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POLICY ANALYSIS FRAMEWORK FOR ROAD PRICING ON A REGIONAL SCALE

September 2005

HDR | HLB Decision Economics Inc.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY III

1: INTRODUCTION 1

2: FRAMEWORK OVERVIEW 2

3: DERIVATION OF TOLLS AND TRAVEL IMPACTS 4

3.1 BENCHMARK TOLLS 4
3.2 DERIVATION OF SOCIAL MARGINAL COSTS TOLLS 4
3.2.1 Endogenous Derivation of Congestion Costs 4
3.2.2 Derivation of Other Components of Social Marginal Costs Tolls 7
3.3 TOLL SCHEDULES 8
3.4 DERIVATION OF TRAVEL IMPACTS 9

4: OTHER KEY INPUT ASSUMPTIONS 11

4.1 TYPES OF ROADS AND TRAFFIC VOLUMES 11
4.2 ELASTICITY OF TRAVEL DEMAND 13
4.3 BASELINE CONGESTION LEVEL 14
4.4 SPEED-FLOW RELATIONSHIP AND INITIAL AVERAGE SPEEDS 15
4.5 SOCIAL BENEFITS AND COSTS OF ROAD PRICING 17

5: MEASUREMENT OF EFFECT OF ROAD PRICING ON INVESTMENT REQUIREMENTS AND ECONOMIC PERFORMANCE OF HIGHWAYS 19

5.1 APPROACH: ESTIMATION OF DEADWEIGHT LOSS 19
5.2 ESTIMATION OF DEADWEIGHT LOSS 21

6: MODEL RESULTS 22

6.1 EFFECT OF ROAD PRICING ON INVESTMENT REQUIREMENTS AND THE ECONOMIC PERFORMANCE OF HIGHWAYS 22
6.2 EFFECTS OF ROAD PRICING ON TRAFFIC CONDITIONS 23
6.3 EFFECT OF ROAD PRICING ON REVENUES AVAILABLE FOR HIGHWAY INVESTMENT 26
6.4 EFFECT OF ROAD PRICING ON SOCIAL BENEFITS AND COSTS 27

7: SENSITIVITY ANALYSIS 28

7.1 TOLL SCHEDULE UNDER ALTERNATIVE PARAMETERS 29
7.2 EFFECT OF ROAD PRICING ON INVESTMENT REQUIREMENTS AND THE ECONOMIC PERFORMANCE OF HIGHWAYS UNDER ALTERNATIVE PARAMETER ASSUMPTIONS 30
7.3 EFFECTS OF ROAD PRICING ON TRAFFIC CONDITIONS UNDER ALTERNATIVE PARAMETER ASSUMPTIONS 31
7.4 EFFECT OF ROAD PRICING ON REVENUES AVAILABLE FOR HIGHWAY INVESTMENT UNDER ALTERNATIVE PARAMETER ASSUMPTIONS 32

APPENDIX A: LIST OF MODEL ASSUMPTIONS A-1

APPENDIX B: MODEL STRUCTURE AND LOGIC B-1

APPENDIX C: DERIVATION OF CONGESTION TOLLS C-1

APPENDIX D: DERIVATION OF SELECTED MODEL ASSUMPTIONS: METHODOLOGICAL APPROACH D-1

APPENDIX E: ADDITIONAL RESULTS OF SENSITIVITY ANALYSIS E-1

EXECUTIVE SUMMARY

The role of road pricing as a means of balancing the supply and demand of roadway capacity has been widely discussed in recent years. Road pricing involves adopting a price for the use of congested road infrastructure. The price is levied in the form of a fee or a toll rate that may vary with the level of congestion and (accordingly) the time of day.

The concept of pricing for the use of congested roads is similar to that employed in other sectors of the economy to ascertain the economic level of provision for commodities in short supply (such as water purification facilities, for example). In levying a price that reflects the cost of supplying roads during congested times of day (including social costs, such as congestion and air pollution), consumers can help reveal the economic level of highway congestion. Some consumers will pay the road price and the use the road system as before. This is a signal that the economic benefits they obtain from the road are at least as great as the toll or fee charged. The revenues arising accordingly are available to help finance infrastructure investment. Other people may reduce the number of trips they make or shift some their trips to uncongested times of day when road prices are lower or zero. Some may divert to uncongested, albeit more circuitous routes, or car pool, or switch some of their trips to public transit.

ISSUES ARISING FROM REGIONAL ROAD PRICING

While the direct implications of road pricing are local, widespread application would have implications for regional policy that have not been explored. To help shed light on the nature and materiality of the regional issues, the Department is developing an analysis framework that focuses less on any particular congested facility and more on the possible effects of the extensive application of road pricing in American cities.

THE ANALYSIS FRAMEWORK

As an illustration of the model framework, this paper simulates the effect of pricing on all moderately-to-severely congested interstate highways and other freeways. Regional sub-simulations are possible under the same framework. The model as applied here assumes that there are 14 different interconnected roadway categories, including interstate highways and freeways as well as other principal arterials, collectors, local roads. Two toll scenarios are modeled here: one based on current practice on tolled roads in the U.S (called benchmark tolls), and another based on social marginal costs of roads that also include congestion and environmental cost.

The framework also accounts for the effect of tolls on transit demand and the effect of tolled roads on free roads or un-tolled times of day. The analysis framework is populated with a reasoned range of empirical evidence with regard to key assumptions. Such assumptions include the various elasticities and cross-elasticities, economic costs, speed-flow relationships, and network connectivity variables that enter into the analysis of road pricing impacts on traffic levels, traffic speeds, and toll revenues. The framework is intended to help crystallize key issues, uncertainties, and research requirements in support of policy analysis.

All impacts are tested under a baseline set of assumptions for the elasticity of demand and the unit value of savings in travel time (Summary Table 1). Baseline assumptions reflect the weight of empirical evidence wherein the elasticity of demand lies beneath -0.50 and the value of time beneath $20/hour (as reflected, for example, in the FHWA HERS model). Alterative assumptions, also shown in Summary Table 1, reflect emerging empirical and theoretical evidence suggestive of significantly higher values for both demand elasticity and value of time. Elasticities at least double those conventionally assumed stem from observations of toll road experience internationally,[1] and from the theoretical expectation that travelers would become more price sensitive in the face of significantly higher money cost (relative to time cost) of travel. Values of time at least double those conventionally assumed are consistent with emerging evidence on the value of reliability and predictability during highly congested periods.[2]

Summary Table 1: Baseline and Alternative Assumptions for Demand Elasticity and Value of Time

FACTOR	BASELINE ASSUMPTIONS	ALTERNATIVE ASSUMPTIONS
Elasticity of Traffic Volume with Respect to User Cost	-0.40	-0.80
Value of Time (Dollars per Hour, in constant 2002 dollars)	$18.60	$37.20

ENDOGENOUS DERIVATION OF CONGESTION TOLLS

The congestion cost component of tolls is derived from the difference between the social marginal cost and average private cost of highway use at the volume of traffic where the social marginal cost curve intersects the demand curve (namely, the equilibrium price). The average and marginal costs are derived from the speed flow-relationship used in the previous HLB reports. Incremental environmental costs were derived from published vehicle emission rates and benchmark emission costs used in similar studies. Operation and maintenance costs on highway construction were derived from the deal structures of recent bond-financed toll road projects.[3]

The results are given in Summary Table 2. The results indicate that, under baseline assumptions, estimated optimal tolls are similar in magnitude to tolls charged today, although they rise over

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[1] Anna Matas and Jose-Luis Raymond, *Demand Elasticity on Tolled Motorways,* Journal of Transportation and Statistics, Volume 6, 2003, Universitat de Barcelona

[2] A contingent valuation study conducted for the National Cooperative Highway Research Program found that the value of time during periods of heavy congestion is in the order to 2.5 times greater than the average value of time. This is due to the high premium travellers place on reliability and predictability of journey times, both of which are significantly eroded by severe congestion. (See, National Cooperative Highway Research Program, *The Value of Reliability in Congested Conditions*, HLB Decision Economics Inc. and University of California at Irvine, Report 431, September, 2001.

[3] Data from HLB analysis of deal structures for three toll road financings prepared on behalf of MBIA Bond Insurance Corporation.

time as congestion mounts. Under alternative elasticity and value of time assumptions, the results indicate that tolls levied today lie significantly beneath optimal congestion tolls.[4]

Summary Table 2: Typical Tolls Charged Today Compared with Estimated Equilibrium Tolls (in 2002 Dollars per Mile)

INITIAL CONGESTION LEVEL (Measured by Volume to Capacity Ratio)	TOLLS BASED ON CURRENT PRACTICE	EQUILIBRIUM TOLLS BASED ON SOCIAL MARGINAL COSTS			
		YEAR 2002		YEAR 2020	
		Baseline Elasticity and Value of Time Assumptions	Alternative Elasticity and Value of Time Assumptions	Baseline Elasticity and Value of Time Assumptions	Alternative Elasticity and Value of Time Assumptions
INTERSTATE HIGHWAYS					
0.71 and 0.79	$0.06	$0.10	$0.13	$0.12	$0.16
0.8 and 0.95	$0.12	$0.13	$0.17	$0.16	$0.22
Greater than 0.95	$0.21	$0.19	$0.26	$0.25	$0.34
FREEWAYS					
0.71 and 0.79	$0.06	$0.10	$0.13	$0.12	$0.16
0.8 and 0.95	$0.12	$0.13	$0.17	$0.16	$0.22
Greater than 0.95	$0.21	$0.21	$0.29	$0.28	$0.38

Notes. (1) Tolls based on social marginal costs include $0.027 to cover emission costs and $0.033 to cover highway O&M costs. The remainder represents the congestion cost. (2) Tolls based on social marginal costs are growing over time because of the increase in the general congestion level that leads to an increase in the congestion cost component.

WHAT THE ABSENCE OF CONGESTION PRICING MEANS FOR THE ECONOMIC PERFORMANCE HIGHWAYS

In the absence of congestion prices on the nation's congested urban interstates and freeways, losses in economic productivity arise for road users who value time highly enough to pay a toll if there was one, but for whom congestion caused by others means significant delay. At the same time, failure to charge for congestion creates a "surplus" economic benefit for those on the road who would not be willing to pay a toll if there was one. The difference between the economic loss to some and the surplus benefit to others is the net loss in the productive value of highways due to the absence of congestion prices. Economists call this net loss a "deadweight" waste of highway resources because the loss in productivity cannot be restored – it is lost forever. HLB has estimated the magnitude of this productivity loss and placed the estimate in context by comparing it with estimated investment requirements to maintain the condition and performance

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[4] This might be the result of private toll road providers, who represent the majority of providers from which the evidence in Table 2 is drawn, maximizing net revenue rather than economic value.

highways at the level achieved in the year 2000. This answers the question, "*How large is the loss of economic value from federal investment in highways and bridges due to the absence of congestion fees*?" The result is given in Summary Table 3.

Summary Table 3 indicates that, under baseline assumptions, the estimated loss in economic value from highway investment due to current highway pricing policies rises over time, from $4.1 billion today (based on 2002 estimates), increasing to $9.6 billion by 2020 (in constant 2002 dollars). This pattern of increasing losses in the economic value of interstates and freeways follows from the projected increase in congestion over the period. This loss represents 15.5 percent of federal highway expenditures needed now to maintain the condition and performance of interstates and freeways; and 36.4 percent of required expenditures in 2020.

Estimated losses in the economic value of highways are materially greater under alternative estimates regarding the elasticity of demand and the value of time. Under these estimates, the loss in economic value from highway investment starts at $11.2 billion today and rises to $26.2 billion by 2020 (in constant 2002 dollars). The loss represents over 40 percent of federal highway expenditures projected by the Department to be needed now to maintain the condition and performance of interstates and freeways; year-2020 losses in economic value represent almost 100 percent of estimated average annual expenditure requirements. Probabilistic risk analysis indicates that this scenario occasions less likelihood than the baseline estimates. This is because the baseline assumptions represent a closer fit to historical evidence regarding elasticities of demand and the value of time. Even so, new evidence is emerging pointing to the prospective legitimacy of the alternative case (see footnote 3), indicating that the risk of higher losses is material.

Summary Table 3: Loss in Economic Value from Interstate and Freeway Investments Due to Absence of Congestion Tolls

YEAR	IN BILLIONS OF 2002 DOLLARS		AS A PERCENT OF PROJECTED AVERAGE ANNUAL REQUIREMENTS TO MAINTAIN CONDITIONS AND PERFORMANCE ON URBAN INTERSTATES AND HIGHWAYS	
	Baseline Elasticity and Value of Time Assumptions	**Alternative Elasticity and Value of Time Assumptions**	**Baseline Elasticity and Value of Time Assumptions**	**Alternative Elasticity and Value of Time Assumptions**
2002	$4.08	$11.20	15.5%	42.4%
2020	$9.61	$26.18	36.4%	99.2%

Note. Investment requirements for period 2002-2020 based on 2002 Conditions and Performance Report

WHAT CONGESTION PRICING WOULD MEAN FOR HIGHWAY INVESTMENT REQUIREMENTS

As shown above, current roadway pricing policies erode the nation's economic return on highway investment. It follows that the imposition of congestion tolls would significantly improve the productive value of the nation's urban interstates and freeways. The implications of congestion tolls for investment requirements are more difficult to gauge, however. Cost Benefit Analysis studies of expanding highly congested transportation facilities indicate that whereas imposing congestion prices reduces demand, facility expansion can remain economically worthwhile. This occurs when the number of users willing to pay the toll is such that congestion remains above economically optimal levels (usually a signal that expanding the facility is long overdue from an economic perspective).[5] Economic feasibility studies of expanding more moderately congested facilities report that pricing-induced reductions in demand can avert or defer the need for investment, with deferrals of as much as five, ten or even 20 years. While analysis at the project level is needed to ascertain the extent to which total budgetary investment requirements would decline with the wide spread imposition of road prices, there is a material likelihood of at least a deferral effect, allowing the nation to get more value from its highway assets per year.

Regardless of the impact of congestion tolls on total investment requirements, road pricing does not come with a risk of "failure." Improving the value of highway investment represents the principal rationale for congestion prices, not reducing investment outlays per se. Even without a reduction in investment requirements, the economic value drawn from highway projects would significantly increase if congestion tolls were in place. This is because those who do not value trips enough to pay the congestion toll would be discouraged from eroding the economic performance of roads for autos and commercial vehicles whose users draw large productivity and other economic benefits from them (as manifest in their willingness to pay a congestion charge). The mix of highway projects would change for the better; the productivity, growth and living standards of regional economies would improve accordingly; and revenues would be generated to help finance infrastructure development (see below).

EFFECTS OF ROAD PRICING ON TRAFFIC CONDITIONS

Summary Table 4 gives the estimated implications for traffic volume and traffic speed of levying congestion prices on highly congested interstates and freeways. Whereas total vehicle miles of travel (over all road system) is estimated to decline by less than two percent, traffic is estimated to decline by more than 12 percent on highly congested urban interstates and freeways. Traffic speed on these roads would increase accordingly. Although average speed would increase by an estimated 11 percent (see Summary Table 3), the relationship between traffic volume and traffic speed is a matter of measurement uncertainty. Under an alternative measurement of this relationship, traffic speed could increase by as much as 20 percent.

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[5] It is important to bear in mind that we are examining the impact of road pricing at a point at which the optimal supply of roadway capacity is unknown. The goal of road pricing is thus not to force the demand for travel to align with the capacity that happens to be available today, but to help ascertain the extent of roadway capacity that people are willing to pay for once having compared the true cost of roads (including congestion) with the benefits they derive from using them.

Summary Table 4: Impact of Tolls on Traffic Volume and Speed on Urban Interstates and Freeways with Volume-to-Capacity Ratio Above 0.95 (Impact in 2020 Relative to Projected Traffic Conditions in the Absence of Congestion Tolls)

TRAFFIC AND SPEED	BASELINE ELASTICITY AND VALUE OF TIME ASSUMPTIONS	ALTERNATIVE ELASTICITY AND VALUE OF TIME ASSUMPTIONS
Reduction in Vehicle Miles of Travel	12.53 Percent	19.03 Percent
Increase in Speed	5.6 mph	8.1 mph
	11.2 Percent	16.0 Percent

EFFECT OF ROAD PRICING ON REVENUES AVAILABLE FOR HIGHWAY INVESTMENT

Summary Table 5 reports the estimated yield from toll revenues and compares them to the estimated 20-year average annual investment requirements to improve the highway system - $112 million, as reported in the 2002 Conditions and Performance Report. Tolling the interstates and freeways is estimated to generate between $83.8 billion and $105 billion in average annual revenue. Assuming that these revenues would be available for highway finance, the average annual gap between investment requirements and fuel tax revenues could, notionally, be eliminated. A range of caveats is in order, however.

