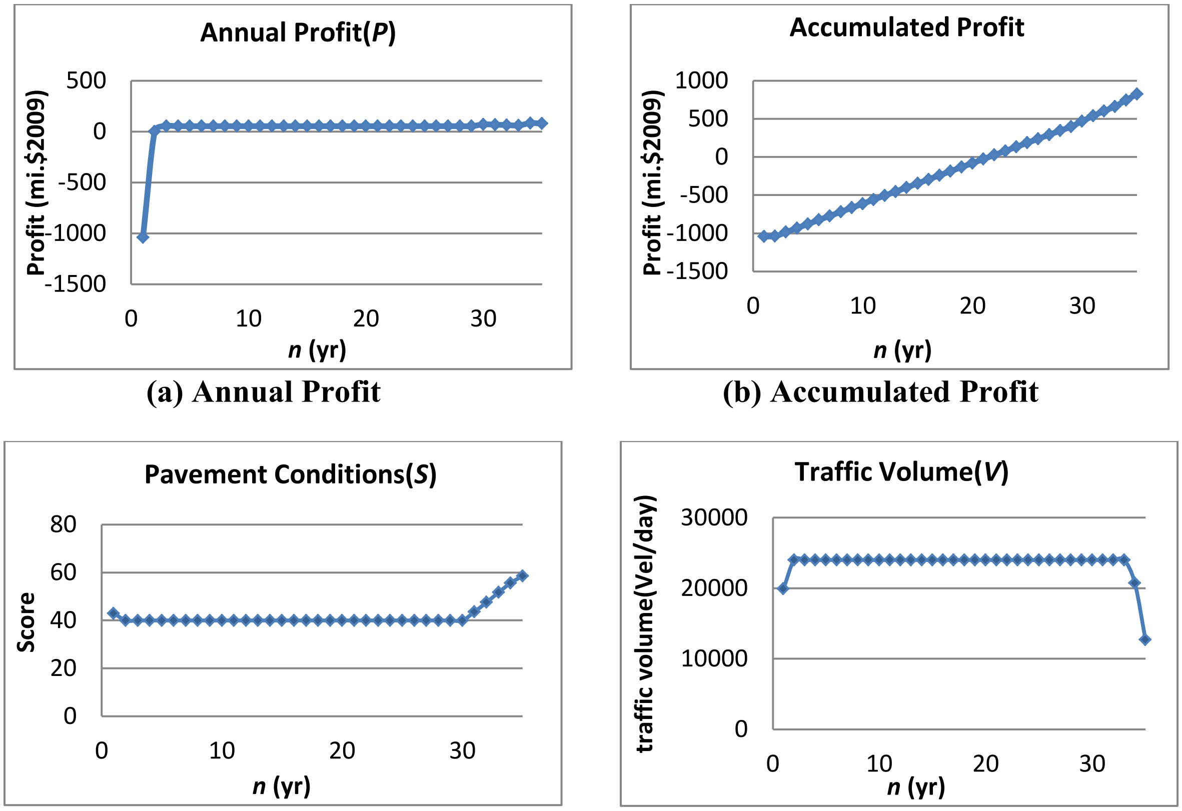
From year 3 through year 30 of the concession period, the system functions in a stable stage, where the toll price is fixed at a level slightly higher than the designed toll rate. This period would also need M&R treatments due to the pavement deterioration process, as doing so helps maintain the demand at its upper limit of 24,000 vehicles per day as indicated in Figure 2 (d). The optimal solutions for this stage lie on the boundary of the feasible region; however, this might not always be the case when different parameter values are used. For example, if the unit pavement maintenance cost were increased by some amount, the optimal solutions could be contingent upon a trade-off between the maintenance costs and the revenue generated.

For the ending stage (n= 31 to 35), the optimal strategies suggest that with the current regulations, no M&R treatment is needed to maintain the pavement conditions above the required level and at the same time, the toll rate can be set higher. During this period, although the pavement condition continuously deteriorates for 5 years, the minimum requirement of the pavement conditions (θ) is still not violated. Also, the toll rate (π) increases significantly to \$22, but it is still in the predefined range, in which requires the highest rate below \$25. From the perspective of the concessionaire, although the revenue may decrease due to the loss of road users, the profit is maximized by reducing the expenditure. For the public sector, the results indicate that the ending stage is a critical time to set their restrictions and standards to regulate the management (e.g., operation and maintenance) of the highway facility and ensure good service. For instance, θ can be used as a policy regulation parameter to avoid undesirable situations, if needed. A constraint of pavement conditions can be imposed for the last five years to keep pavement severability at a desirable level for this stage, by setting θ during this period to a lower value for n = 31 to 35. This model can also be applied to run scenario analysis to help the highway agencies determine the appropriate pre-defined regulations in the contract, which not only meets their management goals but also remains attractive to investment from the private sector.



