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Assessing the Impacts of Placing Tolls on Interstate Highways: An Illustrative Example on Interstate 93 in Boston

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Abstract

As states continue to take on more responsibility in transportation, a major issue State Departments of Transportation (DOTs) face relates to funding future transportation investments. A funding approach being considered is the placement of tolls along selected interstate highways where tolls are not currently collected. Questions of interest to state transportation policy makers and DOT officials relate to the potential impacts of such an approach. An objective of this paper is to present a conceptual framework and analytical methods designed to assist in the evaluation of the impacts related to placing tolls on interstate highways. The application of the framework and methods is demonstrated with an illustrative example on a section of Interstate 93 in Boston. Results of the illustrative example indicate that placing tolls along selected interstate highways has the potential to provide significant revenue for State DOTs even when one considers additional investments to implement countermeasures to address potential privacy and equity impacts. Finally, it should be noted that new tolls are most effective along segments of interstate carrying large traffic volumes and providing readily available power and communication infrastructure. Other factors that can affect level of generated revenues and severity of negative impacts include location, potential for diversion, and spacing of toll plazas. Based on these results, further testing of the framework and methods is recommended as a part of impact analyses on other interstate segments where tolls are being considered. The framework and analytical methods presented in this paper will be of interest to State transportation policy-makers and fiscal planners.

Keywords: Transportation, tolls, congestion pricing

1. Introduction

The future of surface transportation funding is a major concern in the United States. The Federal and state fuel taxes, which are the major sources of revenue, have dwindled over the last few decades as a result of economic, technological, and political reasons. At the same time, expenditures to maintain and expand roadway and transit networks steadily increase and this trend is expected to continue in the future. Hence, identifying new funding approaches and revenue sources is extremely important especially as the Federal government continues to wrestle with its budget deficit and debt ceiling issues and State Department of Transportation (DOTs) are being asked to take on a larger role to suppor transportation networks (National Transportation Policy Project, 2011). At present, many state transportation policymakers and DOT officials are considering alternative funding approaches to generate future revenue sources for transportation investments (Westervelt et al. 2015; Ahmadjian et al. 2009; Persad et al. 2004).

While there are many alternative transportation funding sources being considered by State Departments of Transportation (DOTs), an approach being explored by both state transportation policy makers and DOT officials is the placement of tolls along selected interstate highways where tolls are not currently collected. Examples of reasons for which the placement of tolls on such existing interstate highways is being considered are (WSL-JTC, 2010; Zmud and Arce, 2008):

- Current transportation funding approaches do not generate sufficient revenues to cover growing highway construction, rehabilitation, and maintenance costs;
- Charging tolls represents a simple, direct way to collect a user fee;
- Placing tolls on selected interstate highways may help to restore fairness among travelers in a region and assist in achieving regional equity goals;
- Congestion pricing as part of the toll policy may aid in accomplishing multiple policy objectives related to congestion, air quality, and energy consumption, and
- Tolls generally generate stronger public support over many other transportation funding alternatives.

Questions of interest to state transportation policymakers and DOT officials relate to the potential impacts or consequences of such approaches. Examples of these questions are:

- What will be the capital and operating costs to implement toll-based approaches on interstate highways on which tolls are not currently charged?
- What are the potential levels and nature of the revenues that can be collected with these tolls and how do these revenues compare to other funding approaches such as fuel taxes?
- What changes in demand can be expected? Will mode shifts and route diversion occur and at what levels?
- Will there be equity and privacy concerns that may lead to additional challenges in gaining public acceptance?

2. A Brief History of Toll Roads in the US

The concept of toll roads is not new. Contrary to common beliefs, toll roads became popular well before the invention of the automobile. Shortly after the American Revolution, the National Government began to realize the importance of roads for trade and the development of the country. As the result, the first toll roads on American soil appear in 18th Century. By the middle of 19th century turnpikes became common in the northeast ranging from several dozen to more than a hundred in each state. During the third decade of the 20th Century, many toll roads became limited access highways and an era of modern toll roads began (Federal Highway Administration 2012(2)).

Currently, twenty six states support some portion of their transportation budget from toll revenues and thirty-two states have various toll road authorities. While toll revenues constitute just a small part of the transportation budget in some states (Nevada, less than 1%), for other states toll receipts are indeed a major source of revenues (New Jersey, more than 50%) (Federal Highway Administration 2013; HNTB 2015).

While popular in a few areas in the U.S. for a long time period, the introduction of new toll roads has been somewhat slow throughout the rest of the nation. There are two major reasons for that phenomenon. First, federal, state, and local laws restrict implementation of tolls on many roads where tolls can be efficiently implemented. Second, traditional toll collection techniques that require construction of large toll plazas are expensive to build and operate and also create additional bottlenecks on already congested facilities.