Summary Table 5: Impact of Tolls on Revenue and Funding Requirements[a] (in billions of 2002 dollars)

FOR THE PERIOD 2002-2020	BILLIONS OF 2002 DOLLARS	PERCENT OF TOTAL COST TO IMPROVE
Average Annual Cost to Improve Roads	112.0[a]	-
Motor Fuel Taxes	57.4[a]	51.2
Average Annual Toll Revenue	83.8[b] – 105.0[c]	74.8[b] – 93.8[c]
Remaining Funding Gap After Toll Revenue	Zero	Zero

Notes.
a - From "2002 Conditions and Performance Report," U.S. DOT, revalued to 2002 dollars
b - Reflects baseline elasticity and value of time assumptions
c- Reflects alternative elasticity and value of time assumptions

First, pressure to reduce federal fuel taxes might be expected if widespread tolling were to be put in place. Second, it is unlikely that all revenues from tolls would be available for highway investment. An HLB study currently in progress for the Office of the Secretary indicates that up to a third of toll revenues might be systematically diverted to non-highway purposes such as transit support, environmental mitigation and various means of alleviating problems for low-income travelers. And third, the concept of systematically tolling all congested urban interstates and freeways needs to be seen as a "bookend scenario" rather than an immediate option for federal policy. The other bookend, no tolls, is of course much closer to the reality of congestion pricing today. Indeed, the absence of congestion pricing today is a matter of policy rather than culture and would be that much harder to shift accordingly. What the “congestion pricing bookend” reveals is not an immediate solution but rather the significance of pricing as part of a long-term strategy for reshaping highway finance.

1: INTRODUCTION

This report presents a high-level analysis framework within which the Department can begin to assess issues pertaining to the potential effects of road pricing nationwide. The analysis framework is populated with a reasoned range of empirical evidence with regard to key assumptions. Such assumptions include the various elasticities and cross-elasticities, economic costs, speed-flow relationships, and network connectivity variables that enter into the analysis of road pricing impacts on traffic levels, traffic speeds, and toll revenues. The framework is intended to help crystallize key issues, uncertainties, and research requirements in support of policy analysis.

This report is organized as follows. Section 2 outlines the high-level model logic and structure. Section 3, Section 4, and Section 5 discuss key model methodological and data assumptions. Section 6 reports the results of model simulations and Section 7 reports the results of sensitivity analysis with certain model assumptions. Appendix A presents the detailed list of inputs and their numerical assumptions. Appendix B shows the structure and logic of the key structural model elements that lead to calculation of travel volume and revenue impacts, and Appendix C presents the iterative procedure used to derive congestion tolls, Appendix D shows derivation of selected key model assumptions, and Appendix E presents additional results of sensitivity analysis.

2: FRAMEWORK OVERVIEW

The model developed for this study simulates the effects of tolls on the volume of travel, or vehicle miles traveled (VMT), on the basis of elasticity of demand for travel with respect to driving costs and the percentage change in driving costs caused by tolls. The model takes into account both the effects on tolled roads as well as the effects on alternative roads and alternative times of day where there are no tolls. The latter effects are modeled with the use of cross-elasticity of travel demand on a given road type with respect to the cost of driving on another competing road or during an alternative time of day.

This methodology represents a reduced form model approach in which the observed (or assumed) own price elasticities and cross-elasticies generate a final equilibrium estimate of impact after all interactions and dependencies between travel demand on various roads have been taken into account and already affected driving behavior.

The change in the volume of travel under tolls as compared with the predicted volume of travel under the baseline scenario (i.e. in the absence of tolls) is then used to calculate the congestion level under tolls as measured by the volume-to-capacity ratio (V/C ratio). More specifically, the model assumes a certain initial baseline V/C ratio for all roads. The model then calculates the implied road capacity on the basis of the V/C ratio and the baseline volume of travel and uses it to re-calculate the V/C ratio with a different volume of travel under a toll scenario.

The resulting change in the V/C ratio is then related to the speed-flow relationship. The congestion level and average speeds under tolls are compared with those under a baseline scenario to infer the absolute and percentage change in congestion and average speeds.

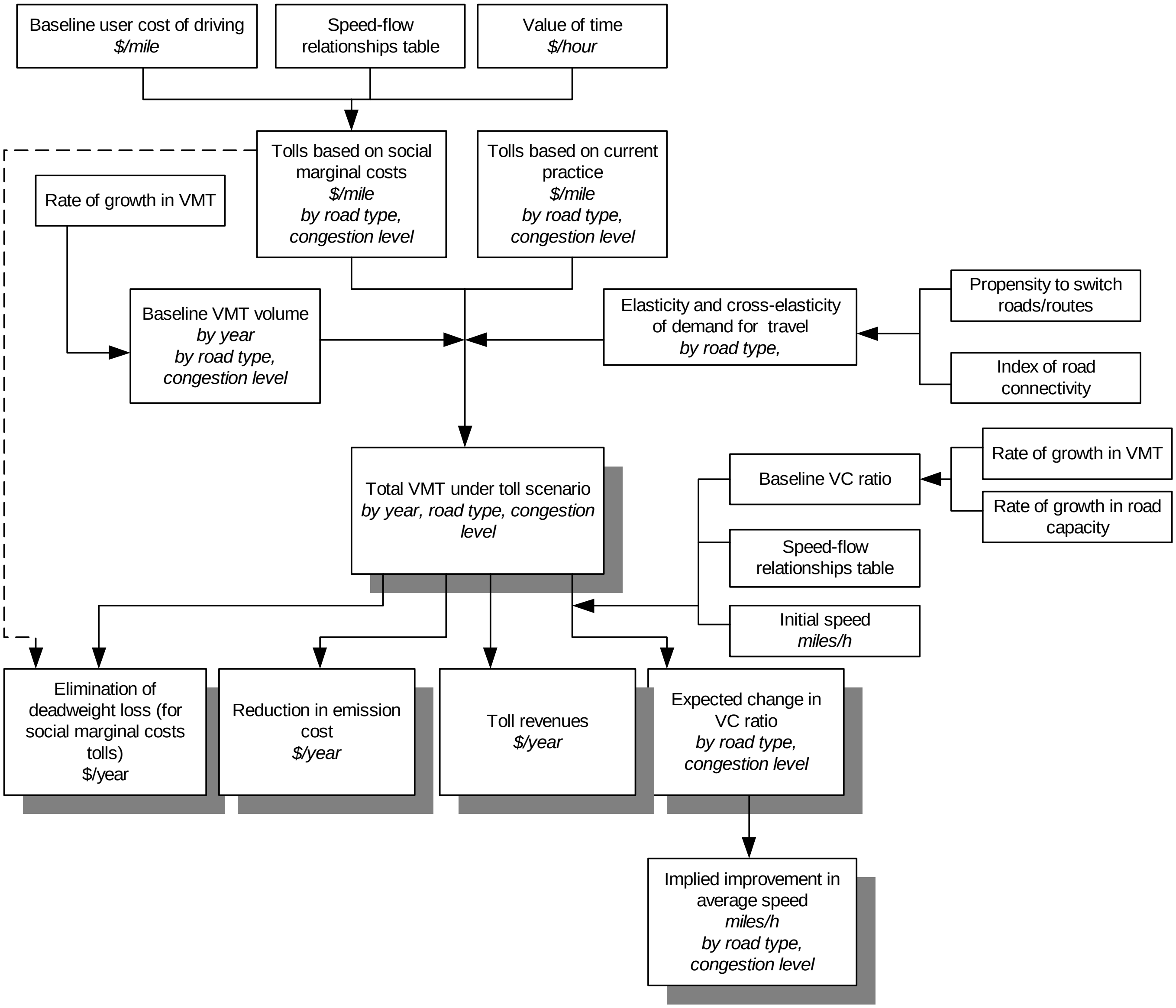
The total volume of travel allows for the estimation of toll revenues, and the change in the volume of travel combined with emission rates and accident rates allows for estimation of emission cost savings and accident cost savings under the toll scenario.

The model considers two toll scenarios: one based on current practice on toll road projects throughout the United States, and the other based on social marginal costs. The latter toll schedule is derived endogenously based on assumptions as to the value of time, baseline costs of driving, and speed-flow relationship. These assumptions are then also used to estimate the magnitude of “deadweight loss”, i.e. the loss in social benefits, or economic efficiency, due to failure to charge congestion tolls.

The model is simulated over the period from year 2002 to year 2020 using input data from statistical sources, published studies and literature, and other reasoned assumptions.

A high-level illustration of the model is presented in Figure 2-1. Appendix B presents the structure and logic of the key model components.

Figure 2-1: High-Level Structure and Logic of the Road Pricing Model



3: DERIVATION OF TOLLS AND TRAVEL IMPACTS

Two toll scenarios are considered in this model:

(1) Tolls based on current practice on tolled roads in the United States, and
(2) Tolls based on social marginal costs of roads that also include congestion costs and environmental cost.

The model assumes that that only congested roads with controlled access are tolled. There are two types of roads that have fully controlled access: interstate highways and “other freeways” using the National Highway Statistics report’s classification terminology. Facilities with VC ratio smaller than 0.71 are assumed to be free, i.e. they are not tolled. Facilities with VC ratio 0.71 and greater have a toll that depends on the magnitude of congestion.

This section provides details of the derivation of benchmark tolls and tolls based on social marginal costs. The resulting toll schedules used in further analysis are reported subsequently.

3.1 Benchmark Tolls

The toll schedule based on current practice for interstate highways and freeways under various congestion levels was based on posted toll schedules on various facilities throughout the US. They reflect the typical tolls charged on different toll road project, or what tolls could be reasonably expected on a typical facility. This toll schedule is the same for interstate and freeway facilities but is broken down by congestion level measured by the VC ratio.

3.2 Derivation of Social Marginal Costs Tolls

Tolls based on social marginal costs represent the sum of marginal congestion cost imposed by a marginal highway user on all other road users, incremental environmental costs created by the additional user, and highway operation and maintenance cost that could be attributed to an individual road user.

Below we discus the derivation of two categories of components of tolls based on social marginal costs: congestion costs and other toll components.

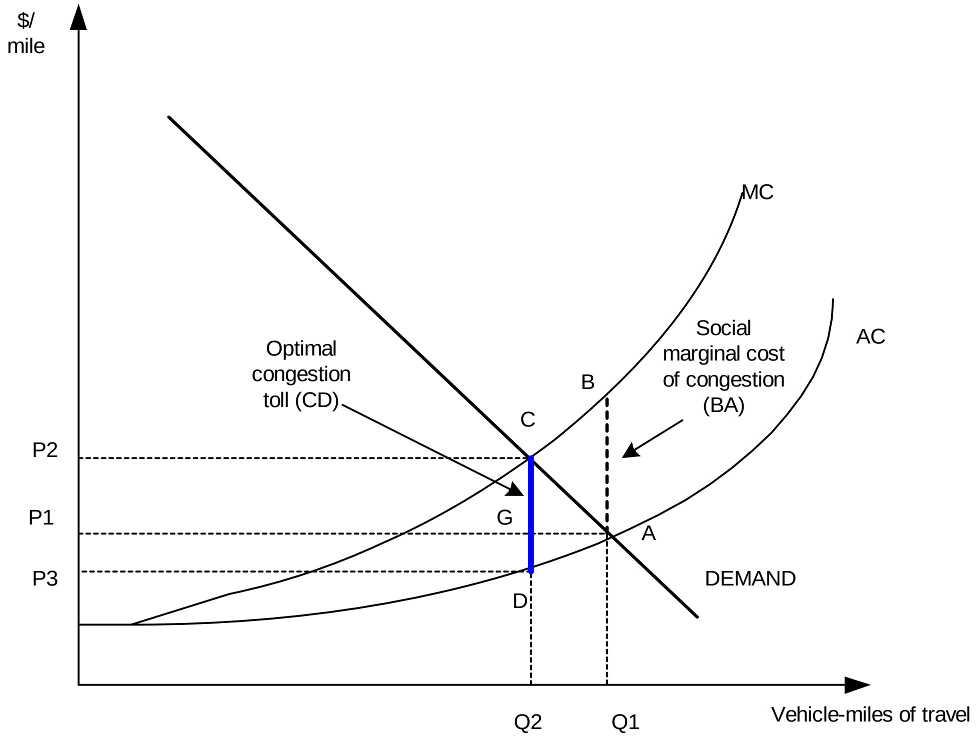
3.2.1 Endogenous Derivation of Congestion Costs

The congestion cost component of tolls based on social marginal costs was derived endogenously as the “optimal congestion toll” that is equal to the difference between the social marginal costs of highway use and average private cost of highway use at the volume of traffic where the social marginal cost curve intersects the demand curve.

This approach is consistent with the traditional modeling of efficient road pricing, or congestion pricing, in the economic literature and reflects the observation that under congested road conditions each additional user entering the road imposes a cost on all other road users because each additional user slows down everyone else who is already on the road. In the absence of road pricing, this cost – a congestion cost – is not fully internalized by the road user. As a result, the volume of travel exceeds the efficient level, or the level that reflects full social costs of driving.

The imposition of tolls corrects for this inefficiency, and the congestion cost at the volume of travel where the social marginal cost curve intersects the demand curve represents the equilibrium congestion toll. This framework is illustrated in Figure 3-1.

Figure 3-1: Economic Analysis of Congestion Pricing



The figure above shows the demand for car trips, or the level of traffic (in terms of vehicle-miles), as a function of the costs of driving. Drivers face a certain cost of driving which includes both car operating costs (gasoline, oil, maintenance, etc.) as well as time cost of driving. This cost increases as traffic on the road increases because more heavy traffic reduces the overall travel speed and thus increases the time cost of driving component. The average private cost function is illustrated in Figure 3-1 by the curve labelled AC.

In the absence of tolls, the volume of travel is determined by the intersection of the private average cost curve and the demand curve. In Figure 3-1, this volume of travel is equal to Q1.

Curve labelled MC in Figure 3-1 represents the social marginal cost curve derived as the marginal cost of total social costs of driving (which in turn are the product of average costs of driving times the volume of travel). Since the average cost curve is increasing, the marginal cost curve lies above the average cost curve.

At the market equilibrium volume of traffic, Q1, not all social costs of driving are fully internalized by drivers. As mentioned earlier, each car entering the road imposes a cost on all other road users by contributing to congestion and reduction in travel speed. This cost is illustrated as distance AB, the distance between the average private costs curve and social marginal costs curve.

The socially optimal volume of traffic is determined by the point where the marginal social cost curve and the demand curve intersect, point C. At this point the volume of traffic is Q2 vehicle-miles. This traffic level is achieved by the use of a congestion toll in the amount of CD dollars per mile imposed on each vehicle.

The quantitative magnitude of the optimal congestion cost as represented by distance CD is derived using an iterative procedure and assumptions with respect to the average cost curve, marginal cost curve, and elasticity of travel demand as follows.

- **Average costs of driving and average cost curve**

The average cost of driving was assumed to be equal to the cash costs of driving (that includes fuel, maintenance, insurance, etc.) and time cost of driving. This cost can be expressed as:

$AC = c + b/v$,

where c is the cash cost of driving and b/v, value of time divided by average effective or congested speed, represents the time cost of driving. The cash cost of driving is assumed constant. However, the time cost of driving increases as the average effective speed falls.

The average effective speed was modeled using the speed-flow relationship commonly referred to as the BPR curve. A speed flow relationship calculates the actual speed as a function of road congestion and speed in uncongested conditions (free-flow speed). The speed-flow relationship used in this study is of the following form:

$v = v_0/[1 + 0.15(Q/CAP)^4]$,

where

v = congested speed;
v_0 = free-flow speed;
Q = volume of travel, and
CAP = road capacity.

Note that volume of travel divided by road capacity is equal to the VC ratio, or congestion level at which travel occurs, i.e.:

$Q/CAP = VC\_Ratio$

- **Marginal social cost curve**

The marginal cost curve is derived from the total cost curve as follows:

$TC = AC \cdot Q$,

where

TC = total social costs;
Q = volume of travel, and
AC = average private cost of driving shown earlier.

Then, using the definition of marginal costs as the differential of total costs and the expressions derived earlier we have:

$MC = \partial TC/\partial Q = AC + Q \cdot \partial AC/\partial Q$, and

$MC = c + b/v_0 + b/v_0 \cdot [1+ 0.75\,(Q/CAP)^4]$

where MC is the marginal cost.

- **Iterative procedure to derive congestion cost**

The congestion cost and the optimal congestion toll was derived endogenously using an iterative procedure and the marginal cost curve, the average cost curves defined above, as well as an assumed elasticity of demand.