(a) Toll Rate **(b) M& R Activities**

FIGURE 1 Optimal path of the policy variables.



(a) Annual Profit **(b) Accumulated Profit**

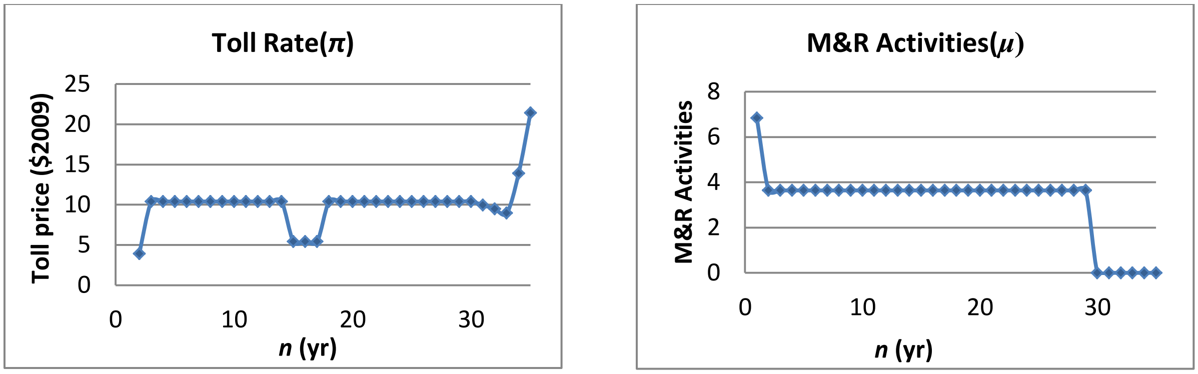
(c) Pavement Conditions **(d) Traffic Volume**

FIGURE 2 Optimal paths of the state variables.

Introducing an economic shock in the demand function

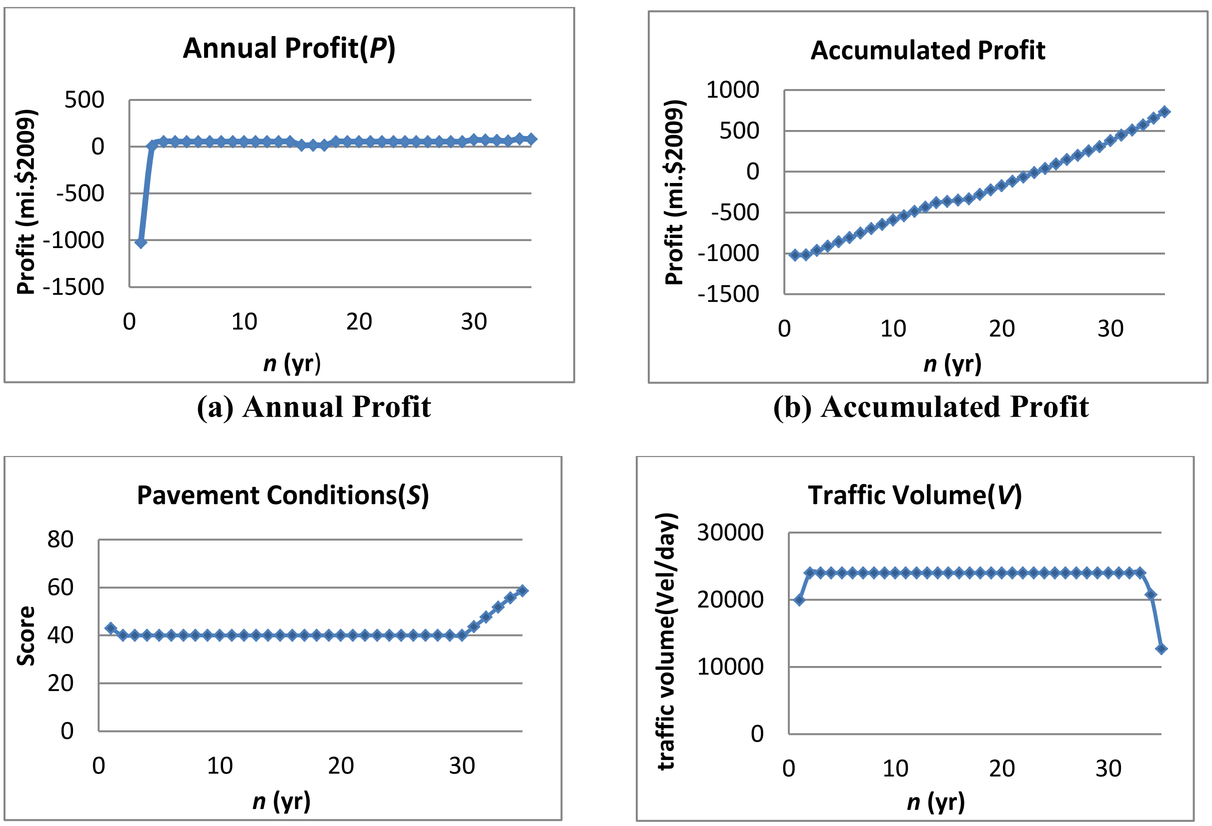
A 3-year economic shock (*E*) from year 15 to year 17 was introduced in the demand function to evaluate its impact on the proposed model. An economic shock that reduces the travel demand can occur due to several reasons including: an increase in oil prices, a recession in the economy, and others.