Recent trends at all levels of government as well as modern advances in technologies suggest that these limitations and challenges can be overcome. For example, Section 1512 in Moving Ahead for Progress in the 21st Century (MAP-21), changes Federal statutory requirements governing tolls on interstates and further promotes the interstate toll pilot program (Federal Highway Administration 2012(1)). Also, the implementation of all-electronic toll collection (AETC) demonstrates the ability to reduce both capital and operating costs up to tenfold while maintaining high levels of accuracy (over 99.6% for toll transponders) without slowing down the traffic (Swank, 2013). As a result, many state transportation policymakers and DOT officials are considering new tolls to generate future revenue sources for transportation investments and looking for new methods to evaluate potential impacts associated with the implementation of toll facilities (Persad et al. 2004; Ahmadjian et al. 2009; Federal Highway Administration 2012 (1); Halsey 2014).This paper is intended to help state officials and policy-makers address these questions with the help of conceptual framework and analytical methods designed to assist in the evaluation of the impacts associated with placing tolls on interstate highways where tolls are not currently collected.

3. A Conceptual Evaluation Framework

Evaluating the impacts of alternative funding approaches (including placing tolls on existing interstate highways) is not a trivial task, because such an evaluation is complex and fraught with uncertainty (Walton et al. 2008). To facilitate the conduct of these evaluations the framework presented in Figure 1 is proposed as a guide.

The framework (4) includes four major elements:

1. Determination of policy objectives and their relative priority
2. Formulation of potential funding alternatives and associated revenue sources
3. Review of short and long range implications of each alternative
4. Identification of anticipated impacts

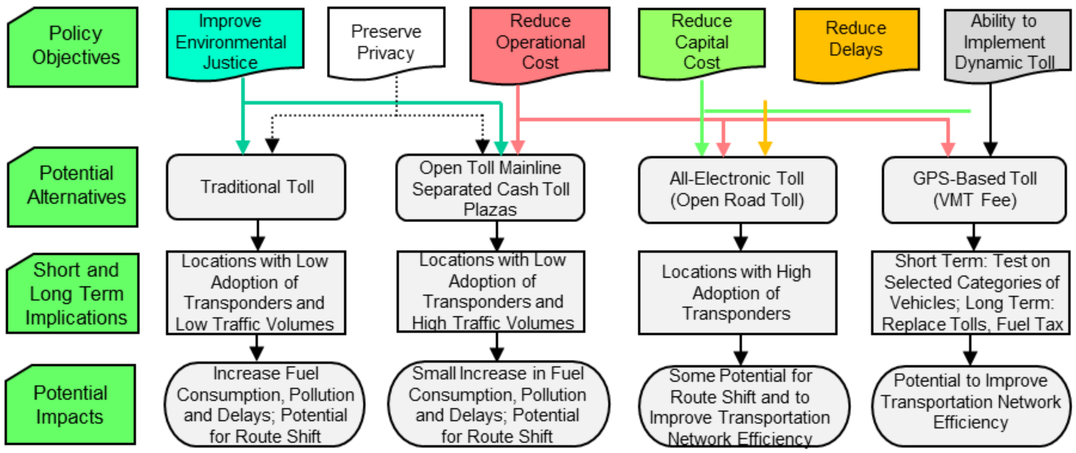

Figure 1. Toll Alternative Evaluation Framework.

Policy objectives may include: to minimize the capital and operating costs, to improve environmental justice, to preserve privacy, to promote fuel efficiency and more rapid adoption of alternative fuel vehicles, to reduce delays and to encourage more efficient use of existing and planned facilities. Potential alternatives may include implementation of traditional toll plazas that accept cash as well as electronic payments; a hybrid toll facility with Open Road Tolling (ORT) for vehicles equipped with electronic transponders along the mainline and traditional saparated toll plazas; an all-electronic Open Road Tolling (ORT); and tolling by location for GPS-equipped vehicles also known as Vehicle-Miles Traveled (VMT) fees. Short and long-term implications may include socio-geographic characteristics for a specific toll alternative, such as "areas with low adoption of electronic transponders"; specifying a level of traffic volumes, such as the "high"; or identifying a target category of vehicles, such as "heavy vehicles". Anticipated impacts relate to investment costs to implement the funding approach (e.g. capital and operating costs to collect tolls on interstate highways); changes in demand in terms of VMT, total trips, mode shift, and route diversion; level and nature of the revenue generated; and equity and privacy concerns. The magnitude of anticipated impacts would be assessed using quantitative and qualitative measures with the analytical methods presented in the next section.

4. Evaluating Impacts

The need for improved analytical methods to evaluate the impacts of various funding alternatives is well documented (Persad et al. 2004) and as suggested above such an evaluation will be a complex challenge. The evaluation approach presented in this paper is based on the premise that a unique set of benefits and costs is associated with each funding alternative, and thus for the purposes of evaluating the impacts of placing tolls on interstate highways where tolls are not presently charged, each funding alternative will be evaluated using one or more types of variables as defined below (Ahmadjian et al. 2009):

- Monetary Variables: these variables represent impacts that have a direct dollar value; examples include, for example, the expense incurred to purchase and install toll collection equipment (cost) and the amount of toll revenue collected (benefit);
- Non-Monetary, Monetizable Variables: these are variables that represent impacts not measured with direct dollar value (as is the case with monetary variables) but can be reasonably converted into monetary units; an example is the anticipated reduction (benefit) or the increase (cost) in user travel time; and
- Qualitative Variables: these are variables that represent potential benefits and costs of anticipated impacts not easily measured in monetary units (as is the case with the other two types of variables above); examples may be the benefits associated with anticipated shifts in travel modes by road users; with the provision of reduced tolls for selected population segments (e.g. local residents); or with preserving privacy.

