CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Assessing the Benefits and Costs of ITS Projects: Volume 2 An Application to Electronic Toll Collection

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SECTION 1: A WORKING EXAMPLE FOR THE DECISION ANALYSIS FRAMEWORK: AN APPLICATION TO ELECTRONIC TOLL COLLECTION [ETC][1]

1.1 PROJECT BACKGROUND: CONTEXT

The Carquinez Bridge ETC project is a pilot project of a statewide toll bridge improvement project undertaken by Caltrans. Caltrans owns and operates nine toll bridges statewide. Over the last five years, traffic on all area bridges has increased from 129 million vehicle crossings in Fiscal year (FY) 1992-93 to 140 million in FY 1996-97, with an average annual rate of 2 percent as indicated in Figure 1. However, the toll facilities are antiquated. The bridges use a toll collection system known as Toll Registration, Audit and Collection (TRAC) installed in the early 1980s, and tolls have been collected manually by toll collectors in tollbooths. With the significant growth in traffic volume in the bridges and deterioration of the facilities, Caltrans decided to replace the TRAC system with the ETC system on all bridges. The objectives of introducing ETC are to[2]:

- reduce the overall toll collection cost;
- provide an acceptable level of service for toll patrons;
- increase the quality of data collection and provide information currently not available;
- reduce traffic congestion on toll bridges and reduce air pollution and fuel consumption.

The entire project is scheduled in three major phases. Phase I is research and development including laboratory prototype testing, on-site prototype testing, and pilot implementation at Carquinez Bridge. Phases II and III include installations of the ETC systems at the other eight bridges, with four bridges in each phase (Table 1).

The Carquinez Bridge was selected as the site for ETC pilot implementation because it has sufficient capacity to handle peak traffic demand with a couple of booths out of service for ETC demonstration. Currently, Caltrans is still in the process of testing and installing the ETC system at the bridge. A dedicated lane has been opened to users who have established an ETC account with Caltrans since August 21, 1997. In addition, two lanes are opened for the use of both manual toll collection and ETC. The ETC system at the bridge is to be completed in 1998.

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[1] Section 7 is a summary of the detailed analysis that is contained in the technical appendix.
[2] See California Department of Transportation, New technology and Research Program, *Advanced Transportation Systems Program Plan: 1996 Update*, December 1996

Figure 1

Total Traffic Volume of Nine Bridges (FY 93 - FY 97)

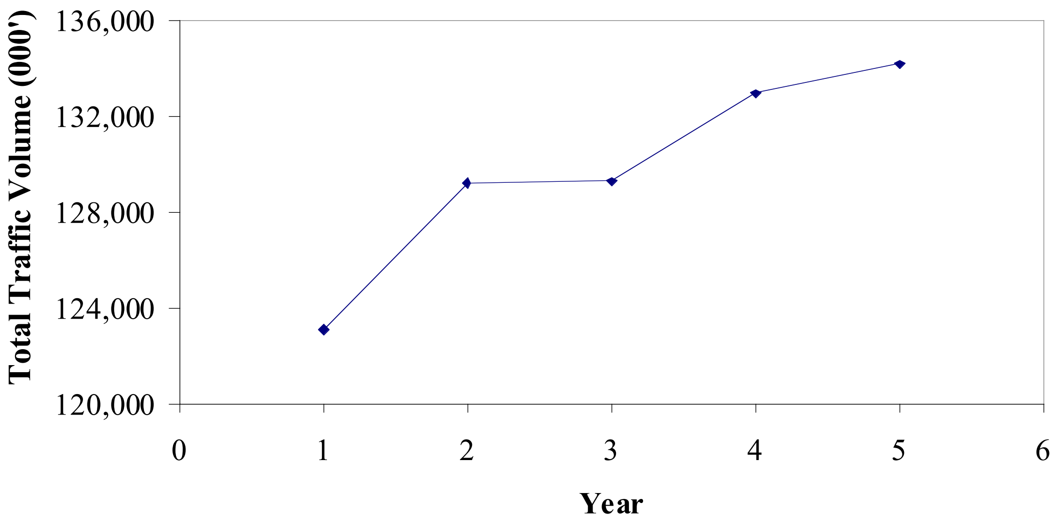

Table 1

ETC Project Schedule (Program, Caltrans 1995)[3]