The iterative procedure involves finding the intersection point between the marginal cost curve and the demand curve in the situation when the precise schedule of the demand curve is not know, and the information about demand that is known is the initial market equilibrium coordinates (i.e. user average cost of driving and traffic volume) and initial elasticity of demand. The details of this procedure are described in Appendix C.

The congestion tolls volumes of traffic on tolled roads were estimated according to the that procedure for years 2002, 2010 and 2020 for each road category of interstate and freeways broken down by ranges of initial congestion level. The initial volumes of travel and road capacity were assumed to be growing from base year at a certain rate discussed in Section 4.

The tolls for the remaining years were prorated according to an implied rate of growth, and the resulting equilibrium volumes of traffic were estimated as discussed in Section 3.4.

3.2.2 Derivation of Other Components of Social Marginal Costs Tolls

Incremental environmental costs, i.e. costs of environmental emissions, were derived based on researched and published vehicle emission rates per vehicle mile and the assumed emission costs typically used in similar studies. Since the emission rates for trucks are substantially higher than for autos, we assumed that 30 percent of total volume of traffic consists of trucks and 70 percent of autos. The emission rate was then calculated as the weighted average of the emission rates for trucks and auto.

Highway operation and maintenance (O&M) costs attributable to individual users were derived based on previous HLB project experience in evaluating toll projects. The O&M cost component was calculated as total O&M cost divided by the volume of vehicles and times the length of the section to give O&M cost per VMT.

The charges for highway O&M and emission costs were assumed to be constant in terms of dollars per mile and independent of the traffic volume. These total charges were added to the marginal cost curve discussed earlier and the resulting optimal toll based on social marginal costs was simulated according to the iterative procedure described in Appendix C.

3.3 Toll Schedules

Assuming the value of time of $18.60[6] and elasticity of demand of –0.4, the resulting social marginal costs tolls are reported in Table 3-1 together with benchmark tolls.

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[6] Value of time was based on values reported in HERS Technical Report, December 2000, page 7-2, Table 7-1 and inflated to 2002 dollars.

Table 3-1: Toll Schedules Considered in this Analysis (Dollars per Mile)

INITIAL CONGESTION LEVEL (Measured by Volume to Capacity Ratio)	BENCHMARK TOLLS (TOLLS BASED ON CURRENT PRACTICE)	EQUILIBRIUM TOLLS BASED ON SOCIAL MARGINAL COSTS	
		YEAR 2002	YEAR 2020
INTERSTATE HIGHWAYS			
Between 0.71 and 0.79	$0.06	$0.10	$0.12
Between 0.8 and 0.95	$0.12	$0.13	$0.16
Greater than 0.95	$0.21	$0.19	$0.25
FREEWAYS			
Between 0.71 and 0.79	$0.06	$0.10	$0.12
Between 0.8 and 0.95	$0.12	$0.13	$0.16
Greater than 0.95	$0.21	$0.21	$0.28

NOTES. (1)The assumed value of time used in the derivation of social marginal cost tolls equals $18.60 per hour. (2) All tolls based on social marginal costs include $0.0265 to cover emission costs and $0.033 to cover highway O&M costs. The remainder represents the congestion cost. (3) Tolls based on social marginal costs are growing over time because of the increase in the general congestion level that leads to an increase in the congestion cost component.

Table 3-1 suggests that current tolls are already very close to the optimal tolls based on social marginal costs, in particular on roads with moderate to heavy congestion (VC ratio equal of greater than 0.8).[7] On heavily congested interstate highways (i.e. roads with VC ratio greater than 0.95), benchmark toll are somewhat higher than optimal congestion tolls. This suggests that toll operators on these toll road projects are already capturing in the toll rate all social costs, including the congestion cost imposed by marginal road users. Since the benchmark toll is actually higher than the optimal social marginal cost toll, the volume of traffic under benchmark tolls is somewhat below the efficient volume.

3.4 Derivation of Travel Impacts

Examination of Figure 3-1 reveals that under an assumption of increasing average costs of driving, the increase in costs of driving following introduction of tolls is smaller than the amount of the toll. In Figure 3-1, the toll is equal to distance CD, while the increase in the total costs of driving experienced by drivers is equal to distance CG.

Distance CG represents thus the net increase in total cost of driving (that include both cash costs of driving and time costs of driving) to road users who still are using the tolled highways, and

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[7] Note that on highly congested freeways the optimal congestion toll is somewhat higher than on interstates. This is because the average congestion level (i.e. the VC ratio on highly congested urban freeways is slightly higher than on highly congested interstates falling into the same road category).

GD represents the reduction in time cost of driving. The time cost of driving under a toll scenario is smaller than under the baseline of no tolls because the traffic volume on the road under the former scenario is smaller than under the latter.

Consequently, the reduction in the volume of travel is smaller than that suggested by the demand curve and the amount of toll alone (and that would result in the case of constant average private costs of driving).

This off-setting effect of tolls on the cost of driving is taken explicitly into account in the estimation of travel volume impacts, and the equilibrium after-toll travel volume is estimated on the basis of the actual net increase in total costs driving, illustrated by distance CG in Figure 3-1. This distance is calculated as the difference between the estimated toll and reduction in the private average cost of driving. The reduction in the average private cost of driving is calculated, in turn, from the average private cost curve as the difference between baseline average private cost of driving and average private cost of driving under a toll scenario.

This net increase in the costs of driving is used then with elasticity and cross-elacticity of demand and baseline travel volumes to estimate the travel volume under a toll scenario by each road type.

4: OTHER KEY INPUT ASSUMPTIONS

This section discusses assumptions with respect to key model inputs. The detailed list of all model inputs, their quantitative magnitude and sources is given in Appendix A.

4.1 Types of Roads and Traffic Volumes

To enrich the model structure, including a richer toll schedule differentiated by the level of congestion and the possibility of shifts in the volume of traffic to roads with no tolls, the model analyzes the traffic impacts broken down by road types and congestion levels.

The National Highway Statistics report VMT broken down by five road types:

- Interstate;
- Other freeways;
- Other principal arterials;
- Minor arterials and collectors, and
- Local roads.

FHWA provided the 2002 data on the breakdown of traffic volumes on the above road types by congestion level. Table 4-1 below provides a summary of the obtained information.

Table 4-1: Volume of Traffic by Urban Road Types and Congestion Level, Year 2002 (in Percent of Total by Road Type)

Road Type	Percentage of Travel Volume in Road Category by VC Ratio				Percent of Total Urban Travel
	VC Smaller than 0.71	VC Between 0.71 and 0.79	VC Between 0.80 and 0 .95	VC Greater than 0.95	
Interstate	27.3%	10.9%	23.0%	38.8%	23.7%
Other Freeways	36.1%	8.8%	21.0%	34.1%	11.0%
Other Principal Arterials	71.8%	8.4%	10.7%	9.2%	23.6%
Minor Arterials	77.9%	4.7%	8.6%	8.9%	27.9%
Collector	79.8%	3.5%	8.0%	8.6%	

Source: Based on FHWA runs on highway sections in the Highway Performance Monitoring System (HPMS) database.

NOTES: The volume of traffic used to calculate percentage shares in the last column includes local traffic. Minor arterials and collectors have been combined in the model into one category of roads.

Local roads are assumed to be uncongested, i.e. to have the VC ratio smaller than 0.71.

There are thus 14 road types combined with congestion level:

- Interstate with VC ratio between 0.71 and 0.79;
- Interstate with VC ratio between 0.8 and 0.95;
- Interstate with VC larger than 0.95;
- Freeways and Expressways with VC ratio between 0.71 and 0.79;
- Freeways and Expressways with VC ratio between 0.8 and 0.95;
- Freeways and Expressways with VC larger than 0.95;
- Principal Arterials with VC ratio between 0.71 and 0.79;
- Principal Arterials with VC ratio between 0.8 and 0.95;
- Principal Arterials with VC ratio larger than 0.95;
- Minor arterials and collectors with VC ratio between 0.71 and 0.79;
- Minor arterials and collectors with VC ratio between 0.8 and 0.95;
- Minor arterials and collectors with VC ratio larger than 0.95;
- Local Roads, and
- Not congested roads (interstate, freeways, principal arterials, and minor arterials roads, all with VC ratio smaller than 0.71).

The particular values of initial VMT for each road category were based on the Highway National Statistics data referring to urban traffic volumes.[8]

The growth in VMT over time was based on historical data. However, we assumed that VMT would increase by the same amount of VMT (e.g. by 100 VMT each year) rather than the same percentage of previous year's volume. This effectively generated a declining rate of growth in VMT ranging from 2.16 percent in 2002 to 1.58 percent in 2020.

The model also considers the effect of tolls on transit, i.e. transit ridership and transit VMT. This impact is similar in nature as that for roads, i.e. through cross-effects (or cross-elasticity) between transit and road travel. The assumed volume of transit travel was based on the volumes of revenue vehicle miles reported in the 2002 Conditions and Performance Report and amounted to 0.1 percent of total VMT.

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[8] Most of the rural traffic was in not congested conditions according to Highway National Statistics. Since reduction in the traffic volume under minimal to mild congestion level leads to minimal improvements in speeds and travel times, rural traffic was not taken into account in this analysis.

4.2 Elasticity of Travel Demand

Elasticity of demand for travel is represented by a matrix of elasticities that includes own price elasticity for each road type and cross-elasticities between various road types. Own price elasticity represents the impact on traffic volume on a road when the cost of driving on that particular road (such as the amount of toll charge) changes. Cross-elasticity represents the impact on traffic volume on a road when the cost of driving on another road in the road network changes. Cross-elasticities larger than zero allow modeling of shifts in travel demand from congested tolled roads to other roads in the system.[9]

Own price elasticities were based on inferences from literature. The average value of own price elasticity ranged from –0.5 to –0.2 and was larger in absolute value for roads of higher hierarchy than on minor roads.

Cross-elasticities of travel demand were assumed to be a function of people's propensity to switch roads as the cost of driving on a particular road changes and road connectivity within a road network. The propensity to switch roads represents a "pure" cross-elasticity as captured by people's willingness to make changes in their daily routines or patterns of behaviour. Road connectivity describes the extent to which roads are connected in the physical sense and allow easy switching from one road to another to get to the same destination. The degree of connectivity is measured by an index with values from 0 to 1, where 0 stands for "no road connectivity: and 1 stands for "perfect connectivity". Thus the cross-elasticity for any particular road type that the model uses is then a product of "pure" cross elasticity (or people's propensity to switch between these roads) and an index of road connectivity.

The detailed matrices of own-price elasticities and propensities to switch routes, road connectivity, and resulting matrix of elasticities and cross-elasticities are shown in Appendix A.

We assumed that the propensities to switch between routes are a function of (i.e. closely related to) own price elasticity for the road where price changes. We also assumed that the volume of traffic that would come off the road where the cost of driving increases would switch in equal proportion to all other road categories, transit, and other modes not captured in the model (walk, bike, and car pool or shared rides). These proportions were then adjusted (i.e. multiplied) by the ratio of traffic volumes on the affected roads (i.e. the road where traffic is transferred to and road where price changes). This adjustment captures the idea that the effect of a change in the cost of driving on road 1 on the traffic volume on road 2 depends on the relative traffic volumes on the two roads. For example, if traffic on road 1 is relatively large compared to road 2, the impact on road 2 may be substantial as traffic coming off road 1 would add a relatively large volume of traffic to road 2. However, if traffic volume on road 1 is small, the effect on road 2 will also likely be small as the additional traffic coming to road 2 would be relatively small.

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[9] An alternative approach to modelling shits from tolled roads to untolled arterials and local roads would be to examine individual trips and find a route that would minimize the time cost of the individual trips. This would involve application of elasticity of demand and value of time to individual trips. Clearly this approach could not be implemented in this model. The use of cross-elasticities represents a reduced form modelling approach in which the observed elasticities generate the final equilibrium.

The indices of road connectivity were based on perceived connectivity between various road types in a road network. For example, connectivity within roads of the same type but differing congestion level (such as between various interstate routes or between various freeways) was assumed very low. This is equivalent to the perception that roads of the same type but different congestion level are not very likely to be close geographically to one another, serve the same destinations, or allow easy switching from one to another. For example, the number of interstate routes and freeways within an urban area is small (although they serve large volumes of traffic) with typically only one route serving a particular set of destinations destination. Therefore, connectivity between congested interstate highways and freeways was assumed zero. This implies that road users who would be willing – in principle – to switch from a highly congested interstate/freeway to a less congested interstate or freeway cannot do that as there is no another interstate or freeway that they could use to get to their destination.

Connectivity between interstate roads and other road categories was also assumed relatively low. This is because major interstate routes are typically separated roads that are connected to the rest of the network through a relatively small number of entry and exit ramps. On the other hand, connectivity of all other categories of roads with uncongested roads (or roads during off-peak times of day) was assumed near perfect as off-peak times of day represent the same roads as the congested roads.

All elasticities, own price elasticities and cross elasticities are assumed to be long-run elasticities that represent all adjustments and final reactions of users to the tolls.

4.3 Baseline Congestion Level

For the purpose of simulating the impacts of tolls on congestion and speeds, the model uses certain assumptions as to the congestion level of roads being analyzed. The average congestion level by road category and congestion range was obtained from FHWA from runs on highway sections from HPMS. These data is summarized in Table 4-2.

Table 4-2: Average VC Ratio by Road Type and Congestion Range

Road Type	Average VC Ratio		
	VC Between 0.71 and 0.79	VC Between 0.80 and 0 .95	VC Greater than 0.95
Interstate	0.75	0.87	1.05
Other Freeways	0.75	0.87	1.10
Other Principal Arterials	0.75	0.86	1.11
Minor Arterials	0.75	0.86	1.14
Collector	0.75	0.87	1.24

NOTE: Based on FHWA runs on highway sections in the Highway Performance Monitoring System (HPMS) database.

The categories of local roads and uncongested roads listed in Section 4.1 were assumed to have a congestion level determined by V/C ratio equal to 0.6.

We assumed that over time road capacity would grow slower than VMT. Based on the analysis of the Texas Transportation Institute and statistics reported in the 2002 Conditions and Performance Report, we assumed that road capacity would be growing on average at 65 percent of traffic growth.[10]

4.4 Speed-Flow Relationship and Initial Average Speeds

This model uses a BPR curve to infer changes in average speeds following a change in the level of congestion as expressed by the volume-to-capacity or VC ratio:

$v = v0/[1 + 0.15(Q/CAP)^4]$,

where

v = congested speed;
v0 = free-flow speed;
Q = volume of travel, and
CAP = road capacity.

This is the same relationship that was used to derive the average cost curve and the marginal cost curve discussed earlier.

As the equation above indicates, the end calculation of congested speed depends crucially on the assumption as to the magnitude of the initial free-flow speed, v0. The free-flow speeds used in this study were the free flow speeds recommended in “NCHRP Report 387: Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications in 1997”. Depending on road category, these speeds range from 40mph to 67 mph. The resulting congested speeds, or average speeds at various congestion levels are shown in Table 4-3.

It should be noted that there have been several speed-flow relationships developed in academia and government transportation agencies. The BPR curve employed in this study represents rather a conservative assessment of the reduction in average effective speed when congestion increases. For example, for highly congested conditions, the MTC curve predicts much higher reductions in average speeds than those assumed in this model and those predicted by the updated BPR curve.

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[10] The assumption that road capacity would be growing over time only at half the rate of the growth in traffic is based on findings of the Texas Transportation Institute that over the past 21 years only half of the roadway capacity that was actually needed to maintain a constant congestion level was actually added. The *2002 Conditions and Performance Report* also reports that there is a considerable backlog of highway investment and annual capital expenditure fall short of estimated average annual costs to maintain the highway system. Although the C&P Report projects the difference between the investment requirements and actual expenditures to fall to 17.5% over the period 2001 to 2020, the shortfall in spending for system expansion in year 2000 amounted to 26 percent. In other words, the actual highway capital expenditure to expand the system amounted to about 80% of the HERS estimated required amount. The assumed rate of 65 percent is thus equal to the average rate inferred from the two sources.