A general formulation of impacts for each funding alternative, in its generalized form, may be represented as follows:

$$V_a = \sum M_b + \sum M_c + \sum N_b + \sum N_c \; and \; (\sum Q); \quad (1)$$

Where:

V_a is a total value of the impacts of each toll alternative
M_b is a monetary benefit
M_c is a monetary cost, usually a negative (-) value
N_b is a non-monetary, monetizable benefit
N_c is a non-monetary, monetizable cost , usually a negative (-) value, and
Q is a qualitative variable, which is analyzed separately.

It is clear, that qualitative variables that require separate evaluation may be a great challenge yet cannot be ignored. New analytical methods presented in this paper propose a more straightforward way to perform an analysis by incorporating the *cost of* *countermeasures to offset negative impacts of qualitative variables* into the calculations of the total value of impacts of each toll alternative.

5. Two Analytical Methods

To assess the total value, V_a, two analytical methods are proposed (Plotnikov 2012). Because the units of the qualitative variables are not in dollars, it is proposed that the impacts associated with these variables be analyzed separately (Method 2) from the impacts represented with monetary and non-monetary, monetizable variables (Method 1). Both Methods are briefly described below and their application is demonstrated with an illustrative example in the next section of the paper.

5.1 Method 1: Analyzing Monetary and Non-monetary, Monetaizable Variables

To analyze impacts that can be measured with monetary and non-monetary, monetizable variables, it is proposed that the Net Present Value Method be used in the following form:

$$NPV = \sum_{n=1}^{n} \frac{M_{b,j,n}}{(1+i)^n} + \sum_{n=1}^{n} \frac{M_{c,j,n}}{(1+i)^n} + \sum_{n=1}^{n} \frac{N_{b,j,n}}{(1+i)^n} + \sum_{n=1}^{n} \frac{N_{c,j,n}}{(1+i)^n}; \qquad (2)$$

Where:

NPV is a net present value for a toll alternative,

$M_{b,j,n}$ is a monetary benefit for variable j during the year n,

$M_{c,j,n}$ is a monetary cost for variable j during the year n,

$N_{b,j,n}$ is a non-monetary monetizable benefit for variable j during the year n,

$N_{c,j,n}$ is a non-monetary monetizable cost for variable j during the year n, and

i is a selected discount rate.

Examples of monetary benefits for a toll alternative will be toll revenues and other revenues such as one from concessions and advertising. Monetary costs will include capital and operating costs to implement selected toll alternative including, for example, the initial cost of toll equipment and recurring operating and maintenance expenses. Non-monetary, monetizable benefits may include time savings resulted from the reduced congestion, among others. It should be pointed out that the calculation of benefits is not a trivial task and should be done cautiously, especially when non-monetary aspects are considered along with monetary benefits. To depict visually the Net Present Value for each toll alternative, it is proposed that cash flow diagrams be prepared. The application of Method 1 is presented in the illustrative example in the next section.

5.2 Method 2: Analyzing Qualitative Variables

Method 2 is proposed in order to assess impacts expressed with qualitative variables which by definition as stated above are not measured in monetary units. Method 2 consists of three steps:

Step1 includes the development of a rating scale to assess each impact. As letter grading is widely accepted in the transportation community (for example, in the conduct of highway capacity analyses), a rating scale consisting of levels A through F is proposed here. Impacts that may be assessed with a rating scale, as proposed in Tables 1, 2, and 3, include privacy, equity, and route shift. Note that the set of impacts to be analyzed is derived from the conceptual framework on a basis of specific set of policy objectives. For example, other factors that may be considered for further evaluation may include mode shift as well as impacts on the environment and other local concerns.

(a) Privacy Impact

In modern society it is practically impossible to preserve the absolute privacy of individuals traveling on today's transportation systems. However, it is desirable to give travelers a range of options to protect their identity. This will allow a wide range of users to select a level of privacy that they may desire depending on personal requirements or specific situations (Blumberg and Eckersley 2009).

Table 1 presents a rating scale designed to evaluate privacy impacts of new tolls:

As can be observed from Table 1, letter "A" is the highest available grade and represents an ideal situation of "absolute" privacy, while letter "F" represents the lowest available grade, a situation with an absolute lack of privacy. Major factors that may affect privacy include technology applications, density of toll equipment installations, presence of cameras and other sensor technologies, and choice of payment system.

(b) Equity Impact

Equity is a difficult impact to assess as it has many dimensions and can be defined in many ways (Collura and Cope 1982). In today's transportation planning lexicon equity impacts fall under the rubric of environmental justice. (Prozzi, J. et. al.) In order to improve the assessment of such impacts, the Boston MPO developed its Transportation Equity Program to provide for a systematic method of considering environmental justice in all of its transportation-planning activities. The results of these activities are incorporated in the development of MPO plans and studies. (CTPS, 2014)

During the preliminary analysis of potential environmental justice impacts on I-93 users it was found that the major impact from toll implementation will be on local residents, specifically those from minority and low-income communities. However, it was also found that changes in accessibility and activity locations can be minimized if special discount programs are made available to such residents. As a result, in the illustrative example presented in this paper, the only countermeasure that has been considered to offset equity impacts associated with placing tolls along the I-93 was a provision of special discounts for the selected categories of road users. Table 2 presents a rating scale to consider equity impacts

Table 1. Rating Scale to Assess Privacy Impacts.