Number	Milestones	Start Date	End Date
1	Procurement Approval	-	Oct. 26, 1992
2	Notice of Intent to Award	-	Dec. 23, 1993
3	Contract Award	-	Dec. 27, 1993
4	TIRU Approval of FSR	-	Sept. 1995
5	Carquinez Pilot Project	Sept. 1995	Dec. 1995
6	Carquinez Installation	Jan. 1996	April, 1996
7	Antioch Installation	May 1996	Nov. 1996
8	Benicia Installation	May 1996	Nov. 1996
9	Richmond Installation	May 1996	Nov. 1996
10	San Francisco-Oakland Bay Bridge	May 1996	Nov. 1998
11	San Mateo Installation	Dec. 1996	May 1998
12	Vincent Thomas Installation	Dec. 1996	May 1998
13	Dumbarton Installation	Dec. 1996	May 1998
14	Coronado Installation	Dec. 1996	May 1998

In the next section we lay out the temporal and spatial framework for the analysis and discuss

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[3] Source:"ATCAS Advanced Toll Collection and Accounting System: Feasibility Study Report," Traffic Operations

the data and the analytical approach for the study. The lists of benefits and costs, the assumptions, and the calculation steps are shown in the fourth section. Section five presents evaluation results. The final section summarizes our findings and discusses their implications

1.2 RESEARCH DESIGN

With the objectives of the ETC project, it is important to examine the trade-offs facing the toll agency, meaning Caltrans, as well as those of users and society. The baseline for the comparison is the existing manual toll collection system, namely the TRAC system. The time frame covered by this study is between FY 1995/96 to FY 2005/06 since the economic lives of many ETC components are about eight to ten years. The spatial effects of the ETC system are limited to the bridge itself since the nearest bridge -- Benicia Martinez Bridge is about 9 miles away and will be equipped with the ETC system right after the completion of the project at Carquinez Bridge. The installation of ETC system in the bridge may not attract or reduce traffic from Benicia Martinez Bridge.

Basic information for the study includes costs of both existing toll service and ETC project, as well as historical data for traffic, toll transactions, and accidents on the Carquinez Bridge. These data are gathered from the Carquinez Bridge and various divisions of Caltrans. For example, the operating costs of the toll plaza at the Carquinez Bridge and traffic data are obtained from the "Annual Financial Reports on State-Owned Toll Bridges" produced by Caltrans Accounting Service Center. Cash flows of the ETC system are derived from data shown in the "Advanced Toll Collection and Accounting System (ATCAS) Feasibility Study Report" and those provided by Carquinez Bridge. Accident data are extracted from the California State highway accident database.

The following steps were undertaken to complete the study: (1) identify the categories of benefits and costs of the ETC project; (2) establish assumptions to provide bases for estimations; (3) quantifiy the benefits and costs of the toll agency, users, and society separately and estimated their values; (4) analyze the total trade-offs using net present value method; (5) examine the distribution of benefits and costs among the toll agency, users, and society; and finally, conduct a sensitivity analysis to investigate the possible effects of changing assumptions on net benefit and distribution of benefits and costs.

1.3 COSTS AND BENEFITS

We first identify and classify the possible costs and benefits of the baseline or basecase and ETC alternative. Next we present basic assumptions for calculating costs and benefits and briefly describe the procedures for estimating costs and benefits. Detailed descriptions of the procedures can be found in Appendices attached in the end of this report.

1.3.1 Classifications of Costs and Benefits

The cost categories of the baseline and the ETC system are listed in Table 2. The costs of the toll agency are expenditures for service provision. The costs of operating and maintaining (O&M) existing toll facility include payments for labor, materials, system maintenance, and other service charges. The ETC alternative requires capital investments in hardware and software, in addition to regular operating and maintenance costs though the O&M costs of the ETC system may be lower than that of the baseline.