Figures 3 and 4 indicate the optimal solutions for policy variables and state variables under an economic shock scenario. Comparing these results with the previously discussed scenarios (without the economic shock), it can be observed that the toll rates during these three years (n =15 to 17) need to be reduced in order to accommodate the declined traffic demand due to economic hardship. As a result of the decreased toll rates, the annual profit of the concessionaire would also decrease during these three years. On the other hand, the reduced toll rates maintain the traffic volume, which should have dropped because of the economic shock and thus optimizes the whole project in terms of the overall profit. As it can be observed, the optimal paths for other variables do not change.



(a) Toll Rate **(b) M& R Activities**

FIGURE 3 Optimal paths of the policy variables.



(a) Annual Profit **(b) Accumulated Profit**

(c) Pavement Conditions **(d) Traffic Volume**

FIGURE 4 Optimal paths of the state variables.

CONCLUSION

This paper discussed a toll-pricing model for investigating the applicability of dynamic optimization models for determining optimal toll pricing in DBFO projects. By simulating the process of a concessionaire to make optimal investment decisions while providing agreed services, the proposed model provides feasible toll-pricing strategies that can help improve mobility, reduce the overall cost for motorists, and attract investment from the private sector. A case study was carried out using data derived from a real world DBFO highway project, State Highway 130 (SH 130) in Texas. Results from the case study indicate that the toll rates charged vary with the stage of the concession period. For example, the concessionaire charges the users with zero-to-very-low toll rates in the initial stages, while maintaining the highway in excellent condition to attract the maximum number of potential users. Going into the next stage of the concession period, the toll rates increase and certain amount of M&R activities are undertaken to maintain the pavement conditions. Towards the end of the concession period, high toll rates are charged to maximize profit; this period is a critical time to regulate highway facility management to ensure that the private sector continues to provide good service. Also, the proposed model is able to factor in the effect of exogenous economic shocks to the system and examine what could be the optimal strategy to adopt in such a situation. In summary, the proposed model can be applied as a tool for decision makers in both the public and the private sectors to make more informed decisions, including the study of optimal strategies to seek the investment return, strategies to handle financial risks, and the determination of predefined regulations in the contract.

Future scope of work for this study may include incorporating additional features. With the parameters in the present numerical study, the ratio of cost-to-revenue for M&R activities is much lower when compared to the other policy variable (toll rate). Thus, the optimal solutions always choose to maintain the pavement in the best possible condition. This is so because ratio of M&R activities could be relatively low during the period where lower toll rates are introduced to attract more users. However, this might not always be the case. Future work can also evaluate other configurations of the parameters to describe project characteristics in other situations, and assess how the M&R activities impact results. Second, the demand function adopted in this study is limited to analyze travelers' choice based on travel time, tolls, ride quality, and other factors on the toll road. It would be also interesting to explore how these factors on other alternate routes influence the travelers' choice at a network level. Third, the model developed in this study is deterministic in nature. A stochastic model that can consider uncertainties in the model should be used so that the results would be closer to the real-world scenario.

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