LEVEL OF PRIVACY	BRIEF DESCRIPTION	EXAMPLE/COMMENT
A	No ability to detect or track vehicles or individuals	No detection
B	Low ability to detect or track vehicles or individuals	Manual data extraction from selective single-location, single-source records (e.g. recorded video)
C	Medium ability to detect or track vehicles or individuals	Automatic data extraction (e.g. ALPR) from single location, single-source records
D	High ability to detect or track vehicles or individuals	Automatic data extraction from multiple location, single-source data records
E	Very High ability to detect or track vehicles or individuals	Automatic data extraction from multiple location, multiple-source data records (e.g. video and toll transponder)
F	Full ability to detect or track vehicles and individuals inside and out of the vehicle	Automatic data extraction from continuous multiple-source data records (e.g. GPS, cellular transmitter, live HD video and ALPR)

(c) Route Shift

While some individuals might argue that route shift impacts should be measured in dollars (i.e. with monetary or non-monetary, monetizable variables), in this illustrative example and many other cases these impacts will be considered with qualitative variables. This is done for simplicity of analysis, and is considered on a basis of priorities set in policy objectives and a robustness of a network model available for a specific region. However if impacts, such as route shifts, wish to be considered in dollars with respect to travel time savings along the main route or delay on alternate routes terms, then non-monetary, monetizable variables could be employed and included in Method 1 and directly factored into the calculation of the Net Present Value. Table 3 presents a rating scale to evaluate levels of traffic diversion.

Step 2 includes the conduct of a survey to determine the views and attitudes of decision-makers regarding the impacts represented with qualitative variables. The survey is based on rating scale developed in the first step and attempt to assess collectively the decision-makers attitudes, views, and priorities of each impact represented with qualitative variables.

Step 3 estimates any additional capital and operational costs resulting from the implementation of measures required to limit undesirable impacts represented with qualitative variables. These costs will then be included in Method 1 and an extended NPV analysis will be performed.

Table 2. Rating Scale to Assess Equity Impacts.

LEVEL OF EQUITY	BRIEF DESCRIPTION
A	Discount for selected categories of users equal to or better than the discounts on other comparable facilities in the region.
B	Discount for selected categories of users equal to 80% discounts on other comparable facilities in the region.
C	Discount for selected categories of users equal to 60% discounts on other comparable facilities in the region.
D	Discount for selected categories of users equal to 40% discounts on other comparable facilities in the region.
E	Discount for selected categories of users equal to 20% discounts on other comparable facilities in the region.
F	No discounts available to any categories of users.

Table 3. Rating Scale to Assess Route Shift Impacts.

EVALUATION LEVEL	MAINLINE TRAFFIC SHIFT, %
Low (A)	Less than 5
Moderate-Low (B)	5-10
Moderate (C)	10-15
Moderate-High (D)	15-25
High (E)	25-40
Very High (F)	More then 40

6. Interstate 93 Boston: An Illustrative Example

The purpose of this section is to present an illustrative example to demonstrate the application of the conceptual framework and analytical Methods 1 and 2. A segment of I-93 in the Boston Metropolitan area will be used in the illustrative example. Central to the illustrative example are the formulation of policy objectives and alternative toll approaches as described in the conceptual framework and the analysis of anticipated impacts associated with each toll approach. Monetary variables will represent capital investment, operating costs and toll revenues. Non-monetary, monetizable variables will represent time savings for I-93 travelers resulting perhaps from less congestion due to some traffic shifts on alternative routes in the area. Qualitative variables will address impacts related to privacy, equity, and route shift on roads other then I-93.

6.1 Objectives and Selection of Toll Alternatives

The following policy objectives have been established to serve as the basis for the evaluation of toll alternatives along the segment of I-93:

- Toll revenues should be sufficient to cover operation and maintenance of the facility while providing substantial revenues to support future corridor improvements.
- Tolling schedules should be simple and easy to implement.
- Toll charges should be fair and equitable to road users; for example, proposed tolls should be comparable to tolls currently charged on similar segments of Massachusetts Turnpike and other toll facilities in Boston Metropolitan Area.
- Proposed conversions of I-93 into a toll facility should not divert significant portions of traffic onto secondary roads. However, minor shifts of traffic that will improve travel conditions for I-93 users may be considered beneficial.
- Road user privacy and equity concerns should be acknowledged and addressed in system design.

In order to satisfy major objectives listed above, an open road tolling (ORT) system on I-93 between exits 7 and 37 in the Boston Metropolitan Area has been proposed for implementation. This I-93 segment is from the I-95 interchange in Woburn north of Boston to the Route 3 interchange at the Braintree split south of Boston. The implementation of all-electronic tolls is included on the basis of recent experiences where innovations in open road tolling (ORT) technology have been implemented successfully to collect tolls at low cost and without slowing traffic (Opiola 2006; Cambridge Systematics 2010; Siegel et al. 2004).