Table 4-3: Speed-Flow Relationship (BPR Curve)

V/C Ratio and Corresponding Speeds	Free-Flow Speed	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.8	0.9	1.00	1.10	1.20	1.30
Interstate	66.8	66.8	66.8	67	66.5	66.2	65.5	64.4	62.9	60.7	57.9	54.6	50.7	46.5
Freeways	66.8	66.8	66.8	66.7	66.5	66.2	65.5	64.4	62.9	60.7	57.9	54.6	50.7	46.5
Principal Arterials	44.4	44.4	44.4	44.3	44.2	44.0	43.5	42.8	41.8	40.4	38.5	36.3	33.7	30.9
Minor Arterial & Collector	44.4	44.4	44.4	44.3	44.2	44.0	43.5	42.8	41.8	40.4	38.5	36.3	33.7	30.9
Local Roads	39.7	39.6	39.6	39.6	39.5	39.3	38.9	38.2	37.3	36.0	34.4	32.4	30.1	27.6
Not congested	57.8	57.8	57.8	57.7	57.6	57.3	56.7	55.8	54.4	52.5	50.1	47.2	43.9	40.2

4.5 Social Benefits and Costs of Road Pricing

The model also considers key high-level social benefits and costs of road pricing to determine whether the net benefit of road pricing is likely to be positive. The benefits and costs taken into account include the following:

- Benefits:
  - Toll revenue;
  - Accident costs savings to all users;
  - Total savings in travel time to road users
  - Total value of environmental savings (air quality and greenhouse gases);
- Costs:
  - Costs of Toll collection, and
  - Reduction in consumer surplus to road users.

Accident cost savings are to be estimated based on researched and published accident rates by type and average accident costs and implied accident cost per mile of travel. Specifically, accident costs savings are then equal to the difference between total accident costs under baseline and under the toll scenario.

Savings in travel time are to be calculated as the difference in total time spent to travel the given VMT between baseline and the toll scenario. The travel time, in turn, was estimated by dividing total VMT by the average speed on each road type.

Costs of toll collection were estimated assuming a certain percentage of toll revenue. This percentage was assessed based on review of recent literature. Specifically, the model assumes that the costs of toll collection would amount to 20 percent of toll revenue. [11]

Reduction in consumer surplus will be estimated as the reduction in welfare to road users due to higher costs of traveling. Using Figure 3-1, the loss in consumer surplus can be illustrated by area P2CAP1 which can then be broken down into two areas: CGA and P2CGP1.

The triangular area CGA represents consumer surplus to road users who would not be on the road under tolls. It can be approximated assuming that it is a proper triangle and using formula for the area of a triangle:

$$CGA = CG \cdot (Q1 - Q2)/2,$$

Where

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[11] This assumption is based on David Friedman and Joel Waldfogel (1994), “The Administrative and Compliance Costs of Manual Highway Toll Collection: Evidence from Massachusetts and New Jersey, *National Tax Journal*, Vol. 47, no.2 (June 1994), pp.217-28. The referred to paper discusses costs of manual toll collection. Although electronic toll collection has the potential of substantial reductions in the costs of collection, recent experience suggests that the actual outcomes have a large range of variation and may not be substantially below the manual costs of collection (see ITS Decision, Service and Technologies, at www.calccit.org/itdecision).

CG = the net increase in driving costs due to tolls;
Q1 = initial (market equilibrium volume of travel), and
Q2 = volume of travel under tolls.

The rectangular area P2CGP1 represents the loss of consumer surplus who continue to use the tolled roads after tolls are introduced. This consumer surplus can be estimated as the product of the volume of travel under the toll scenario and the net increase in the cost of driving due to tolls:

$$P2CGP1 = CG \cdot Q2.$$

5: MEASUREMENT OF EFFECT OF ROAD PRICING ON INVESTMENT REQUIREMENTS AND ECONOMIC PERFORMANCE OF HIGHWAYS

Changes in the value of economically worthwhile investment projects are driven by the effect of user costs (which could include any tolls) on the benefits of highway travel to users. Therefore, an appropriate methodology of estimating the extent to which road pricing eliminates the need for an investment project would involve a cost-benefit analysis under the baseline and under a toll scenario at the project level.

Although an analysis at the project level is in principle feasible, it could not be implemented within the scope of this assignment and timeline. To make the results of such methodology statistically significant and be able to generalize them to the national level, several hundreds of sample highway sections (with possibly multiple candidate investment projects) would have to be examined. The level of effort and cost of such undertaking are clearly beyond the scope of this study.

This section discusses an alternative approach to assessing the implications of the absence of road pricing on the nation's total economic welfare, potential highway investment requirements and their economic performance.

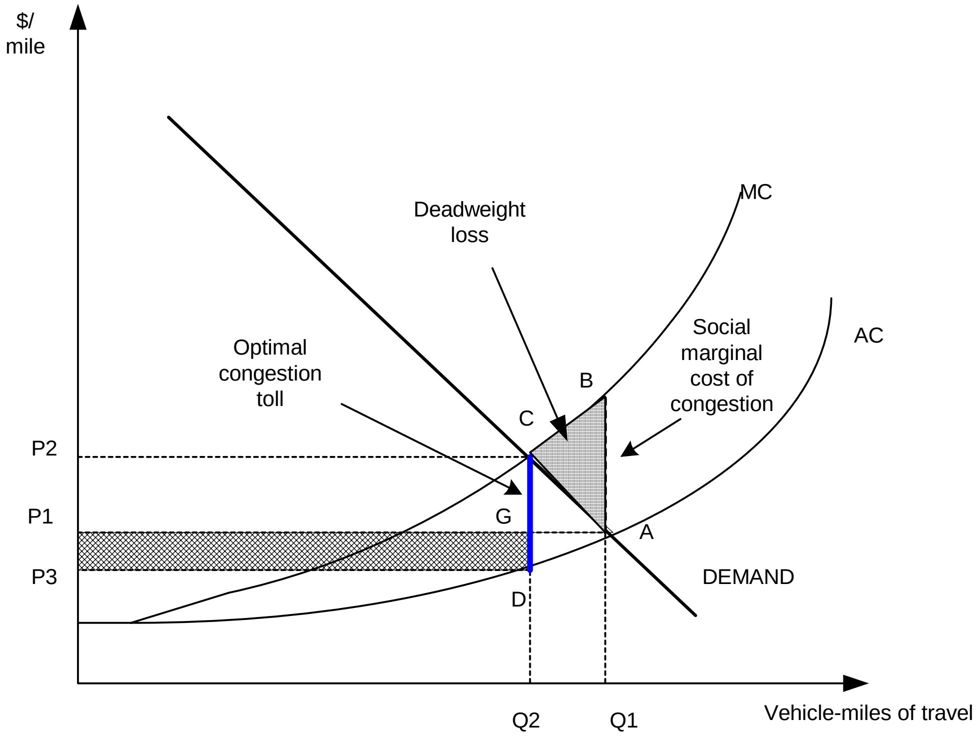
5.1 Approach: Estimation of Deadweight Loss

The effects of market inefficiencies are often quantified in empirical research using the concept of deadweight loss resulting directly from that inefficiency. The deadweight loss is a net loss in social benefits, or welfare, that results because the benefit generated by an action is smaller than its cost.

Failure to charge for road congestion creates a loss in economic benefit as for some marginal road users – those users who would not be willing to pay a toll if there was one – total social costs of highways exceed total benefits that these users derive from highway use. In the case of transportation, this inefficiency consists primarily of travel delays as well as costs of externalities (e.g. emissions) and highway maintenance partially reduced by the consumer surplus to those road users who would not be on the road in the presence of road charges.

Deadweight loss is often referred to as "welfare triangle" as graphically, the deadweight loss can be illustrated by a triangular area between the marginal cost curve and the demand curve at the market volume of travel (area CBA at the volume of travel equal to Q1 in Figure 5-1).

Figure 5-1: Deadweight Loss of Failure to Charge for Road Congestion



The incidence of deadweight loss poses questions such as

(1) *How large is the loss of economic value from federal investment in highways and bridges due to the absence of congestion fees*?, and
(2) *What would congestion pricing mean for highway investment requirements*?

Since in the absence of road pricing, total social welfare is reduced, it follows that the imposition of congestion tolls would significantly improve the productive value of the nation's urban interstates and freeways. The implications of congestion tolls for investment requirements are more difficult to gauge, however. Cost Benefit Analysis studies of expanding highly congested transportation facilities indicate that whereas imposing congestion prices reduces demand, facility expansion can remain economically worthwhile. This occurs when the number of users willing to pay the toll is such that congestion remains above economically optimal levels (usually a signal that expanding the facility is long overdue from an economic perspective).[12] Economic feasibility studies of expanding more moderately congested facilities report that pricing-induced reductions in demand can avert or defer the need for investment, with deferrals of as much as five, ten or even 20 years. While analysis at the project level is needed to

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[12] It is important to bear in mind that we are examining the impact of road pricing at a point at which the optimal supply of roadway capacity is unknown. The goal of road pricing is thus not to force the demand for travel to align with the capacity that happens to be available today, but to help ascertain the extent of roadway capacity that people are willing to pay for once having compared the true cost of roads (including congestion) with the benefits they derive from using them.

ascertain the extent to which total budgetary investment requirements would decline with the wide spread imposition of road prices, there is a material likelihood of at least a deferral effect, allowing the nation to get more value from its highway assets per year.

5.2 Estimation of Deadweight Loss

The deadweight loss is equal to the difference between the area under the marginal cost curve and the demand curve between the optimal and the market traffic volume. This in turn is equal to the difference between travel time savings to road users that remain on the road after tolls are introduced and consumer surplus to road users who are using the roads in the absence of tolls but who would not be using the roads after introduction of tolls (and reduced by the amount of highway charges, emission costs and highway O&M costs discussed in Section 3) that would fall on these users. Appendix D presents in detail derivation of this result). Using notation of Figure 5-1 this can be written as:

$DWL = P1GDP3 – [CGA – \alpha\cdot (Q1-Q2)]$

where:

DWL = deadweight loss;
α = charge for highway O&M and emission costs in terms of $/mile;
Q1 = initial or market equilibrium volume of travel;
Q2 = volume of travel under tolls;
P1GDP3 = travel time savings to road users that remain on the road after tolls are introduced;
CGA = consumer surplus to road users who are using the roads in the absence of tolls but who would not be using the roads after introduction of tolls, and
$\alpha\cdot (Q1-Q2)$ = the amount of highway charges (emission costs and highway O&M costs) that would fall on road users who are using the roads in the absence of tolls but who would not be using the roads after introduction of tolls.

The rectangular area P1GDP3 is calculated using the estimated equilibrium volume of travel under the toll scenario, Q2, and the reduction in cash costs of driving compared to the initial market equilibrium, GD. As explained in Section 3.4, this distance is calculated as the reduction in the private average cost of driving. The reduction in the average private cost of driving is calculated, in turn, from the average private cost curve as the difference between baseline average private cost of driving and average private cost of driving under a toll scenario.

The triangular area CGA of consumer surplus to road users who would not be on the road under tolls was approximated as a proper triangle:

$CGA = CG \cdot (Q1 – Q2)/2.$

6: MODEL RESULTS

In this section, we report key results of the model in terms of:

- Effect of road pricing on highway investment requirements and economic performance of highways;
- Effects of Road pricing on Traffic Conditions, and
- Effect of road pricing on revenues available for highway investment.

Since the estimated social marginal costs tolls are very close in magnitude to benchmark tolls, only the results for social marginal costs are reported here.

6.1 Effect of Road Pricing on Investment Requirements and the Economic Performance of Highways

Table 6-1 shows the annual estimates of deadweight loss due to current inefficient pricing of highways and compares it with highways investment requirements.

Table 6-1: Annual Loss in Economic Efficiency Due to the Absence of Congestion Pricing

Year	IN BILLIONS OF 2002 DOLLARS	AS A PERCENT OF PROJECTED AVERAGE ANNUAL REQUIREMENTS TO MAINTAIN CONDITIONS AND PERFORMANCE ON URBAN INTERSTATES AND HIGHWAYS
2002	$4.08	15.5%
2020	$9.61	36.4%

Note. Investment requirements for period 2002-2020 based on 2002 Conditions and Performance Report

As the table indicates, the estimated loss in economic value from highway investment due to current highway pricing policies rises over time, from $4.08 billion in 2002 to $9.61 billion by 2020. This increasing pattern of economic waste follows from the projected increase in congestion over the period. This loss in the economic value of highway investment represents 15.5 percent of projected investment requirements to maintain conditions and performance of the interstate and freeways highway system. By the year 2020, the absence of congestion prices is estimated to cause a loss in economic value equivalent to over 36 percent of the cost to maintain the condition and performance of urban interstates and freeways. The implication is that congestion fees would bring about significantly greater net economic return on the federal highway dollar.

As argued in Section 5, while current roadway pricing policies erode the nation's economic return on highway investment, it is not necessarily the case that levying congestion tolls would diminish the optimal level of highway spending. The significance of road pricing as an economic policy option is nonetheless apparent in the sizeable loss of economic value resulting from current pricing policy.

6.2 Effects of Road Pricing on Traffic Conditions

Table 6-2 shows the results of the model and the simulated effects of tolls on traffic conditions in terms of volume of travel, congestion level, and average speeds.

The results are reported for five road systems representing an aggregate of the road categories considered in the detailed analysis:

1. Most congested principal roads: interstate and freeways with initial VC ratio greater than 0.95;

2. Moderately congested principal roads: interstate and freeways with initial VC ratio smaller than or equal to 0.95 but greater than 0.7;

3. Other congested roads: principal arterials, minor arterials, and collectors with initial VC ratio greater than 0.7;

4. Not congested roads: interstate, freeways, principal arterials, minor arterials, and collectors with initial VC ratio smaller 0.71, and

5. Local roads.

Table 6-2: Effect of Tolls on Traffic Conditions

Impact of Tolls on Traffic Conditions in Terms of	Estimated Impact	
Effect on Volume of Travel Compared to Baseline of No Tolls (Year 2020)		
Total Reduction in VMT	1.69 Percent	
Reduction in VMT on Most Congested Principal Roads	12.53 Percent	
Reduction in VMT on Moderately Congested Principal Roads	7.90 Percent	
Increase in VMT on Other Congested Roads	*4.33 Percent*	
Increase in VMT on Not Congested Roads	*0.3 Percent*	
Increase in VMT on Local Roads	*0.56 Percent*	
Effect on Congestion level (V/C Ratio) (Year 2020)		
VC Ratio on Most Congested Principal Roads	1.06 under Tolls	1.21 under Baseline
VC Ratio on Moderately Congested Principal Roads	0.83 under Tolls	0.91 under Baseline
VC Ratio on Other Congested Roads	*1.07 under Tolls*	*1.03 under Baseline*
VC Ratio on Not Congested Roads	*0.67 under Tolls*	*0.67 under Baseline*
VC Ratio on Local Roads	*0.68 under Tolls*	*0.67 under Baseline*
Effect on Average Speeds Compared to Baseline of No Tolls (Year 2020)		
Increase in Speed on Most Congested Principal Roads	5.65 mph	11.18 Percent
Increase in Speed on Moderately Congested Principal Roads	1.67 mph	2.79 Percent
Reduction in Speed on Other Congested Roads	*0.91 mph*	*2.58 Percent*
Reduction in Speed on Not Congested Roads	*0.02 mph*	*0.04 Percent*
Reduction in Speed on Local Roads	*0.03 mph*	*0.07 Percent*

NOTE: Most Congested Principal Roads include interstate highways and freeways with initial VC ratio greater than 0.95. Moderately Congested Principal Roads include interstate highways and freeways with initial VC ratio smaller than or equal to 0.95 but larger than 0.7. Other Congested Roads include principal arterials, minor arterials, and collectors with initial VC ratio greater than 0.7. Not Congested Roads include interstate, freeways, principal arterials, minor arterials, and collectors with initial VC ratio smaller 0.71.

An analysis of model results in Table 6-2 leads to the following observations and conclusions:

- **Effect on total volume of travel.** Introduction of tolls would lead to an overall reduction in the annual volume of travel on most congested interstate and freeways (as expressed in vehicle-miles traveled each year) compared to the baseline of no tolls of almost 13 percent. On less congested interstate and freeways, the reduction in the volume of travel would be somewhat smaller at about 8 percent. Overall, the impact on total volume of traffic would be quite small at less than 2 percent of total volume of travel on all roads.

- **Effect on volume of travel on lower order and local roads.** On lower order roads, including principal arterials, minor arterials, collector, local roads and off-peak times of the day, there would be a slight increase in the volume of traffic. More specifically, there would be an increase in the volume of traffic of 4.33 percent on congested principal arterials, minor arterials, collector, and an increase of 0.3 on not congested roads and 0.56 percent on local city.

As indicated earlier, the increase in the volume of travel on local roads and other un-tolled roads is driven by the positive cross-elasticity of demand between various road categories and shifts in travel demand between them. The cross-elasticities larger than zero imply that when the cost of driving on road *i* increase, the volume for travel on road *j* increases by some percentage. Intuitively, this effect is due to people switching their travel behavior when the relative prices of using different roads change. For example, when tolls are introduced, some people will switch to lower hierarchy roads with no tolls, or to other times of day when no tolls are charged.