Users' costs of the baseline and ETC alternative are composed of two categories: time and service charges including tolls and interest generated from prepayments. Under the baseline, users are not required to prepay for the service. The only service charge is the toll. However, users are required to stop at the tollbooth for payment. With the ETC alternative, there is a time reduction for users because they do not need to stop at the toll booth this will result in a reduction in the full costs of using the facility (this time reduction will show up as a benefit on the benefit side of the accounting ledger). However with the electronic option users can be required to prepay and maintain a minimum balance in their accounts or they can be billed once a month as with credit cards. The installation of the ETC system does not affect the toll rate. Hence, the full cost to most users under the baseline alternative is the time for transacting at the tollbooth and the payment of the toll. Under the ETC alternative there will be an opportunity cost of funds that are left on account with Caltrans (or the operator).

The cost to the community/society refers to environmental cost. Since the ETC system is expected to reduce vehicle emissions, the difference in environmental cost between the two alternatives will be a benefit. Therefore, the environmental costs of both alternatives are not indicated in the cost category.

Table 2

Cost Categories of Baseline and ETC System

Costs	Service Provider	Users	Society/Community
Cost of Baseline			
O&M costs	*		
Time		*	
Service charge		*	
Others			
Cost of ETC Alternative			
Capital costs	*		
O&M costs	*		
Time		*	
Service charge		*	
Others			

Major benefits of the ETC system include cost and timesavings. Among other benefits are the reduction of vehicle emission, the increase of travel convenience, and the facilitation of data collection and policy implementation (Table 3).

The cost savings of the toll agency may result from reductions in labor cost for toll collection, accounting service, cash handling, and cost of equipment replacement and maintenance. Toll agency may also avoid loss of revenue due to computer failure and generate interest revenue from the balance of ETC user accounts, which equals users' cost of using the ETC system. For ETC users, the cost savings include reductions in fuel cost. There is no direct cost saving for the community under the ETC alternative.

Table 3

Benefit Categories of ETC

Benefits	Service Provider	Users	Community/Society
Cost Savings			
O&M costs of toll facility	*		
Fuel consumption		*	
Vehicle operation		*	
Time Savings			
Travel time		*	
Safety Improvement			
Fatality and injury		?	
Property damage		?	
Environmental Improvement			
Vehicle emissions			*
Others			
Data quality and quantity	*		*
Convenience		*	
Enhanced facility (?)	*		
Other induced effects (?)			*

Travel timesaving is a benefit for users, due to the automatic toll transaction by the ETC system. The toll agency and the community do not directly benefit from travel timesaving.

Since the use of the ETC system can eliminate vehicle acceleration, deceleration, and stops -- events that produce vehicle emissions, the ETC system can provide environmental benefits.

Some studies suggest that ETC systems can improve safety. For example, Oklahoma Turnpike Authority reported that there were no accidents in its PIKEPASS lane in the first year after the installation of the ETC system, as compared to 71 accidents in its regular lanes (Ort, 1995). A safety improvement is not only a benefit to users, but also to society. Other identifiable benefits include increasing user travel convenience, improving the quality and quantity of data collection, and allowing the toll agency to set the toll price according to traffic conditions.

1.3.2 Basic Assumptions

In order to estimate cost and benefit of the ETC alternative, a number of basic assumptions are made. They include those for the calculations of traffic growth, market share of ETC usage, toll transaction time by type of payments, travel speed, and design configuration of Carquinez Bridge. These assumptions are listed in Table 4 and explained below. Additional assumptions for the estimation of specific costs or benefits are provided in the sub-sections where individual costs or benefits are shown.