Consistent with established policy objectives, an extensive preliminary evaluation was performed including seven potential tolling alternatives ranging from a single toll segment to a toll at every exit ramp. While the number and size of segments in each alternative vary, the total charge for the entire tolled segment of I-93 remains constant at $4. Following the preliminary analysis, three toll alternatives were subjected to a more detailed, comprehensive evaluation:

- Alternative 1: Two toll segments, $2 each (Approximate toll locations are represented with number (1) on Figure 2);
- Alternative 2: Four toll segments, $1 each (Approximate toll locations are represented with numbers (1) and (2) on Figure 2);
- Alternative 3: Eight toll segments, $0.50 each. (Approximate toll locations are represented with numbers (1), (2), and (3) on Figure 2. Also, two tolled ramps are added to minimize traffic diversion in the most congested downtown area. Ramp locations are not shown on Figure 2 because of the relatively large scale of the map.)

The first Alternative has been selected for its simplicity and low capital costs. The third Alternative has been selected for its ability to improve equity while keeping the total number of toll areas within reasonable limits. The second Alternative was selected as a compromise solution between the first and the third Alternatives.

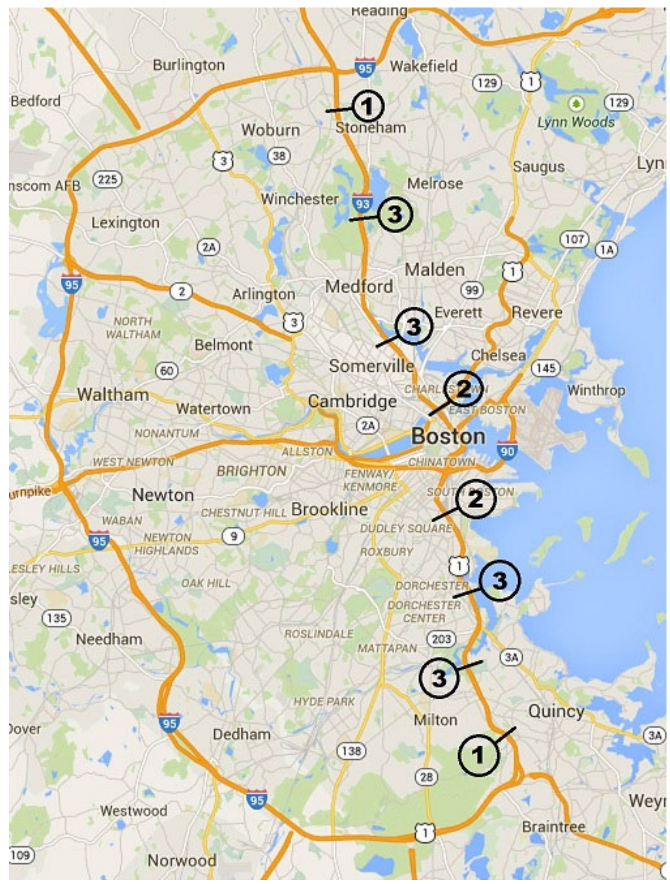

Figure 1. Approximate toll locations along I-93 for Alternatives 1, 2, and 3.

6.2 Method 1: Analyzing Monetary and Non-Monetary, Monetizable Variables

Cost Estimates (Monetary Costs, M_c)

Capital and operating cost estimates were obtained for the selected toll Alternatives based on costs incurred during the implementation of similar projects (Florida Turnpike 2011;

MassDOT 2011) and on the basis of estimates provided in relevant studies (Cambridge Systematics 2010).

Capital cost estimates include expenses associated with construction and purchasing of major items, such as electronic transponders (assumed to be distributed to road users free of charge), field equipment, such as ETC receivers and Automated License Plate Reader (ALPR), full-span gantries to carry field equipment, processing center with equipment, and communication. The cost of minor items is included in the contingency lump sum, which is assumed to be ten percent of total itemized capital costs. All capital costs are also presented in annualized form for the NPV analysis.

Operational cost estimates include the following: maintenance of electronic equipment at the gantries and at the processing center, infrastructure and communication maintenance, salary and benefits of toll road personnel. The maintenance cost of field electronic equipment was assumed to be 10 to 20 percent of equipment capital cost, depending on the selected gantry type. The maintenance cost associated with transponder operations was assumed to be 10 percent of capital cost. Cost to maintain the processing center was assumed to be 5 percent of capital cost. Operational cost to maintain and support fiber-optic trunk and related communication equipment was estimated to be 1 per cent of capital cost. In the case of existing fiber-optic network in place, it was assumed that a similar maintenance fee will be paid to lease required bandwidth from its owner. It was assumed the gate structure will not require any maintenance for the life of the structure. The average salary of personnel was assumed to be similar to the salary level of Massachusetts Turnpike employees and equal to $70,000 (Cambridge Systematics 2010). All operational costs are expressed on an annualized basis.

Revenue Estimate (Monetary Benefits, M_b)

The revenue estimates presented are based on actual (2010) traffic volumes, projected changes in traffic volumes generated by EMME - travel demand forecasting software, and a network model used in the Boston Metropolitan Area.