This study suggests that on average the effect of switching the travel pattern to lower order un-tolled road facilities and local roads is likely to be small. However, some studies using data on actual travel behavior and choice of routes in congested urban areas find that the effect on un-tolled roads may be quite substantial leading to an overall larger network congestion than before tolls.[13]

- **Impact on congestion and average speed.** The impact on congestion as described by the percentage reduction or increase in the VC ratio is the same as the impact on the volume of traffic and thus is not reported in Table 6-2. The tables report, however, the VC ratios by road category after tolls and under baseline that assumes no tolls.

Specifically, the tables demonstrate that under the baseline, the VC ratio on most congested principal roads would equal to about 1.21 by year 2020. This VC ratio falls to 1.08 under the toll scenario. For moderately congested principal roads, the VC ratio under baseline would equal to 0.91 by year 2020, and after tolls, the VC ratio on these roads would fall to 0.83.

This represents a significant reduction in the VC ratio that translates into a substantial improvement in average speeds. The average speed on most congested principal roads would improve on average by almost 6 miles per hour. The average speed on moderately congested roads would improve on average by almost 2 miles per hour.

The differential effects on improvement in speeds on various road categories are due to the properties of the speed-flow relationship. This relationship predicts that the improvement in average speed depends on the magnitude of reduction in congestion (i.e. reduction in the VC ratio) but also on the baseline VC ratio. As illustrated in the Table 4-3, under high VC ratios, particularly under VC ratios in excess of 1, even a relatively small reduction in congestion leads to a substantial improvement in speeds. For example, Table 4-3 shows that when the VC ratio decreases from 1.1 to 1.0 on interstate roads, the average speed increases by 3.3 m/h. On the other hand, when the VC ratio decreases on the same facilities from 0.8 to 0.7, the average speed increases only by 1.5 m/h.

- **Impact on congestion and average speed on lower order or un-tolled roads.** As pointed out earlier, the volume of traffic on lower order congested roads, uncongested roads and local roads will increase. This will then lead to an increase in congestion and

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[13] See Anderson, David and Herb Mohring (1996), "Congestion Cost and Congestion Pricing for the Twin Cities", August 1996, report for Minnesota Department of Transportation.

reduction in average speeds. On congested principal arterials, minor arterials, and collectors the average VC ratio under the baseline scenario is expected to rise to about 1.03 by year 2020. Under tolls, the average VC ratio on these roads is expected to go up to 1.07 by year 2020. This will then lead to a reduction in average speed of about 1 mile per hour (or about 3 percent). The impact on not congested roads and local roads is very minimal: the VC ratio is expected to increase by 0.01 or less and the reduction in speed will amount to less than 0.5 miles per hour.

6.3 Effect of Road Pricing on Revenues Available for Highway Investment

The table below reports the estimated yield from toll revenues and compares them to the estimated 20-year average annual investment requirements to improve the highway system -- $112 billion, as reported in the 2002 Conditions and Performance Report. Tolling the interstates and freeways is estimated to generate $83.8 billion in average annual revenues. Assuming that these revenues would be available for highway finance, the gap between investment requirements and fuel tax revenues would thus be completely covered and leave some surplus. Moreover, since the introduction of pricing could diminish investment requirements to some extent (as discussed earlier), the surplus could even be higher.

Table 6-3: Impact of Tolls on Revenue and Funding Requirements (in billions of 2002 dollars)

For the period 2002-2020	Billions of 2002 Dollars	Percent Of Total Cost To Improve
Average Annual Cost to Improve Roads	$112.0*	-
Motor Fuel Taxes	$57.4*	51.2
Average Annual Toll Revenue	$83.8	74.8
Remaining Funding Gap After Toll Revenue	zero	zero
Surplus Available	$21.2	18.9

* Source: 2002 Conditions and Performance Report, revalued to 2002 dollars

Although the nation's highway finance gap could be materially diminished with road pricing, three caveats to the results reported above are in order. First, a policy of tolling all congested interstates and freeways would represent a radical departure from the modest rate at which tolling is being introduced at present. Second, pressure to reduce fuel taxes might be expected if widespread tolling were to be put in place. And third, it is unlikely that all revenues from tolls would be available for highway investment. Policy considerations already give rise to the allocation of some proportion of such revenues to transit investment, environmental mitigation, and to various means of alleviating problems for low-income travelers and others for whom tolls would represent a serious financial burden.

6.4 Effect of Road Pricing on Social Benefits and Costs

This section reports results on the effect of road pricing on social benefits and costs. The benefits and costs taken into account include the following:

- Benefits[14]:
    - Toll revenue;
    - Accident costs savings to all users;
    - Total savings in travel time to road users;
- Costs:
    - Reduction in consumer surplus to road users, and
    - Costs of toll collection.

Table 6-4: Account of Annual Social Costs and Benefits of Road Pricing, (Billions of 2002$)

SOCIAL BENEFITS AND COSTS OF TOLLS	2002	2020
Benefits		
Toll Revenue	$61.9	$108.3
Accident Costs Savings	$8.9	$14.9
Time Savings	$9.8	$19.5
Total Benefits	$80.6	$142.8
Costs		
Reduction in Consumer Surplus	$60.0	$102.3
Costs of Toll Collection (20% of Toll Revenue)	$12.4	$21.7
Total Costs	$72.3	$124.0
Net Benefit	**$8.3**	**$18.8**

Table 6-4 shows that road pricing is likely to generate overall positive net benefits. In other words, socio-economic benefits of road pricing including toll revenue generation, accident cost savings, and travel time savings to all road users are very likely to exceed total costs of road pricing that include costs of toll collection as well as reduction in consumer surplus. Overall, the net benefit is estimated at $8.3 billion in year 2002 and $18.8 billion in year 2020. It should be noted, however, that the key to this result is the management of costs of toll collection. Recent experience indicates that an assumption of the costs of toll collection in the amount of 20 percent of total toll revenue is reasonable under currently available technologies. However, an increase in costs to about 32 – 35 percent would make net benefit equal to zero.

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[14] Emission cost savings are not included in the list of benefits considered in this section as a charge for emission costs is already included in the toll.

7: SENSITIVITY ANALYSIS

The assumptions with respect to key model parameters represent the weight of empirical evidence or approach used in similar studies. In particular, the assumption with respect to elasticity of travel demand of -0.40 reflects the range of values of elasticity of car travel demand most commonly reported in published academic studies. Also, the value of time beneath \$20/hour is consistent with assumptions in similar types of models, for example, assumptions used in the FHWA HERS model.

Alternative assumptions with respect to elasticity of car travel demand and value of time shown in Table 7-1 reflect emerging empirical and theoretical evidence suggestive of significantly higher values for both demand elasticity and value of time. Elasticities at least double those conventionally assumed stem from recent observations of toll road experience internationally,[15] and from the theoretical expectation that travelers would become more price sensitive in the face of significantly higher money cost (relative to time cost) of travel. Values of time at least double of those conventionally assumed are consistent with emerging evidence on the value of reliability and predictability during highly congested periods.[16]

Table 7-1: Baseline and Alternative Assumptions for Demand Elasticity and Value of Time

FACTOR	BASELINE ASSUMPTIONS	ALTERNATIVE ASSUMPTIONS
Elasticity of Traffic Volume with Respect to User Cost	-0.40	-0.80
Value of Time (Dollars per Hour, in constant 2002 dollars)	\$18.60	\$37.20

This section reports thus the model results under the alternative set of assumptions listed in Table 7-1 to assess the magnitude of changes and possible higher range of effects discussed in Section 6.

Appendix D reports results for two additional scenarios: one in which only the elasticity of demand is increased in absolute value from 0.4 to 0.8 (and other parameters stay the same as in baseline), and another in which the value of time is increased to \$37.2 (and other parameters remain the same as in the baseline).

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[15] Anna Matas and Jose-Luis Raymond, *Demand Elasticity on Tolled Motorways,* Journal of Transportation and Statistics, Volume 6, 2003, Universitat de Barcelona

[16] A contingent valuation study conducted for the National Cooperative Highway Research Program found that the value of time during periods of heavy congestion is in the order to 2.5 times greater than the average value of time. This is due to the high premium travellers place on reliability and predictability of journey times, both of which are significantly eroded by severe congestion. (See, National Cooperative Highway Research Program, *The Value of Reliability in Congested Conditions*, HLB Decision Economics Inc. and University of California at Irvine, Report 431, September, 2001.

7.1 Toll Schedule Under Alternative Parameters

Table 7-2 shows the toll schedule that results from the alternative parameter assumptions and compares this schedule with the baseline toll schedule and benchmark tolls.

Table 7-2: Toll Schedule Under the Baseline and Alternative Parameter Assumptions and Compared to Benchmark Tolls

INITIAL CONGESTION LEVEL (Measured by Volume to Capacity Ratio)	TOLLS BASED ON CURRENT PRACTICE	EQUILIBRIUM TOLLS BASED ON SOCIAL MARGINAL COSTS			
		YEAR 2002		YEAR 2020	
		Baseline Elasticity and Value of Time Assumptions	Alternative Elasticity and Value of Time Assumptions	Baseline Elasticity and Value of Time Assumptions	Alternative Elasticity and Value of Time Assumptions
INTERSTATE HIGHWAYS					
0.71 and 0.79	$0.06	$0.10	$0.13	$0.12	$0.16
0.8 and 0.95	$0.12	$0.13	$0.17	$0.16	$0.22
Greater than 0.95	$0.21	$0.19	$0.26	$0.25	$0.34
FREEWAS					
0.71 and 0.79	$0.06	$0.10	$0.13	$0.12	$0.16
0.8 and 0.95	$0.12	$0.13	$0.17	$0.16	$0.22
Greater than 0.95	$0.21	$0.21	$0.29	$0.28	$0.38

Notes. (1) Tolls based on social marginal costs include $0.027 to cover emission costs and $0.033 to cover highway O&M costs. The remainder represents the congestion cost. (2) Tolls based on social marginal costs are growing over time because of the increase in the general congestion level that leads to an increase in the congestion cost component.

The results reported in Table 7-2 indicate that, under baseline assumptions, estimated optimal tolls are similar in magnitude to tolls charged today, although they rise over time as congestion mounts. Under alternative elasticity and value of time assumptions, the results indicate that tolls levied today lie significantly beneath optimal congestion tolls.

7.2 Effect of Road Pricing on Investment Requirements and the Economic Performance of Highways under Alternative Parameter Assumptions

Table 7-3 shows the estimated deadweight loss or loss in economic values from interstate and freeways in the absence of tolls under the alternative assumptions as to the value of time and price elasticity of car travel demand and relates them to projected investment requirements to maintain conditions and performance of urban interstate and highways. To facilitate the assessment of the impact arising from the alternative assumptions, the baseline effects as reported in Section 6 are also shown.

Table 7-3: Annual Loss in Economic Value from Interstate and Freeway Investments Due to Absence of Congestion Tolls

YEAR	IN BILLIONS OF 2002 DOLLARS		AS A PERCENT OF PROJECTED AVERAGE ANNUAL REQUIREMENTS TO MAINTAIN CONDITIONS AND PERFORMANCE ON URBAN INTERSTATES AND HIGHWAYS	
	Baseline Elasticity and Value of Time Assumptions	Alternative Elasticity and Value of Time Assumptions	Baseline Elasticity and Value of Time Assumptions	Alternative Elasticity and Value of Time Assumptions
2002	$4.08	$11.20	15.5%	42.4%
2020	$9.61	$26.18	36.4%	99.2%

Table 7-3 indicates that, under baseline assumptions, the estimated loss in economic value from highway investment due to current highway pricing policies rises over time, from $4.08 billion today (based on 2002 estimates), increasing to $9.61 billion by 2020 (in constant 2002 dollars). Estimated losses in the economic value of highways are materially greater under alternative estimates regarding the elasticity of demand and the value of time. Under these estimates, the loss in economic value from highway investment starts at $11.2 billion today and rises to $26.18 billion by 2020 (in constant 2002 dollars). The loss represents over 40 percent of federal highway expenditures projected by the Department to be needed now to maintain the condition and performance of interstates and freeways; year-2020 losses in economic value represent almost 100 percent of estimated average annual expenditure requirements. Probabilistic risk analysis indicates that this scenario occasions less likelihood than the baseline estimates. This is because the baseline assumptions represent a closer fit to historical evidence regarding elasticities of demand and the value of time. Even so, as discussed earlier, new evidence pointing to the prospective legitimacy of the alternative case, indicates that the risk of higher losses is material.

7.3 Effects of Road Pricing on Traffic Conditions under Alternative Parameter Assumptions

Table 7-4 below presents the effects of road pricing on traffic conditions under the alternative parameter assumptions.

Table 7-4: Effects of Tolls on Traffic Conditions under Alternative Assumptions

Impact of Tolls on Traffic Conditions in Terms of	**Estimated Impact**	
Effect on Volume of Travel Compared to Baseline of No Tolls (Year 2020)		
Total Reduction in VMT	2.67 Percent	
Reduction in VMT on Most Congested Principal Roads	19.03 Percent	
Reduction in VMT on Moderately Congested Principal Roads	13.22 Percent	
Increase in VMT on Other Congested Roads	*6.83 Percent*	
Increase in VMT on Not Congested Roads	*0.48 Percent*	
Increase in VMT on Local Roads	*0.89 Percent*	
Effect on Congestion level (V/C Ratio) (Year 2020)		
VC Ratio on Most Congested Principal Roads	0.98 after tolls	1.21 under Baseline
VC Ratio on Moderately Congested Principal Roads	0.79 after tolls	0.91 under Baseline
VC Ratio on Other Congested Roads	*1.10 after tolls*	*1.03 under Baseline*
VC Ratio on Not Congested Roads	*0.68 after tolls*	*0.67 under Baseline*
VC Ratio on Local Roads	*0.68 after tolls*	*0.67 under Baseline*
Effect on Average Speeds Compared to Baseline of No Tolls (Year 2020)		
Increase in Speed on Most Congested Principal Roads	8.11 mph	16.04 Percent
Increase in Speed on Moderately Congested Principal Roads	2.61 mph	4.36 Percent
Reduction in Speed on Other Congested Roads	*1.46 mph*	*4.13 Percent*
Reduction in Speed on Not Congested Roads	*0.03 mph*	*0.06 Percent*
Reduction in Speed on Local Roads	*0.04 mph*	*0.12 Percent*

NOTE: Most Congested Principal Roads include interstate highways and freeways with initial VC ratio greater than 0.95. Moderately Congested Principal Roads include interstate highways and freeways with initial VC ratio smaller than or equal to 0.95 but larger than 0.7. Other Congested Roads include principal arterials, minor arterials, and collectors with initial VC ratio greater than 0.7. Not Congested Roads include interstate, freeways, principal arterials, minor arterials, and collectors with initial VC ratio smaller 0.71.

Table 7-4 demonstrates larger in magnitude impacts of tolls based on alternative assumptions compared to baseline assumptions. Larger reductions in traffic volume on congested interstate and freeways translate then into larger reduction in congestion (VC ratios) and better improvements in speed. More specifically, the volume of traffic on most congested principal roads would decline by more than 19 percent which translate into a reduction in VC ratio from 1.21 to 0.98 and an improvement in average speed of over 8 mph. For moderately congested principal roads, the reduction in the traffic volume would amount to over 13 percent. This would lead to a reduction in VC ratio from 0.91 to 0.79 and an improvement in average speed of almost 3 m/h.

Under the alternative parameter scenario, the increase in the volume of traffic on lower order congested roads is estimated at almost 7 percent. This in turn is estimated to lead to an increase in the VC ratio by year 2020 from 1.03 to 1.10 and a reduction in average speeds of about 2 mph.

The impact on uncongested and local roads is somewhat larger under the alternative parameters but still quite low in absolute terms: an increase in the volume of traffic of less than 1 percent and a reduction in the average speed of less than 0.5 mph.

7.4 Effect of Road Pricing on Revenues Available for Highway Investment under Alternative Parameter Assumptions

Table 7-5 shows the estimated toll revenues under the alternative parameter assumptions and compares them with average annual investment requirements to improve the US road network to assess the extent of funding gap after accounting for availability of motor fuel taxes.

The table shows that under the alternative parameter assumptions, the toll revenues are higher than under the baseline. This is because of higher estimated congestion tolls which outweigh the effect of a lower traffic volume. Since the toll revenues under the baseline scenario were already sufficient to eliminate the funding gap, it follows that under the alternative assumptions with respect to elasticity of demand and value of time, the funding surplus would be even higher than under the baseline.