- Traffic growth: Total traffic volume in the Carquinez Bridge is assumed to increase at an average rate of 3 percent per year.
- ETC market share: The percentage of ETC transactions over total toll transactions is assumed to be 6 percent in FY97/98 and 15 percent in FY98/99, and increase 5 percent per year afterward up to 50 percent.
- Transaction time by type of payments: It is assumed the average time is 10 seconds per cash transaction, 4.5 seconds per ticket transaction, and 2.4 seconds per ETC transaction respectively.
- Normal travel speed: The normal travel speed is assumed to be 55 miles per hour. This is the maximum speed allowed on the bridge.
- Design configuration of the Carquinez Bridge: The distance on ramps prior to or leading from the toll plaza is about 0.2 miles. Total distance on both sides of the toll plaza is about 0.4 miles.
- Demand is assumed to be inelastic or insensitive to timesaving meaning there is no induced traffic

The assumptions were made on the basis of historical data for traffic volume at Carquinez Bridge, ETC market share information from Carquinez and other ETC systems in the nation, and information provided in Caltrans' feasibility study report.

1.3.3 Cost Estimation

There are two common approaches for cost estimation. One is an engineering bottom-up approach and the other uses econometric modeling. The engineering approach requires detailed knowledge about the design of a facility, unit prices for the facility capital components, and other factors such as labor and materials. Econometric modeling employs a statistical criterion and a sample of data. In this study, we use the engineering approach because the design features of the ETC system are available. The ATCAS Feasibility Study Report provides aggregated data for the costs of the nine bridges (Caltrans, 1995). To construct cost estimates for Carquinez Bridge, the data must be disaggregated and re-assembled. In general, the costs that are shared by all nine bridges are divided in proportion to the toll lanes or number of bridges, depending on whether the cost is most likely to be associated with a lane or a bridge. The estimation procedures are briefly described in the following sections. Detailed descriptions of the estimations are provided in the Technical Appendix.

1.3.3.1 Baseline costs

The operation and maintenance costs of the toll agency for continuing the current service are the major tangible cost of the baseline. User and society costs of the baseline can be considered to have a zero base and any additional or reduction in user and/or society costs generated by ETC will be calculated in the sections of cost and benefit estimations of ETC.

Table 4

General Assumptions

Items	Assumptions
Annual traffic growth rate (i_{TV})	3%
Annual growth rates of ETC transactions (i_{ETC})	6% in FY97/98, 15% in FY98/99, 5% annually afterward
Seconds/cash transaction	10
Seconds/ticket transaction	4.5
Seconds/ETC transaction	2.4
Normal travel speed (mph)	55
Ramp distance prior to or leading from the toll plaza (mile)	0.2

The continuing current maintenance and operating (M & O) costs include *total information technology cost* and *total program cost*. That is:

$$TC_{base} = OC = C_{info} + C_{prg} \qquad (1)$$

The *information technology cost* includes the costs of "continuing staff" and "hardware/software." "Cost of continuing staff" is the cost of one-person year (PY) for the computer service support to assist the personnel of the accounting center at District 4 with problems downloading and storing toll data. "Cost of continuing hardware/software" are materials and operation costs, such as the costs of printer paper, ribbons, diskettes, troubleshooting, recovering lost data, and locating parts and service vendors.

The *program cost* consists of the "cost of the toll collecting and accounting staff," and "other costs" such as the commute ticket booklet contract, and maintenance costs for the existing system. The number of PYs of the baseline is assumed to remain the same over the whole evaluation period. The M&O cost estimates are shown in Table 5.

1.3.3.2 ETC Project Costs

Tangible costs of ETC alternative include expenditures for acquiring ETC equipment and those for ETC operation and maintenance. The capital and operating costs for providing ETC service are those of toll agency. Since ETC users are required to prepay for setting up an ETC account and maintain a certain amount of balance in their accounts, there is a user cost involved under the ETC alternative. There is no tangible social cost directly involved in the ETC project. The costs of the toll agency and users are estimated as follows.