In order to make estimates of the potential revenues resulting from the introduction of the open road tolling on I-93, it was assumed that the following parameters will be similar to parameters observed along I-93 in Boston Metropolitan Area:

- Projected traffic growth
- Composition of traffic
- Population demographics
- Proportion of vehicles with toll transponders
- Toll rates, per mile
- Additional surcharges for vehicles without transponders, and
- Toll schedule for different categories of vehicles

Table 4 provides a comparison of capital and operating costs as well as toll revenues that might be expected from the implementation of toll collection on I-93. To acknowledge the uncertainty surrounding these cost and revenue estimates, ranges (rather than point estimates) are presented in Table 4 based on different assumptions regarding the technology option chosen.

Table 4. Costs and Revenues for Selected Toll Alternatives.

	TOLL ALTERNATIVE		
	1	2	3
Capital Costs ($M)	22.5- 61.4	28.6- 68.4	35.2- 78.1
Operational Costs ($M/year)	3.6-5.2	4.5-6.2	5.6-7.3
Toll Revenues ($M/year)	106.5-130.2	127.2-155.5	143.5-175.4

As can be observed from Table 4, both capital and operating costs vary significantly depending on a combination of selected toll Alternative and equipment options. Also, there is significant variation in projected revenues that can be attributed primarily to different levels of traffic diversion to avoid tolls. A variation of traffic diversion between alternatives resulted from a combination of the following factors: a) ease to avoid tolls and b) potential savings to traveler. However, the preliminary estimates suggest that implementation of any alternative is capable of providing sufficient revenue to cover both capital and operational costs as well as generating additional surplus of funds toward road maintenance and improvements, all within the first year of operations.

Time Savings or Losses

In order to make the impact analysis more complete, time savings or losses experienced by travelers affected by new toll road can either be monetized and included in the Net Present Value calculations or alternatively incorporated into the analysis as qualitative variables. Because calculations of travel time savings or losses for the entire road network that will be impacted by the implementation of proposed tolls can be extremely cumbersome and time consuming, only the time savings of travelers along I-93 has been estimated. Table 5 presents average travel times along the proposed I-93 toll segment. Travel time impacts on alternate routes resulting from diverted I-93 traffic were analyzed as a qualitative variable as discussed later.

The next step is to monetize projected travel time savings for NPV analysis. Total savings resulting from the reduction of travel time calculated as a sum of individual time savings for all three types of vehicles. The first type includes light/single occupancy vehicles (SOV), the second includes high occupancy vehicles (HOV) and medium trucks, and the third includes large trucks and buses. Composition of traffic and value of time by vehicle type are derived from regional traffic analysis models and presented in Table 6.

Table 5. Average Travel Times on I-93 During the AM Peak: Current Conditions and Alternatives 1, 2 and 3 for Both Directions from the I-95 Interchange in Woburn to the Route 3 Interchange at the Braintree Split.

ALTERNATIVE	AVERAGE TRAVEL TIME, MINUTES*
Current conditions: No tolls	40
Alternative 1: Two toll segments, $2 each	37
Alternative 2: Four toll segments, $1 each	36
Alternative 3: Eight toll segments and two ramps, $0.50 each	35

*Note: Travel time estimates presented in the table are based on actual (2010) traffic volumes, projected changes in traffic volumes generated by EMME - travel demand forecasting software, and a network model used in the Boston Metropolitan Area.

Table 6. Composition of Traffic and Value of Time by Vehicle Type.

VEHICLE CATEGORY	RELATIVE VOLUME IN AADT, %	VALUE OF TIME, $ PER HOUR
Type 1	67	30
Type 2	18	60
Type 3	15	120

6.3 Method 2: Analyzing Qualitative Variables

Method 2 assesses qualitative variables in three steps. The impacts of route shift, privacy, and equity will be considered as qualitative variables.

Step 1

In order to assess route shift resulting from implementation of tolls along I-93 in the Boston Metropolitan area, a comprehensive analysis for each toll Alternative was performed using EMME with the help of the Central Transportation Planning Staff in Boston.

The goal of the simulation was to identify toll schedules that will generate substantial revenues while minimizing potential negative impacts such as significant shift of traffic onto alternative secondary roads that do not have sufficient capacity. Table 7 provides a brief summary on potential route shift impacts as a result of implementing different toll Alternatives.

With the use of Tables 1, 2, 3 each toll Alternative is assessed by the transportation analyst in terms of privacy, equity, and route shift as presented in Table 8.

As can be observed from Table 8, Alternatives 1, 2 and 3 differ in anticipated levels of privacy. This is a result of several factors, including the density of toll equipment installation. It is assumed here (as indicated in Table 1) that the higher the density of toll equipment installations (including readers and cameras) the greater the potential for privacy concerns. The level of equity is graded at F in all three Alternatives because no discount was included in the original design to any category of drivers. Finally, the fewer number of toll collection locations will lead to higher levels of route shifts as higher tolls charged at a single location provide additional incentives to road users to avoid them.

Step 2

The second step in Method 2 includes the conduct of a survey to determine the views and attitudes of decision-makers regarding the impacts represented with the qualitative variables. The survey questionnaire consists of two sections and each section consists of three questions.