Table 7-5: Impact of Tolls on Revenues and Funding Requirements

For the period 2002-2020	Billions of 2002 Dollars	Percent Of Total Cost To Improve
Average Annual Cost to Improve Roads	$112.0*	-
Motor Fuel Taxes	$57.4*	51.2
Average Annual Toll Revenue	$105.0	93.8
Remaining Funding Gap After Toll Revenue	Zero	Zero
Surplus Available	$50.4	45.0

APPENDIX A: LIST OF MODEL ASSUMPTIONS

Table A-1: List of Input Assumptions

INPUT ASSUMPTION	VALUE	UNIT	SOURCE	COMMENTS
FIRST YEAR BASELINE TOTAL URBAN VMT				
Interstate	408618	VMT/yr (Millions	2002 Highway Statistics	
Other freeways and expressways	189634	VMT/yr (Millions	2002 Highway Statistics	
Other principal arterial	408336	VMT/yr (Millions	2002 Highway Statistics	
Minor arterial and collector	481261	VMT/yr (Millions	2002 Highway Statistics	
Local traffic	239747	VMT/yr (Millions	2002 Highway Statistics, FHWA	
TRAFFIC VOLUME BY ROAD CATEGORY AND CONGESTION				
Interstate, VC ratio 0.71 to 0.79	27.3%	% of total on road category	FHWA	
Interstate, VC ratio 0.8 to 0.95	10.9%	% of total on road category	FHWA	
Interstate, VC ratio>0.95	23.0%	% of total on road category	FHWA	
Freeways, VC ratio 0.71 to 0.79	38.8%	% of total on road category	FHWA	
Freeways, VC ratio 0.8 to 0.95	36.1%	% of total on road category	FHWA	
Freeways, VC > 0.95	8.8%	% of total on road category	FHWA	
Principal, VC ratio 0.71 to 0.79	21.0%	% of total on road category	FHWA	
Principal, VC ratio 0.8 to 0.95	34.1%	% of total on road category	FHWA	
Principal, VC ratio > 0.95	71.8%	% of total on road category	FHWA	
Minor, VC ratio 0.71 to 0.79	8.4%	% of total on road category	FHWA	
Minor, VC ratio 0.8 to 0.95	10.7%	% of total on road category	FHWA	
Minor, VC ratio > 0.95	9.2%	% of total on road category	FHWA	
Local, VC<0.71	100%	% of total on road category	HLB	
Uncongested, all roads with VC<0.71	Traffic volumes under VC<0.71		HLB	Calculated as a “remainder” or the sum of traffic volumes on all road categories (except local) with congestion smaller than 0.71
Transit	0.1%	% of total urban road traffic	HLB based on 2002 Conditions and Performance Report	

Table A–1 (continued)

INPUT ASSUMPTION	VALUE	UNIT	SOURCE	COMMENTS
BENCHMARK TOLLS ON ROADS AT VARIOUS CONGESTION LEVELS				
Interstate, VC ratio 0.71 to 0.79	0.06	$/mile	HLB based on average tolls charged across the US and sized to be higher on principal roads and facilities with a higher congestion level.	
Interstate, VC ratio 0.8 to 0.95	0.12	$/mile		
Interstate, VC ratio>0.95	0.21	$/mile		
Freeways, VC ratio 0.71 to 0.79	0.06	$/mile		
Freeways, VC ratio 0.8 to 0.95	0.12	$/mile		
Freeways, VC > 0.95	0.21	$/mile		
FREE FLOW SPEEDS				
Interstate	66.8	m/ph	HLB Based on NCHRP Report 387	
Other freeways and expressways	66.8	m/ph		
Other principal arterial	44.4	m/ph		
Minor arterial and Collector	44.4	m/ph		
Local traffic	39.7	m/ph		
Not Congested	57.8	m/ph		
FIRST YEAR AVERAGE VC RATIO ON CONGESTED ROADS				
Interstate, VC ratio 0.71 to 0.79	0.60	V/C	FHWA	
Interstate, VC ratio 0.8 to 0.95	0.75	V/C		
Interstate, VC ratio>0.95	0.87	V/C		
Freeways, VC ratio 0.71 to 0.79	1.05	V/C		
Freeways, VC ratio 0.8 to 0.95	0.60	V/C		
Freeways, VC > 0.95	0.75	V/C		
Principal, VC ratio 0.71 to 0.79	0.87	V/C		
Principal, VC ratio 0.8 to 0.95	1.10	V/C		
Principal, VC ratio > 0.95	0.60	V/C		
Minor, VC ratio 0.71 to 0.79	0.75	V/C		
Minor, VC ratio 0.8 to 0.95	0.86	V/C		
Minor, VC ratio > 0.95	1.11	V/C		
Local	0.60	V/C		
Uncongested Roads	0.60	V/C		
Transit	0.60	V/C		

Table A–1 (continued)

INPUT ASSUMPTION	VALUE	UNIT	SOURCE	COMMENTS
OTHER GENERAL ASSUMPTIONS				
VMT growth 2002 to 2020, Interstate	8,816	VMT/yr (Millions)	HLB. Calculated based on average growth rate in VMT over the period 1997 to 2002. The resulting growth rate, 2.16%, was then applied to 2002 VMT to calculate VMT increase over the period to 2020.	
VMT growth 2002 to 2020, Other freeways and expressways	4,091	VMT/yr (Millions)		
VMT growth 2002 to 2020, Other principal arterial	8810	VMT/yr (Millions)		
VMT growth 2002 to 2020, Minor arterial and collector	10,384	VMT/yr (Millions)		
VMT growth 2002 to 2020, Local traffic	5,173	VMT/yr (Millions)		
User price/ cash cost of driving	$0.37	$/mile	HLB based on AAA annual analysis of costs of driving	Includes cost of gas, oil, maintenance, and 40 % of average depreciation. Constant over time. Does not include time cost of driving. (Time cost of driving calculated from speed flow relationship by road type)
Speed Flow Coefficient	0.15		BPR Curve	Congested Speed = (Free-Flow Speed)/(1+0.15[volume/capacity]^4)
Transit share of VMT	0.1	%	HLB based on 2002 Conditions and Performance Report, Chapter 2	
Road capacity growth rate: 2002 to 2020	65	% of VMT growth	HLB based on Texas Transportation Institute and 2002 Conditions and Performance Report	
Average value of time	$18.60	$/hour	HERS Technical Report, 2000, Section 7.	
Emission cost: autos	0.007	$/mile	HLB, StratBENCOST model	
Emission cost: trucks	0.072	$/mile	HLB, StratBENCOST model	
Emission cost: weighted average	0.0265	$/mile	HLB	
Average accident cost	$0.3673	$/mile	HLB, StratBENCOST model	

Table A–1 (continued)

INPUT ASSUMPTION	VALUE	UNIT	SOURCE	COMMENTS
OTHER GENERAL ASSUMPTIONS				
Average Annual Cost to Maintain the National Highways and Bridge System	$75.6	$Billion, annually	2002 Conditions and Performance Report	Cost expressed in year 2000 dollars. In this model, cost estimate is inflated to 2002 dollars.
Average Annual Cost to Improve the National Highways and Bridges System	$106.9	$Billion, annually	2002 Conditions and Performance Report	Cost expressed in year 2000 dollars. In this model, cost estimate is inflated to 2002 dollars.
Costs of revenue collection	20%	Percent of total toll revenue	David Friedman and Joel Waldfogel (1994), "The Administrative and Compliance Costs of Manual Highway Toll Collection: Evidence from Massachusetts and New Jersey, *National Tax Journal*, Vol. 47, no.2 (June 1994), pp.217-28	

Table A-2: Input Assumptions for Interconnectivity Between Road Types (Index of Road Connectivity)*

Road Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**1.00**	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.95	0.50
2	0.00	**1.00**	0.00	0.00	0.00	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.95	0.50
3	0.00	0.00	**1.00**	0.00	0.00	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.95	0.50
4	0.00	0.00	0.00	**1.00**	0.00	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.95	0.50
5	0.00	0.00	0.00	0.00	**1.00**	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.95	0.50
6	0.00	0.00	0.00	0.00	0.00	**1.00**	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.95	0.50
7	0.50	0.50	0.50	0.50	0.50	0.50	**1.00**	0.20	0.20	0.75	0.75	0.75	0.75	0.95	0.50
8	0.50	0.50	0.50	0.50	0.50	0.50	0.20	**1.00**	0.20	0.75	0.75	0.75	0.75	0.95	0.50
9	0.50	0.50	0.50	0.50	0.50	0.50	0.20	0.20	**1.00**	0.75	0.75	0.75	0.75	0.95	0.50
10	0.50	0.50	0.50	0.50	0.50	0.50	0.75	0.75	0.75	**1.00**	0.75	0.75	0.75	0.95	0.50
11	0.50	0.50	0.50	0.50	0.50	0.50	0.75	0.75	0.75	0.75	**1.00**	0.75	0.75	0.95	0.50
12	0.50	0.50	0.50	0.50	0.50	0.50	0.75	0.75	0.75	0.75	0.75	**1.00**	0.75	0.95	0.50
13	0.50	0.50	0.50	0.50	0.50	0.50	0.75	0.75	0.75	0.75	0.75	0.75	**1.00**	0.95	0.50
14	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	**1.00**	0.50
15	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	**1.00**

NOTE: *For coding, refer Table A-6

Table A-3: Input Assumptions for Propensity to Change Routes Between Road Types*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-0.5	0.033	0.033	0.027	0.027	0.027	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
2	0.033	-0.5	0.033	0.027	0.027	0.027	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
3	0.033	0.033	-0.5	0.027	0.027	0.027	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
4	0.033	0.033	0.033	-0.4	0.027	0.027	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
5	0.033	0.033	0.033	0.027	-0.4	0.027	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
6	0.033	0.033	0.033	0.027	0.027	-0.4	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
7	0.033	0.033	0.033	0.027	0.027	0.027	-0.3	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
8	0.033	0.033	0.033	0.027	0.027	0.027	0.02	-0.3	0.02	0.01	0.01	0.01	0.01	0.01	0.01
9	0.033	0.033	0.033	0.027	0.027	0.027	0.02	0.02	-0.3	0.01	0.01	0.01	0.01	0.01	0.01
10	0.033	0.033	0.033	0.027	0.027	0.027	0.02	0.02	0.02	-0.2	0.01	0.01	0.01	0.01	0.01
11	0.033	0.033	0.033	0.027	0.027	0.027	0.02	0.02	0.02	0.01	-0.2	0.01	0.01	0.01	0.01
12	0.033	0.033	0.033	0.027	0.027	0.027	0.02	0.02	0.02	0.01	0.01	-0.2	0.01	0.01	0.01
13	0.033	0.033	0.033	0.027	0.027	0.027	0.02	0.02	0.02	0.01	0.01	0.01	-0.2	0.01	0.01
14	0.033	0.033	0.033	0.027	0.027	0.027	0.02	0.02	0.02	0.01	0.01	0.01	0.01	-0.2	0.01
15	0.033	0.033	0.033	0.027	0.027	0.027	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	-0.2

NOTE: *For coding, refer Table A-6

Table A–4: Matrix of Relative Traffic Volumes for Adjusting Propensities to Switch Routes

Road Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**1**	2.11	3.57	0.38	0.90	1.45	0.77	0.98	0.84	0.44	0.90	0.95	5.39	19.16	0.04
2	0.47	**1.00**	1.69	0.18	0.42	0.69	0.36	0.46	0.40	0.21	0.43	0.45	2.55	9.07	0.02
3	0.28	0.59	**1.00**	0.11	0.25	0.41	0.22	0.27	0.24	0.12	0.25	0.27	1.51	5.37	0.01
4	2.66	5.63	9.51	**1.00**	2.39	3.87	2.04	2.61	2.25	1.18	2.39	2.52	14.36	51.05	0.12
5	1.12	2.36	3.98	0.42	**1.00**	1.62	0.86	1.09	0.94	0.49	1.00	1.06	6.02	21.39	0.05
6	0.69	1.45	2.45	0.26	0.62	**1.00**	0.53	0.67	0.58	0.30	0.62	0.65	3.71	13.18	0.03
7	1.30	2.75	4.65	0.49	1.17	1.89	**1.00**	1.28	1.10	0.58	1.17	1.23	7.02	24.97	0.06
8	1.02	2.16	3.64	0.38	0.91	1.48	0.78	**1.00**	0.86	0.45	0.92	0.97	5.50	19.57	0.05
9	1.18	2.50	4.23	0.44	1.06	1.72	0.91	1.16	**1.00**	0.53	1.06	1.12	6.38	22.70	0.05
10	2.26	4.76	8.05	0.85	2.02	3.28	1.73	2.21	1.90	**1.00**	2.02	2.14	12.16	43.22	0.10
11	1.11	2.35	3.97	0.42	1.00	1.62	0.85	1.09	0.94	0.49	**1.00**	1.05	6.00	21.34	0.05
12	1.06	2.23	3.77	0.40	0.95	1.54	0.81	1.03	0.89	0.47	0.95	**1.00**	5.69	20.24	0.05
13	0.19	0.39	0.66	0.07	0.17	0.27	0.14	0.18	0.16	0.08	0.17	0.18	**1.00**	3.56	0.01
14	0.05	0.11	0.19	0.02	0.05	0.08	0.04	0.05	0.04	0.02	0.05	0.05	0.28	**1.00**	0.00
15	22.51	47.54	80.30	8.45	20.16	32.73	17.27	22.04	19.00	9.98	20.21	21.31	121.30	431.28	**1.00**

NOTE: *For coding, refer Table A-6

Table A-5: Matrix of Travel Demand Elasticities*

Road Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**-0.400**	0.000	0.000	0.000	0.000	0.000	0.008	0.010	0.008	0.003	0.006	0.006	0.036	0.243	0.000
2	0.000	**-0.400**	0.000	0.000	0.000	0.000	0.004	0.005	0.004	0.001	0.003	0.003	0.017	0.115	0.000
3	0.000	0.000	**-0.400**	0.000	0.000	0.000	0.002	0.003	0.002	0.001	0.002	0.002	0.010	0.068	0.000
4	0.000	0.000	0.000	**-0.400**	0.000	0.000	0.020	0.026	0.022	0.008	0.016	0.017	0.096	0.647	0.001
5	0.000	0.000	0.000	0.000	**-0.400**	0.000	0.009	0.011	0.009	0.003	0.007	0.007	0.040	0.271	0.000
6	0.000	0.000	0.000	0.000	0.000	**-0.400**	0.005	0.007	0.006	0.002	0.004	0.004	0.025	0.167	0.000
7	0.017	0.037	0.062	0.007	0.016	0.025	**-0.300**	0.005	0.004	0.006	0.012	0.012	0.070	0.316	0.000
8	0.014	0.029	0.049	0.005	0.012	0.020	0.003	**-0.300**	0.003	0.005	0.009	0.010	0.055	0.248	0.000
9	0.016	0.033	0.056	0.006	0.014	0.023	0.004	0.005	**-0.300**	0.005	0.011	0.011	0.064	0.288	0.000
10	0.030	0.064	0.107	0.011	0.027	0.044	0.026	0.033	0.029	**-0.200**	0.020	0.021	0.122	0.547	0.001
11	0.015	0.031	0.053	0.006	0.013	0.022	0.013	0.016	0.014	0.005	**-0.200**	0.011	0.060	0.270	0.000
12	0.014	0.030	0.050	0.005	0.013	0.020	0.012	0.016	0.013	0.005	0.009	**-0.200**	0.057	0.256	0.000
13	0.002	0.005	0.009	0.001	0.002	0.004	0.002	0.003	0.002	0.001	0.002	0.002	**-0.200**	0.045	0.000
14	0.001	0.003	0.005	0.000	0.001	0.002	0.001	0.001	0.001	0.000	0.001	0.001	0.004	**-0.200**	0.000
15	0.300	0.634	1.071	0.113	0.269	0.436	0.173	0.220	0.190	0.067	0.135	0.142	0.809	2.875	**-0.200**

NOTE: *For coding, refer Table A-6

Table A-6: Coding of Road Types

ROAD TYPE	CODING
Interstate, VC ratio 0.71 to 0.79	1
Interstate, VC ratio 0.8 to 0.95	2
Interstate, VC ratio>0.95	3
Freeways, VC ratio 0.71 to 0.79	4
Freeways, VC ratio 0.8 to 0.95	5
Freeways, VC > 0.95	6
Principal, VC ratio 0.71 to 0.79	7
Principal, VC ratio 0.8 to 0.95	8
Principal, VC ratio > 0.95	9
Minor, VC ratio 0.71 to 0.79	10
Minor, VC ratio 0.8 to 0.95	11
Minor, VC ratio > 0.95	12
Local	13
Not Congested	14
Transit	15

APPENDIX B: MODEL STRUCTURE AND LOGIC

This Appendix presents the structure and logic of the key structural model elements that lead to calculation of travel volume and revenue impacts.