Agency cost

The agency costs for the ETC alternative include three major categories: one-time capital costs of the process control components (KC_1); data processing costs (KC_2); and continuing existing (M&O) costs (OC). A summary of process control and data processing costs are listed in Table A-1 in Appendix IIA. Total cost is expressed in the following equation:

$$TC_{ETC} = KC_1 + KC_2 + OC \qquad (2)$$

The process control costs include capital investments for the "*In-Lane Subsystems*" and the "*ETC Addition to In-Lane Subsystems*." Basic components of the process control include the ETC reader, lane controller, automatic vehicle classification system, violator detection system, patron toll display, and terminals. A complete list of the process control components, the unit cost of each component, the number of unit associated with each component, are shown in Table A-2 in the Technical Appendix. The cost of each component is calculated by multiplying the number of units and the unit cost. Data process costs are expenditures for *ETC hardware/software and services* as shown in Table A-3 in Appendix A.

As indicated earlier, the continuing existing (M&O) costs contain both *total information technology costs* and *total program cost*. *Total information technology costs* include recurrent costs of staff and hardware/software for the support and operation of ETC data process at the center office. *Total program costs* are expenditures incurred at the toll plaza, such as toll collector, administrative PYs, material and maintenance costs, and other miscellaneous operation costs such as expenditure for service contracts, and credit card transaction fees. Travel volume and the market share of ETC usage largely determine the cost of PYs. The more travelers who use ETC and the more dedicated ETC lanes that are opened, the more can PYs be reduced. The cost of PYs is estimated on the basis of the following assumptions in addition to the basic assumptions outlined earlier:

- all ETC transactions are concentrated so that the toll agency can open dedicated ETC lanes for the transactions; and
- the toll agency has complete flexibility for hiring part-time employees who are paid on an hourly basis.

The annual PY cost is calculated by subtracting total PY costs from PY reduction. PY reduction is calculated by the following formula:

$$PY_{Sn} = (ETC_n / ETC_{Cap}) / U_{PY} \qquad (3)$$

Where:

PY_{Sn}:	Annual PY reduction in year n;
ETC_n:	Total ETC transactions in year n;
ETC_{Cap}:	The capacity of an ETC lane equals 1500 (3600/2.4) transactions per hour;
U_{PY}:	Hours per PY, which is assumed to be 1768 by Caltrans.

It should be noted that if the above assumptions do not hold, namely the ETC transactions are dispersed during the time of a day and there is a restriction on the use of part-time labor, the toll agency may not be able to open more ETC lanes or operate ETC lanes for longer time period and have to operate toll lanes in mixed mode. As a result, the toll agency may not be able to save as many PYs as it would have been.

The cash flows of the baseline and ETC project are discounted to FY95 dollars in order to compare with benefits. The cost estimates of the ETC project are listed in Table 6.

User cost

Under the ETC alternative, the main user cost is the loss of interest generated from the deposit for ETC transponders and any balance in the users' ETC accounts. The estimation of user cost is based on the following assumptions:

- The average use rate of ETC accounts is 160 per ETC account per year.
- The average tag per account is 1.35.
- About 64 percent of the ETC accounts are established with cash or checks, and 36 percent are opened with credit cards.
- The average balance is $48.80 for cash or check accounts and $19.52 for credit card accounts (in FY95 dollars).