Questions presented in the first section ask decision-makers to identify an acceptable level for each qualitative variable on the basis of a rating scale. The rating scale uses numerical values rather then letters, unlike the rating scale presented earlier. There are two reasons for this change. The first is that only some of the decision makers are likely to be familiar with a letter-based scale that is commonly used in typical transportation level of service analyses. The second is that numerical values facilitate an evaluation of the opinions of the diverse group of decision makers by providing an "average" numerical rating that in turn can be easily converted back to a letter-based scale as necessary.

Questions presented in the second section ask decision-makers to identify their perceived level of relative importance of each qualitative variable on the basis of the rating scale provided. Again, the rating scale uses numerical values for consistency with rating scales presented in first section of the survey. After data is collected, an average score is calculated and then converted to match a desired scale (in our case it is 0 to 1, 1 being the most important). A survey also provides additional space for comments, so that additional requirements can be identified and included in the analysis.

Results of the survey are summarized in Table 9. Please note that the results presented in Table 9 are provided for illustrative purposes to demonstrate the application of Method 2.

Table 7. I-93 Mainline Volume Drop as a Result of Different Toll Alternatives.

ALT	MAINLINE ROUTE SHIFT
1	• Very High on the Northern Expressway • Very Low on the Bridge and at the Tunnel • Very High on the Southeast Expressway
2	• Moderate-High on the Northern Expressway • High on the Bridge • Very Low at the Tunnel • High on the Southeast Expressway
3	• Low on the Northern Expressway • Moderate on the Bridge • Moderate-Low at the Tunnel • Low on the Southeast Expressway

Table 8. Levels of Privacy, Equity and Route Shift for selected Toll Alternatives without Privacy and Equity Countermeasures.

ALTERNATIVE	**1**	**2**	**3**
Number of Toll Plazas	2	4	8*
Level of Privacy	C	D	E
Level of Equity	F	F	F
Level of Route Shift	F	E	G

*Note: Also two tolled ramps to minimize traffic diversion in the most congested downtown area.

Table 9. Summary of Completed Surveys on Acceptable Levels of Privacy, Equity, and Route Shift.

	DESIRED LEVEL	RELATIVE IMPORTANCE
Level of User Privacy Requirements for the Proposed Toll Road	C	0.8
Discount Requirements for the BMA Local Residents	A	0.7
Maximum Acceptable Level of Route Shift	C	0.5

Step 3

In the third step, additional capital and operational costs resulting from the implementation of countermeasures required to address impacts represented with qualitative variables are estimated.

Because the survey in Step 2 determined that the relative levels of importance of privacy (.8) and equity (.7) are viewed as high priorities by decision-makers, countermeasures to address privacy and equity concerns should be considered and where appropriate integrated into one or more Alternatives. For the purposes of the illustrative example additional costs associated with privacy countermeasures include capital costs for development of more robust and secure hardware and software system, increased operating costs due to more complex methods required for anonymous toll transactions, and potential losses of revenue due to reduced accountability of the system. Additional costs associated with equity countermeasures include potential losses of revenue associated with the development and implementation of a set of toll discounts for local residents similar to existing toll discounts on facilities in the Boston area. While countermeasures could also be formulated to address route diversion concerns, for the purposes of the illustrative example no such countermeasures were considered at this time. However, at the discretion of the decision-makers and depending on policy objectives this aspect could be revisited later.

Net Present Value Calculation for monetary and non-monetary variables

All calculations for the NPV analysis have been made on a basis of annualized benefits and costs and with the following assumptions (Cambridge Systematics 2010; Ahmadjian et al. 2009 Bazelon and Smetters, 1999), fairly typical for such economic analyses in the public sector :

- Toll rates and operating costs increase proportionally with inflation
- The discount rate is assumed to be 2% per year
- Traffic growth is assumed linear and consistent with the growth trends observed over previous decades (about 1% per year)
- The NPV is calculated for a 25 year period
- Capital costs of equipment with a life span less than 25 years are assumed to increase with the rate of inflation.

An inflation rate has been assumed to be 2% on the basis of recent trends in the U.S. economy. According to Department of Labor (Bureau of labor Statistics, 2013; Davis, 2014) , an average inflation rate during the five year period when this research has been conducted (2008-2012) was about 2.07% per year. For simplicity, the closest round inflation rate (2%) has been used for analysis.

Table 10 presents an evaluation matrix for Alternatives 1, 2, and 3. On the basis of performed evaluation, Alternative 3 appears to be the "best" way to implement tolls along the selected segment of I-93. It has the highest NPV, generates the greatest level of expected toll revenues, provides the highest time savings to travelers, and satisfies the decision-makers' privacy and equity concerns as well as the other Alternatives do, while minimizing traffic diversion.

While presenting the evaluation results in a format shown in Table 10 is appealing to some decision makers, others may prefer a graphic representation showing benefit-cost streams and NPV values (Ahmadjian and Collura 2012). Figure 3 provides an example of these benefit-cost streams and the resulting estimate of NPV for Alternative 3. Included are both monetary and non-monetary, monetizable costs identified in Method 1, as well as the monetary costs of the countermeasures intended to minimize potential privacy and equity concerns addressed in Method 2. These incorporate the capital and operating costs of the more robust and secure system and expected reduction in revenue due to the implementation of discounted tolls for local residents.