Figure 1: Forecasting of VMT Volumes Over Time

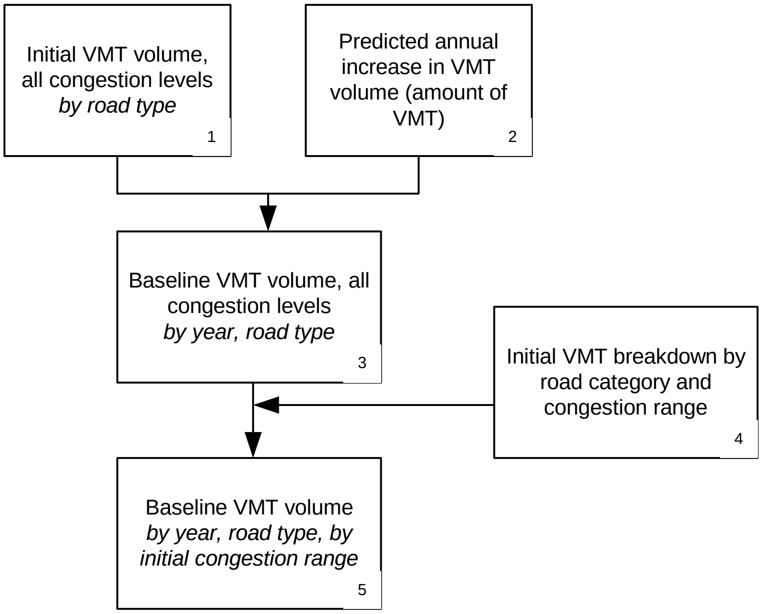


Figure 2: Calculation of implied road capacity

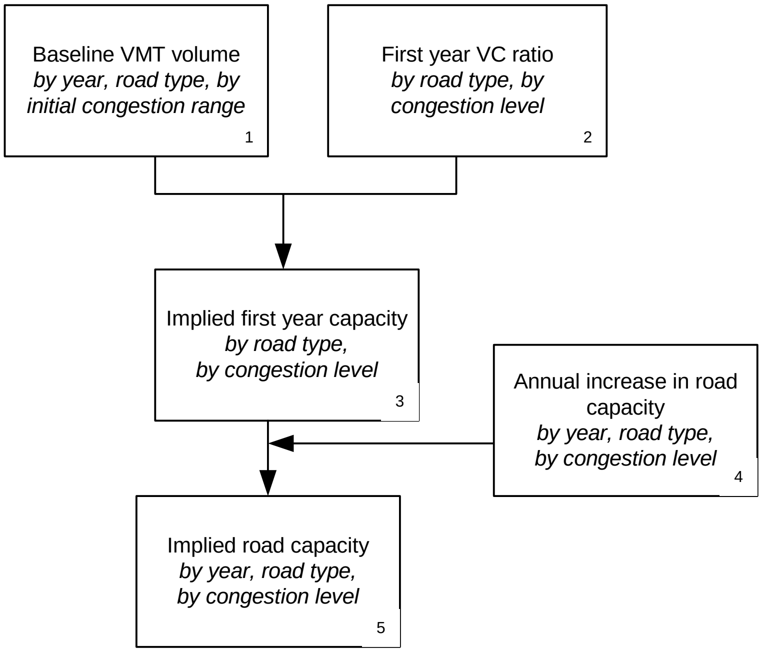


Figure 3: Calculation of Baseline (No Tolls) VC Ratio

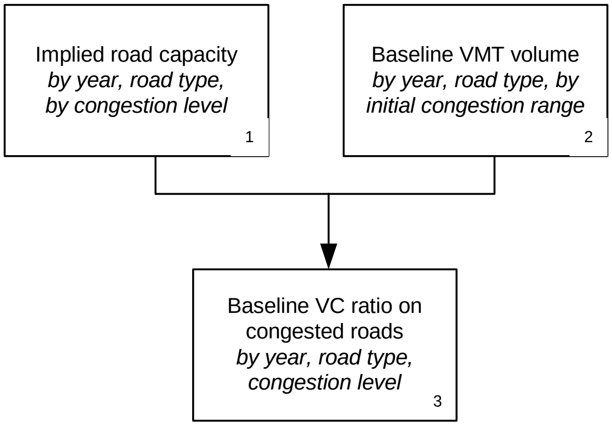
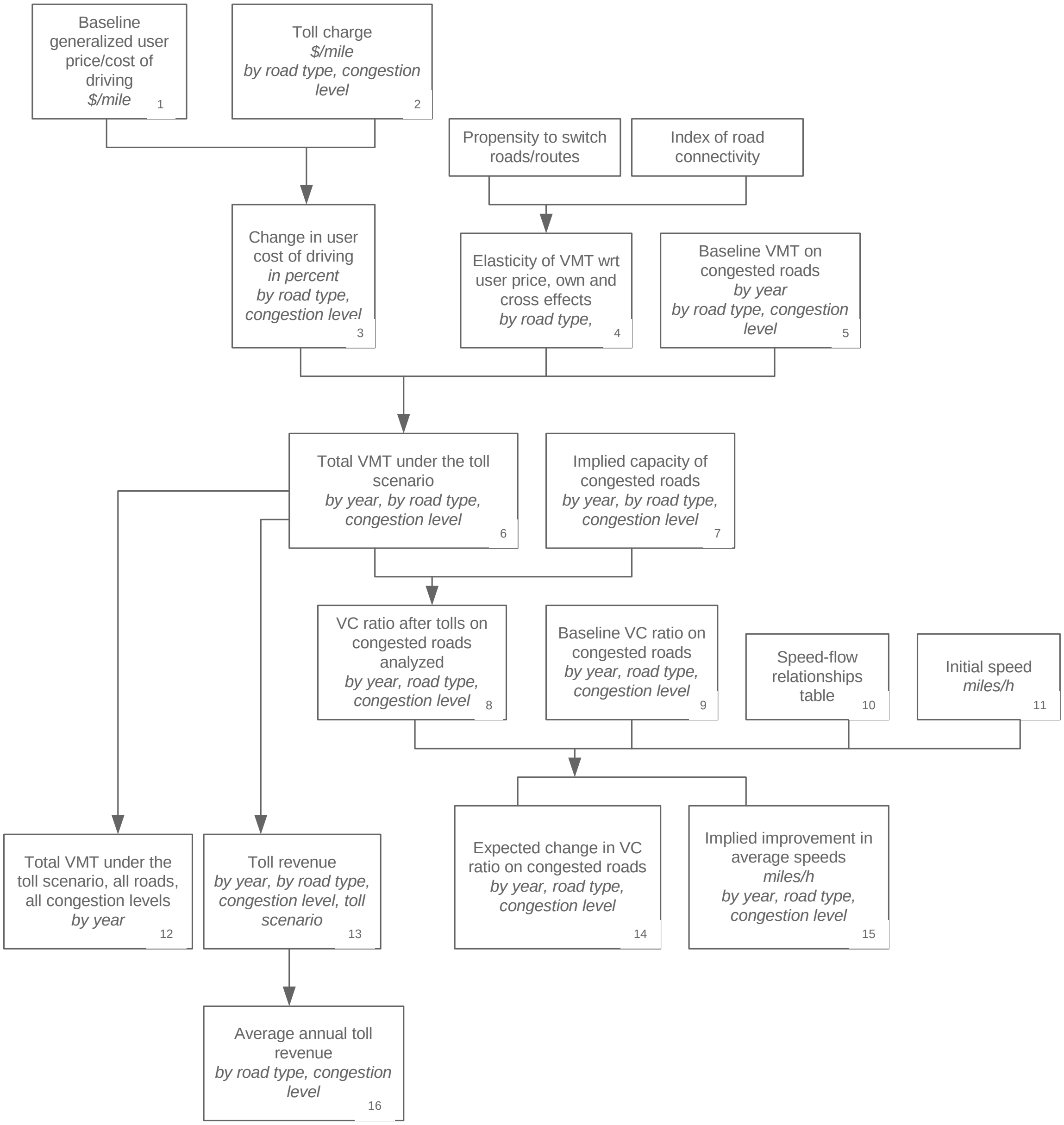


Figure 4: Main Model



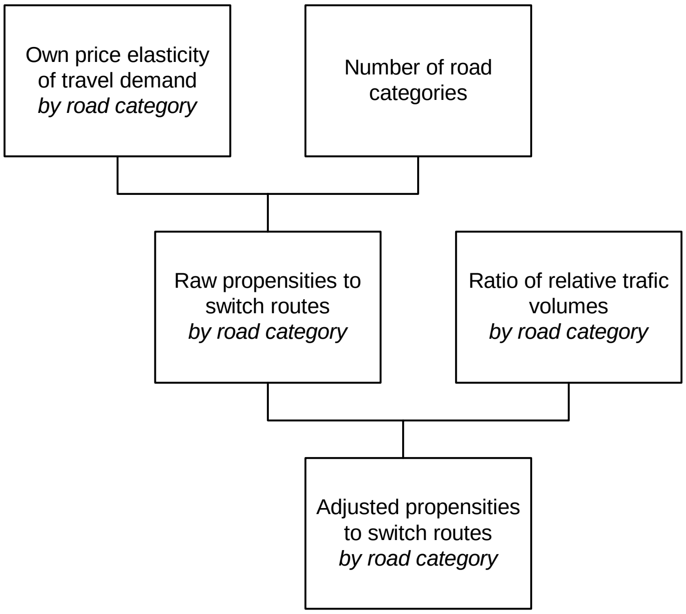


Figure 5: Calculation of Propensities to switch routes

Figure 6: Calculation of time savings

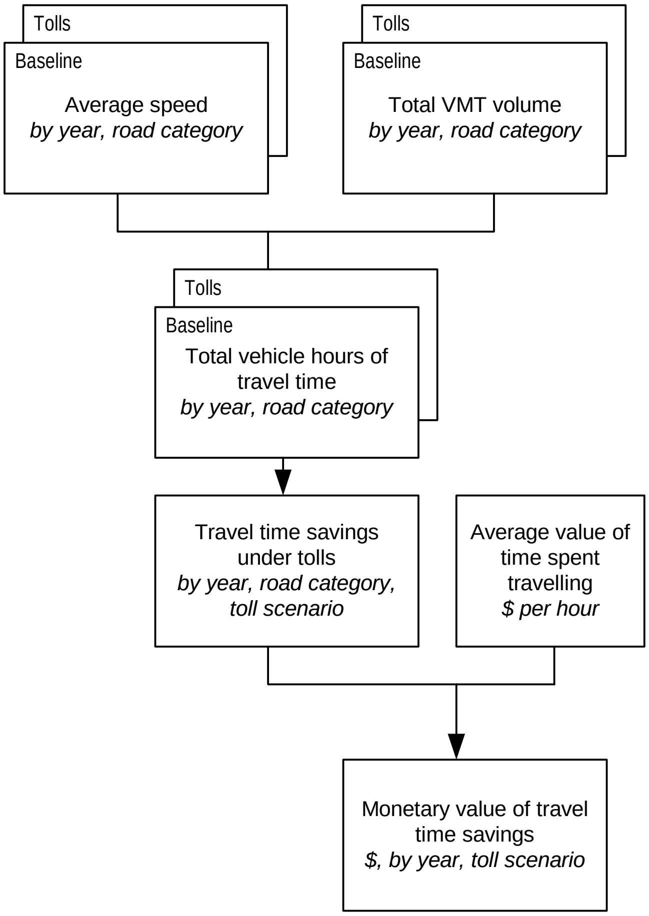
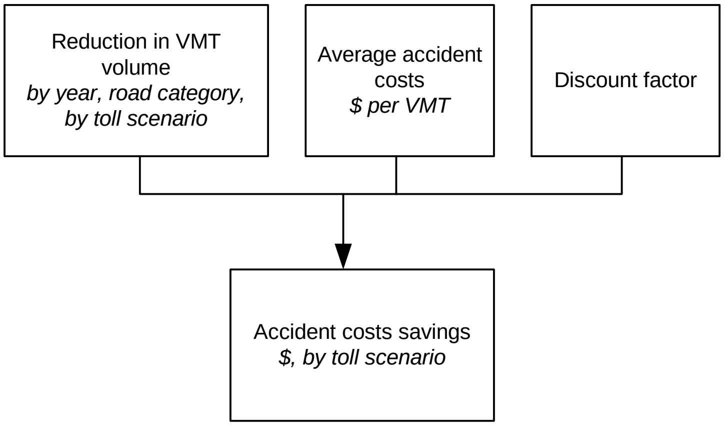


Figure 6: Calculation of accident costs savings



APPENDIX C: DERIVATION OF CONGESTION TOLLS

This Appendix describes an iterative procedure used to simulate or estimate congestion tolls used in the main model of road pricing. This procedure consists of five steps described below and illustrated in Figure C-1.

<u>Step 1:</u> Calculate of the average costs and marginal costs using the cost curves defined earlier and the initial volume of travel, Q0 (point E0 and A in Figure 3-2).

<u>Step 2:</u> Calculate volume of travel that would correspond to market price equal to marginal cost calculated in Step 1. This volume of travel, indicated by Q1 in Figure 3-2, is estimated using the definition of elasticity and the assumed elasticity of demand:

$$Q1 = Q0 + \Delta Q = Q0 + \varepsilon \cdot (MC0 - P0)/P0 \cdot Q0.$$

Where

ΔQ = change in the volume of travel resulting from the change in market price, and
ε = elasticity of travel demand.

<u>Step 3:</u> Calculate the average of Q1 and Q0, or Q2 that lies half the distance between Q0 and Q1 in Figure 3-2.

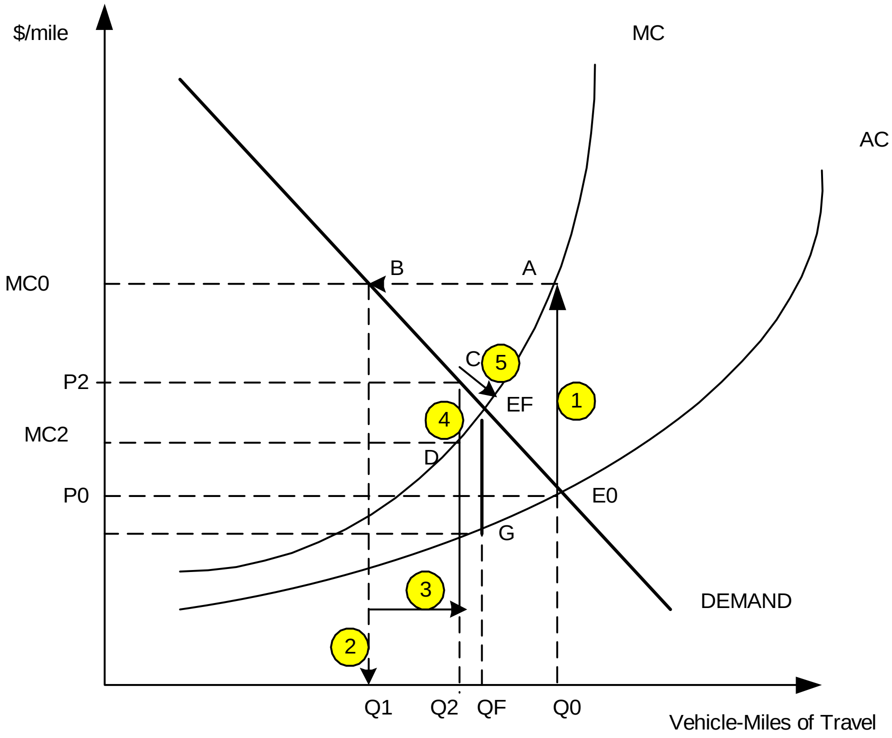
<u>Step 4:</u> Calculate the marginal cost at the travel volume of Q2. Calculate the implied market price at this volume and compare with the marginal cost. The implied market price is calculated again using the definition of elasticity of demand:

$$P2 = P0 + \Delta P = P0 + (Q2 - Q0)/(\varepsilon \cdot Q0) \cdot P0$$

<u>Step 5:</u> Check if the implied market price and the marginal cost at Q2 are equal (P2 = MC2?) If so, equilibrium has been reached. The optimal congestion toll is then equal to the difference between marginal cost and average cost at the volume of travel of Q2.

If the implied market price and marginal cost are not equal, the volume of travel is adjusted or changed slightly and Step 4 and Step 5 are repeated until an equilibrium of marginal cost equal to implied market price at the trial traffic volume is reached.