Table 5

Baseline Cost Estimates

	FY 95/96		FY 96/97		FY 97/98		FY 98/99		FY 99/00		FY 00/01		FY 01/02		FY 02/03		FY 03/04		FY 04/05		FY 05/06		TOTAL
	PYs	**Amts**	**PYs**	**Amts**	**PYs**	**Amts**	**PYs**	**Amts**	**PYs**	**Amts**	**PYs**	**Amts**	**PYs**	**Amts**	**PYs**	**Amts**	**PYs**	**Amts**	**PYs**	**Amts**	**PYs**	**Amts**	**Amts**
Continuing Existing Costs:																							
**** information technology costs:***																							
staff	0.11	$7,222	0.11	$7,439	0.11	$7,662	0.11	$7,892	0.11	$8,129	0.11	$8,373	0.11	$8,624	0.11	$8,882	0.11	$9,149	0.11	$9,423		$9,706	$92,501
hardware/software		$8,356		$9,390		$10,587		$11,975		$13,589		$15,472		$17,673		$20,252		$23,280		$26,841		$31,038	$188,454
total information technology cost		$15,578		$16,829		$18,249		$19,867		$21,718		$23,845		$26,297		$29,134		$32,428		$36,264		$40,744	$280,955
**** program costs:***																							
staff	61.5	$3,997,500	61.5	$4,117,425	61.5	$4,240,948	61.5	$4,368,176	61.5	$4,499,221	61.5	$4,634,198	61.5	$4,773,224	61.5	$4,916,421	61.5	$5,063,913	61.5	$5,215,831	61.5	$5,372,306	$51,199,163
other		$297,120		$302,720		$308,800		$315,200		$322,240		$329,760		$339,653		$349,842		$360,338		$371,148		$382,282	$3,679,103
total program costs		$4,294,620		$4,420,145		$4,549,748		$4,683,376		$4,821,461		$4,963,958		$5,112,877		$5,266,263		$5,424,251		$5,586,979		$5,754,588	$54,878,266
Total Continuing Existing Costs:		$4,310,198		$4,436,974		$4,567,997		$4,703,243		$4,843,180		$4,987,803		$5,139,174		$5,295,398		$5,456,680		$5,623,243		$5,795,332	$55,159,221
Total Costs		$4,310,198		$4,436,974		$4,567,997		$4,703,243		$4,843,180		$4,987,803		$5,139,174		$5,295,398		$5,456,680		$5,623,243		$5,795,332	$55,159,221

Table 6

ETC Cost Estimates

	FY 95/96		FY 96/97		FY 97/98		FY 98/99		FY 99/00		FY 00/01		FY 01/02		FY 02/03		FY 03/04		FY 04/05		FY 05/06		TOTAL
	PYs	Amts	PYs	Amts	PYs	Amts	PYs	Amts	PYs	Amts	PYs	Amts	PYs	Amts	PYs	Amts	PYs	Amts	PYs	Amts	PYs	Amts	Amts
Process Control Costs																							
In-lane subsystems (without ETC)		$786,560		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$786,560
ETC addition to in-lane subsystems		$1,113,265		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$1,113,265
subtotal		$1,899,824		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$1,899,824
contigencies 5%		$94,991		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$94,991
Total Process Control Costs		$1,994,816		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$1,994,816
Data Processing Costs																							
**** One-Time costs:***																							
staff		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$0
hardware/software		$1,014,524		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$1,014,524
data center services		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$0
contract services		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$0
agency facilities		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$0
other		$0		$0		$284,813		$448,581		$273,801		$289,568		$306,036		$323,231		$341,183		$359,920		$379,475	$3,006,608
Total one-time costs		$1,014,524		$0		$284,813		$448,581		$273,801		$289,568		$306,036		$323,231		$341,183		$359,920		$379,475	$4,021,132
**** Continuing costs:***																							
staff	0.11	$7,222		$7,439	0.11	$7,662	0.11	$7,892	0.11	$8,129	0.11	$8,373	0.00	$8,624	0.11	$8,882	0.11	$9,149	0.11	$9,423	0.9	$9,706	$92,501
hardware/software		$8,356		$9,390		$3,600		$3,780		$3,969		$4,167		$4,376		$4,595		$4,824		$5,066		$5,319	$57,442
data center services		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$0
contract services		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$0
agency facilities		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$0
other		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$0
Total continuing costs		$15,578		$16,829		$11,262		$11,672		$12,098		$12,540		$13,000		$13,477		$13,973		$14,489		$15,025	$149,943
Total Data Processing Costs		$1,030,102		$16,829		$296,075		$460,253		$285,899		$302,108		$319,036		$336,708		$355,156		$374,409		$394,500	$4,171,075
Continuing Existing Costs:																							
**** information technology costs:***																							
staff		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$0
hardware/software		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$0
total information technology cost		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0		$0	$0
**** program costs:***																							
staff	61.5	$3,997,500	61.5	$4,117,425	61	$4,213,364	60.4	$4,290,046	59.9	$4,382,169	59.5	$4,483,492	59	$4,579,191	58.5	$4,676,595	58	$4,775,723	57.4	$4,868,109	56.8	$4,961,739	$49,345,354
other		$301,760		$325,760		$122,080		$133,760		$133,920		$134,080		$138,102		$142,245		$146,513		$150,908		$155,435	$1,884,564
total program costs		$4,299,260		$4,443,185		$4,335,444		$4,423,806		$4,516,089		$4,617,572		$4,717,293		$4,818,841		$4,922,236		$5,019,017		$5,117,175	$51,229,918
Total Continuing Existing Costs:		$4,299,260		$4,443,185		$4,335,444		$4,423,806		$4,516,089		$4,617,572		$4,717,293		$4,818,841		$4,922,236		$5,019,017		$5,117,175	$51,229,918
Total Costs		$7,324,178		$4,460,014		$4,631,519		$4,884,059		$4,801,987		$4,919,680		$5,036,328		$5,155,549		$5,277,392		$5,393,426		$5,511,675	$57,395,809