Table 10. The Evaluation Matrix for Alternatives 1, 2, and 3.

	Alternative 1	Alternative 2	Alternative 3
Initial Capital Costs, $M	22.5-61.4	28.6-68.4	35.2-78.1
Annualized Capital Costs, $M	2.1-5,6	2.7-5.9	3.3-6.5
Annual Operational Costs, $M	3.6-5.2	4.5-6.2	5.6-7.7
Annual Operational Revenues, $M	106.5-130.2	127.2-155.5	143.5-175.4
Annual Monetized Time Savings, $M*	21.0-25.7	37.9-46.4	51.6-63.1
Annual Costs to Satisfy Privacy Requirements, $M	-	4.5	7.8
Annual Costs to Satisfy Equity Requirements, $M	7.9	9.5	10.7
NPV Estimated for 25 Year Period, $B	2.5	3.2	3.8

*Note: This non-monetary benefit may or may not be counted toward the total NPV of the alternative.

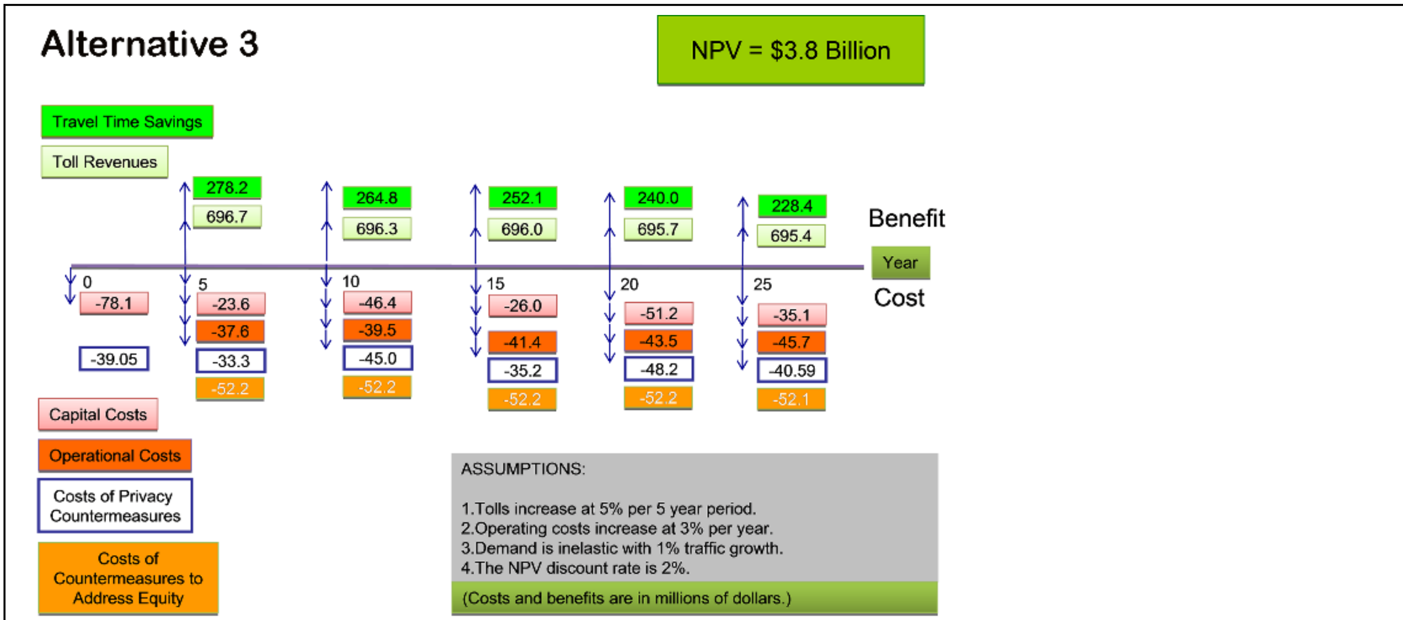

Figure 3. Benefit-Cost Streams for Alternative 3.

6. Conclusions and Recommendations

A major conclusion is that the conceptual framework and analytical methods presented in this paper can serve as useful tools for state transportation policymakers and DOT officials as they consider different toll alternatives. Another important conclusion is that careful selection of tolling schedules as well as the number and location of toll gantries along the road segment can significantly increase gross revenues, while at the same time may reduce the undesirable diversion of traffic to alternative routes that do not have sufficient capacity. The results of the illustrative example indicate that placing tolls along selected interstate highways has the potential to provide a significant source of revenue for State DOTs even if additional investments to implement countermeasures to address potential privacy and equity impacts are considered. Finally, it should be noted that new tolls are most effective along segments of interstate that carry large traffic volumes and have readily available power and communication infrastructure. Other factors that can affect level of generated revenues and severity of negative impacts include location and spacing of toll plazas. Based on the results reported in this paper, a further testing of the framework and analytical methods is recommended as a part of benefit-cost analyses on new tolls along selected interstate highways. The framework and analytical methods presented in this paper will be of interest to State transportation policy-makers and fiscal planners.

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