Figure C-1: Iterative Procedure Used to derive Congestion Tolls



Step 1: calculation of marginal congestion cost at market equilibrium

Step 2: calculation of Q1, volume of travel corresponding to point where price equals marginal cost at market equilibrium volume

Step 3: calculation of Q2, volume of travel equal to average of Q0 and Q1 (or half the distance between Q1 and Q0 in the diagram

Step 4: calculate MC at Q2 and implied market price (resulting from demand curve) at Q2

Step 5 : Check if MC at Q2 is equal to implied market price at Q2. If not, adjust Q and repeat Step 4 and Step 5 until equilibrium has been reached

The congestion toll was estimated using the above procedure separately for various categories of congested road, i.e. interstate highways and freeways under various congestion levels (Section 4 provides detailed breakdown of all road categories considered). The road capacity, CAP, necessary for the calculation of average effective speed was calculated as the implied road capacity from the definition of the volume-to-capacity ratio and the reported average VC ratio, i.e.

$$CAP = Q/VC.$$

The specific adjustment described in Step 5 involved an optimization procedure with a goal seek scenario feature available within Excel.

The congestion tolls volumes of traffic on tolled roads were estimated according to the above procedure for years 2002, 2010 and 2020 for each road category of interstate and freeways broken down by ranges of initial congestion level. The initial volumes of travel and road capacity were assumed to be growing from base year at a certain rate discussed in Section 4.

The tolls for the remaining years were prorated according to an implied rate of growth, and the resulting equilibrium volumes of traffic were estimated as discussed in Section 3.4.

APPENDIX D: DERIVATION OF SELECTED MODEL ASSUMPTIONS: METHODOLOGICAL APPROACH

This Appendix provides detailed derivation of key formulas used in the toll model discussed in the main body of this report.

Estimating the Deadweight Loss of Inefficient Road Pricing

As pointed out in Section 5, the effects of market inefficiencies are often quantified in empirical research using the concept of deadweight loss resulting directly from the inefficiency.

The deadweight loss is equal to the difference between the area under the marginal cost curve and the demand curve between the optimal and the market traffic volume. Using the notation of Figure C-1, the deadweight loss can be derived as follows:

$$DWL = \int_{Q2}^{Q0} MC_2 dQ - \int_{Q2}^{Q0} DEMANDdQ = \int_{Q2}^{Q0} (MC + \alpha)dQ - \int_{Q2}^{Q0} DEMANDdQ =$$

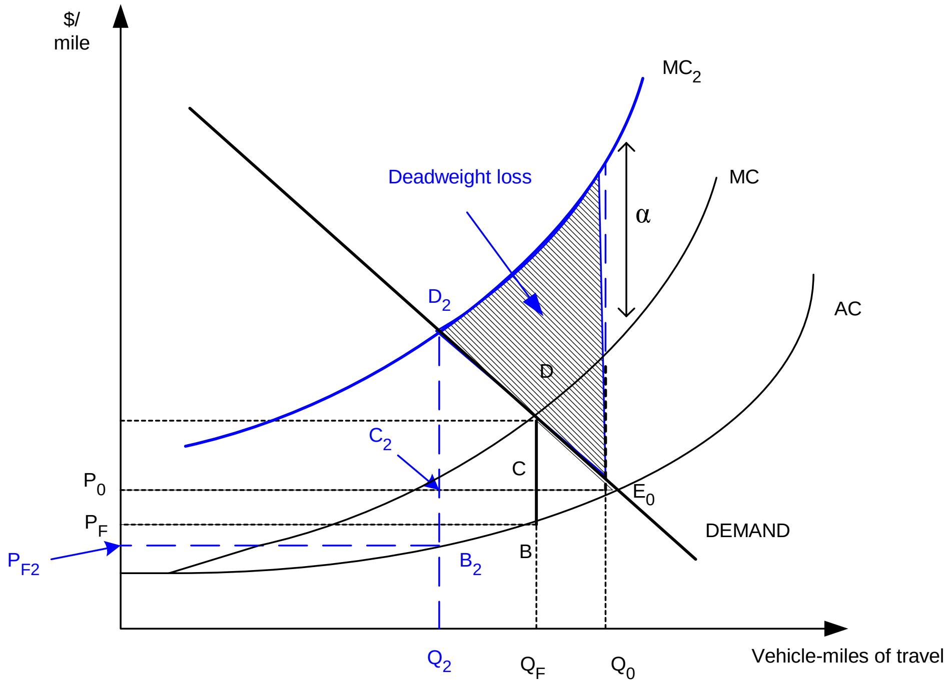
$$DWL = \int_{Q2}^{Q0} MCdQ + \alpha(Q0 - Q2) - \int_{Q2}^{Q0} DEMANDdQ \qquad \text{(C-1)}$$

where α is the per mile charge to cover O&M and emission costs.

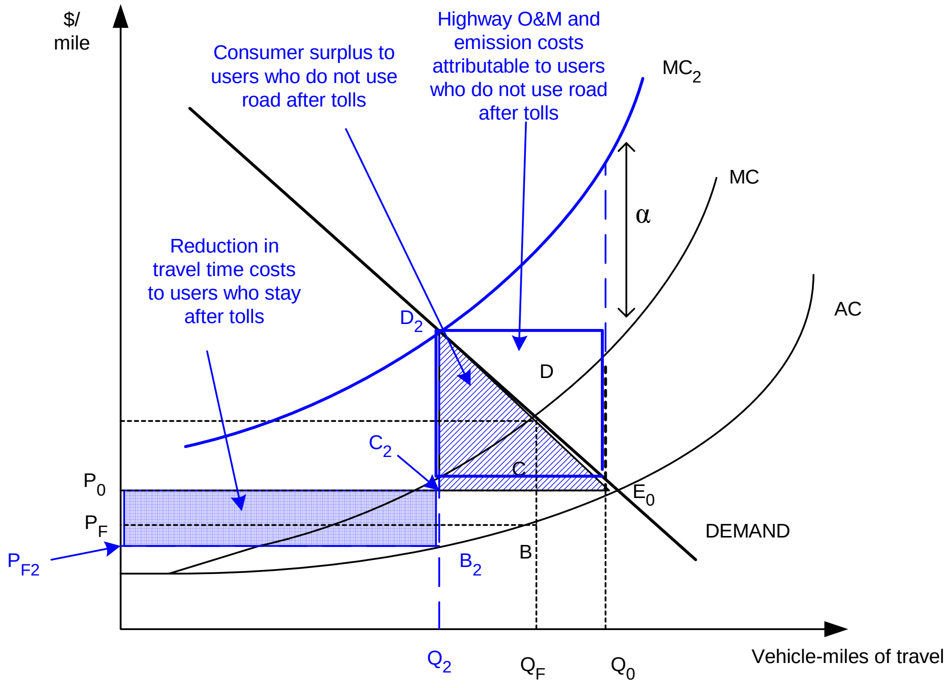
Figure D-1 provides a graphical illustration of the components of deadweight loss.

Figure D-2: Calculating the Magnitude of Deadweight Loss

Panel A



Panel B



Since marginal costs are defined as the differential of total costs with respect to quantity, it follows that the integral of marginal costs is equal to total costs. Therefore, calculation of deadweight loss in Equation C-9 can be continued using the areas shown in Figure C-2 as follows:

$$DWL = (P_0 E_0 Q_0 0 - P_{F2} B_2 Q_2 0) + \alpha(Q_0 - Q_2) - (D_2 C_2 E_0 + C_2 E_0 Q_0 Q_2)\,. \qquad \text{(C-10)}$$

Simplifying equation C-10, we obtain:

$$DWL = P_0 C_2 B_2 P_{F2} + \alpha(Q_0 - Q_2) - D_2 C_2 E_0$$

where

$P_0 C_2 B_2 P_{F2}$ are the travel time savings to road users that remain on the road after tolls are introduced;

$D_2 C_2 E_0$ is the consumer surplus to road users who are using the roads in the absence of tolls but who would not be using the roads after introduction of tolls, and

$\alpha(Q_0 - Q_2)$ is the amount of highway charges (emission costs and highway O&M costs) that would fall on road users who are using the roads in the absence of tolls but who would not be using the roads after introduction of tolls

APPENDIX E: ADDITIONAL RESULTS OF SENSITIVITY ANALYSIS

This Appendix provides additional sensitivity results for two additional scenarios: one in which only the elasticity of demand on interstate and freeways is increased in absolute value from 0.4 to 0.8 (and other parameters stay the same as in baseline), and another in which the value of time is increased to $37.2 (and other parameters remain the same as in the baseline).

SCENARIO 1: Value of time = $37.2

Table E-1: Model Results for Scenario 1

CATEGORY OF EFFECT	IMPACT
Effect on Volume of Travel (Year 2020)	
Total Reduction in VMT (in Percent)	-1.82%
Reduction in VMT on Most Congested Principal Roads (in Percent)	-13.64%
Reduction in VMT on Moderately Congested Principal Roads (in Percent)	-8.29%
Change in VMT on Other Congested Roads (in Percent)	4.66%
Increase in VMT During Off-Peak Times of Day (in Percent)	0.317%
Increase in VMT on Local Roads (in Percent)	0.59%
Effect on Congestion level (V/C Ratio) (Year 2020)	
VC Ratio After Tolls on Most Congested Principal Roads	1.04
VC Ratio After Tolls on Moderately Congested Principal Roads	0.83
VC Ratio After Tolls on Other Congested Roads	1.08
VC Ratio After Tolls During Off-Peak Times of Day	0.67
VC Ratio After Tolls on Local Roads	0.68
Baseline Congestion Level (V/C Ratio) (Year 2020)	
VC Ratio Before Tolls on Most Congested Principal Roads	1.21
VC Ratio Before Tolls on Moderately Congested Principal Roads	0.91
VC Ratio Before Tolls on Other Congested Roads	1.03
VC Ratio Before Tolls During Off-Peak Times of Day	0.67
VC Ratio Before Tolls on Local Roads	0.67
Effect on Average Speeds (Year 2020)	
Increase in Speed on Most Congested Principal Roads (in m/h)	6.09
Increase in Speed on Moderately Congested Principal Roads (in m/h)	1.76
Increase in Speed on Other Congested Roads (in m/h)	**-0.98**
Reduction in Speed During Off-Peak Times of Day (in m/h)	-0.02
Reduction in Speed on Local Roads	-0.03
Percentage Increase in Speed on Most Congested Principal Roads (in m/h)	12.06%
Percentage Change in Speed on Moderately Congested Principal Roads	2.93%
Percentage Increase in Speed on Other Congested Roads	**-2.78%**
Percentage Change in Speed During Off-Peak Times of Day	-0.04%
Percentage Change in Speed on Local Roads	-0.08%

Table E-1 (continued)

CATEGORY OF EFFECT	IMPACT
Effect on Toll Revenue	
Toll Revenue 2002 (in $ Millions)	$98,078
Toll Revenue 2020 (in $ Millions)	$177,593
Average Annual Total Toll Revenue (in $ Millions)	$135,312
Average Annual Toll Revenue from Most Congested Principal Roads (in $ Millions)	$90,618
Social Benefits and Net Benefits (Year 2002)	
Toll Revenue ($ Millions)	$98,078
Accident Costs ($ Millions)	$9,491
Time Savings	$20,776
Total Benefits (Toll Revenue + Accident Costs Savings+ travel time savings))	$128,345
Reduction in Consumer Surplus ($ Millions)	$92,809
Costs of Toll Collection (20% of Toll Revenue) ($ Millions)	$19,616
Total Costs	$112,425
NET BENEFIT ($ Millions)	$15,920
Net Benefits (Year 2020)	
Toll Revenue ($ Millions)	$177,593
Accident Costs ($ Millions)	$16,066
Time Savings	$41,631
Total Benefits (Toll Revenue + Accident Costs Savings+ travel time savings))	$235,289
Reduction in Consumer Surplus ($ Millions)	$162,691
Costs of Toll Collection (20% of Toll Revenue) ($ Millions)	$35,519
Total Costs	$198,209
NET BENEFIT ($ Millions)	$37,080
GAP ANALYSIS, TOLL REVENUE AND INVESTMENT REQUIRES, COSTS TO IMPROVE	
Average Annual Costs to Improve, $Billions (2002 $)	$112.0
Motor Fuel Taxes in $Billions (2002$)	$57.4
Average Annual Toll Revenue, $Billions (2002$)	$135.3
Remaining funding GAP after toll revenue, $ Billions (2002$). If <0, no funding GAP remains	-80.7
Deadweight Loss Calculated from No toll to Optimal Congestion Toll	
2002 (in $ Billions)	$7.56
2020 (in $ Billions)	$18.78

SCENARIO 2: Elasticity of travel demand on interstate and freeways = -0.8

Table E-2: Model Results for Scenario 2

CATEGORY OF EFFECT	IMPACT
Effect on Volume of Travel (Year 2020)	
Total Reduction in VMT (in Percent)	-2.60%
Reduction in VMT on Most Congested Principal Roads (in Percent)	-18.31%
Reduction in VMT on Moderately Congested Principal Roads (in Percent)	-13.16%
Change in VMT on Other Congested Roads (in Percent)	6.64%
Increase in VMT During Off-Peak Times of Day (in Percent)	0.468%
Increase in VMT on Local Roads (in Percent)	0.88%
Effect on Congestion level (V/C Ratio) (Year 2020)	
VC Ratio After Tolls on Most Congested Principal Roads	0.99
VC Ratio After Tolls on Moderately Congested Principal Roads	0.79
VC Ratio After Tolls on Other Congested Roads	1.10
VC Ratio After Tolls During Off-Peak Times of Day	0.68
VC Ratio After Tolls on Local Roads	0.68
Baseline Congestion Level (V/C Ratio) (Year 2020)	
VC Ratio Before Tolls on Most Congested Principal Roads	1.21
VC Ratio Before Tolls on Moderately Congested Principal Roads	0.91
VC Ratio Before Tolls on Other Congested Roads	1.03
VC Ratio Before Tolls During Off-Peak Times of Day	0.67
VC Ratio Before Tolls on Local Roads	0.67
Effect on Average Speeds (Year 2020)	
Increase in Speed on Most Congested Principal Roads (in m/h)	7.85
Increase in Speed on Moderately Congested Principal Roads (in m/h)	2.59
Increase in Speed on Other Congested Roads (in m/h)	-1.42
Reduction in Speed During Off-Peak Times of Day (in m/h)	-0.03
Reduction in Speed on Local Roads	-0.04
Percentage Increase in Speed on Most Congested Principal Roads (in m/h)	15.54%
Percentage Change in Speed on Moderately Congested Principal Roads	4.33%
Percentage Increase in Speed on Other Congested Roads	-4.01%
Percentage Change in Speed During Off-Peak Times of Day	-0.06%
Percentage Change in Speed on Local Roads	-0.11%

Table E-2(continued)

CATEGORY OF EFFECT	IMPACT
Effect on Toll Revenue	
Toll Revenue 2002 (in $ Millions)	$49,946
Toll Revenue 2020 (in $ Millions)	$84,617
Average Annual Total Toll Revenue (in $ Millions)	$66,414
Average Annual Toll Revenue from Most Congested Principal Roads (in $ Millions)	$42,203
Social Benefits and Net Benefits (Year 2002)	
Toll Revenue ($ Millions)	$49,946
Accident Costs ($ Millions)	$14,489
Time Savings	$14,498
Total Benefits (Toll Revenue + Accident Costs Savings+ travel time savings))	$78,933
Reduction in Consumer Surplus ($ Millions)	$47,086
Costs of Toll Collection (20% of Toll Revenue) ($ Millions)	$9,989
Total Costs	$57,076
NET BENEFIT ($ Millions)	$21,858
Net Benefits (Year 2020)	
Toll Revenue ($ Millions)	$84,617
Accident Costs ($ Millions)	$22,885
Time Savings	$26,572
Total Benefits (Toll Revenue + Accident Costs Savings+ travel time savings))	$134,073
Reduction in Consumer Surplus ($ Millions)	$76,010
Costs of Toll Collection (20% of Toll Revenue) ($ Millions)	$16,923
Total Costs	$92,934
NET BENEFIT ($ Millions)	$41,140
GAP ANALYSIS, TOLL REVENUE AND INVESTMENT REQUIRES, COSTS TO IMPROVE	
Average Annual Costs to Improve, $Billions (2002 $)	$112.0
Motor Fuel Taxes in $Billions (2002$)	$57.4
Average Annual Toll Revenue, $Billions (2002$)	$66.4
Remaining funding GAP after toll revenue, $ Billions (2002$). If <0, no funding GAP remains	-11.8
Deadweight Loss Calculated from No toll to Optimal Congestion Toll	
2002 (in $ Billions)	$6.36
2020 (in $ Billions)	$14.08