The above assumptions are derived from the statistics of ETC usage on Carquinez Bridge (Appendix A) and results of the ETC user survey conducted by PATH in 1991. Based on these assumptions, we estimate annual user cost by the following steps:

- Estimate the number of annual ETC transactions by multiplying the projected annual toll transactions by the percentage of ETC transactions.

- Estimate the number of ETC accounts established by cash and credit card respectively. This is done by first dividing the number of ETC transactions by the average ETC usage rate to derive the total number of ETC accounts (# ETC). The number (#ETC) is then multiplied by percentages of cash and credit card payment to obtain the numbers of ETC accounts established by cash and credit card. The equations are listed below:

$$ETC_{cash} = ETC * \% \text{ cash payment} \quad (4)$$

$$ETC_{credit} = ETC * \% \text{ credit card payment} \quad (5)$$

- Compute the balance in cash and credit card accounts, that is;

$$B_{cash} = ETC_{cash} * (\$19.52 + \$29.28 * 1.35) \quad (6)$$

$$B_{credit} = ETC_{credit} * \$19.52 \quad (7)$$

- Calculate total balance by summing the balance of cash and credit card accounts;

- Assess annual interest revenue, which is the product of total balance and interest rate to reflect the opportunity cost of funds held.

The users cost estimates are shown in Table 7. Toll charge is not included in the user cost calculation because the toll is not affected by the introduction of ETC. In general, user cost also includes time. Since it is presumed that the use of ETC system can reduce users' travel time for passing toll facilities, the difference between times for passing a manual toll plaza and an ETC toll facility will be a benefit, and its calculation will be shown in the section of time savings.

1.3.4 Estimations of Agency Benefits

1.3.4.1Agency and User Operating Cost savings

The cost savings of the toll agency can result from reductions in costs for toll collection services, accounting services, cash handling, and equipment replacement and maintenance. Cost savings also include the savings in lost revenue sometimes attributable to electronic systems failure. Those savings have been captured in cost estimation of ETC. Additional cost savings are interest revenues, which equal the users' cost for using ETC as indicated in Table 7

Table 7
User Cost Estimates

Year	Minimum ETC Account Balance			
	Cash Account	Credit Card Account	Total ETC account balance	Annual interest (i = 2 %)
95/96	$0	$0	$0	$0
96/97	$0	$0	$0	$0
97/98	$278,283	$51,747	$330,030	$6,601
98/99	$716,579	$133,248	$849,828	$16,997
99/00	$984,102	$182,994	$1,167,096	$23,342
00/01	$1,267,032	$235,605	$1,502,637	$30,053
01/02	$1,566,051	$291,208	$1,857,259	$37,145
02/03	$1,881,871	$349,935	$2,231,806	$44,636
03/04	$2,215,231	$411,923	$2,627,155	$52,543
04/05	$2,566,899	$477,316	$3,044,216	$60,884
05/06	$2,937,674	$546,262	$3,483,936	$69,679

The operating cost savings for users are captured entirely by reductions in fuel cost. Because the ETC system allows toll transactions to be performed while vehicles travel at normal or near normal speeds, vehicle deceleration, acceleration, and idling events that consume more fuel is eliminated. The reduction in fuel use is the difference between fuel consumption that vehicles would have under the current manual toll scenario and those when ETC is in place. Specific assumptions for the estimation of fuel savings include:

- Average travel speed is 55 mph;
- Average fuel consumption is 25 miles per gallon;
- Vehicle decelerate and/or accelerate with an average speed of 27.5 mph; and
- Cost per gallon is $1.10 in FY95 dollars.

To calculate fuel cost saving, the average hourly fuel consumption is first calculated by dividing average travel speed by average fuel consumption, which equals 2.2 gallons per hour, based on the above assumptions. Secondly, total vehicle time savings resulted from the use of ETC are calculated. Finally, the fuel cost saving is estimated by multiplying total vehicle timesaving by hourly gasoline consumption (g/h) and the unit price of gasoline. Table 8 shows the estimates of fuel reduction cost.[4]

[4] To be correct the loss of fuel tax revenue should be considered in the calculation.

Table 8

Estimates of Fuel Cost Reduction

Year	Time Saving of Toll Transactions		Time Saving of Movement	Total Time Saving	Total Fuel Saving (Gallon)	Value of Fuel Saving (in FY95$)
	ETC vs. Ticket	ETC vs. Cash				
95/96	0	0	0	0	0	$0
96/97	0	0	0	0	0	$0
97/98	591	348	4,284	5,224	11,492	$12,641
98/99	1,623	529	11,032	13,185	29,008	$31,908
99/00	2,090	1,231	15,151	18,473	40,640	$44,704
00/01	2,153	3,533	19,507	25,193	55,425	$60,968
01/02	2,218	5,972	24,111	32,300	71,061	$78,167
02/03	2,284	8,554	28,973	39,811	87,585	$96,343
03/04	2,353	11,286	34,105	47,744	105,036	$115,540
04/05	2,423	14,174	39,519	56,116	123,456	$135,802
05/06	2,496	17,225	45,228	64,948	142,887	$157,175

To estimate total vehicle timesaving, annual traffic volumes, annual ticket ($Ticket_n$) and cash ($Cash_n$) transactions, and annual ETC usage respectively were projected. Based on our assumptions about the annual changes from ticket to ETC payments, we then estimated the numbers of ETC transactions changing from ticket and cash respectively. These numbers are first multiplied by time savings per transaction, that is 2.1 seconds per transaction changing from ticket to ETC payment and 7.6 seconds from cash to ETC payment respectively, and then summed up to derive time savings for toll transactions. In addition, time reductions resulting from eliminating deceleration and acceleration are computed. The sum of these timesavings is the total vehicle timesaving in this study. For complicated cases involving traffic congestion, time reductions resulting from reducing queuing delays and vehicle headway -- the time between two consecutive vehicles as one leaves and another stops at the toll plaza, should be added to the calculation of time savings. Detailed estimation procedure and assumptions are described in the first seven steps of Appendix B.

1.3.4.2 Passenger Time Saving

Passenger timesavings are the source of the majority of benefits from ETC user. Timesavings are calculated by multiplying the total vehicle timesavings by vehicle occupancy (VOC) weighing factor. To estimate the factor, we made the following two assumptions:

- The split among the ETC users is considered to be 94.76 percent for automobiles, 5.11 percent for trucks, and 0.13 percent for buses. These numbers are derived from the "1996-97 Annual Financial Report: State Owned Toll Bridges." The split is applied to the calculations after FY98/99 because in FY97/98, only 2-axle vehicles are allowed to use the ETC lane.[5] Since most 2-axle vehicles are automobiles, the timesavings in FY97/98 include only timesaving from automobiles.

- Average vehicle occupancy is assumed to be 1.8 for automobiles, 1.1 for trucks, and 20 for buses. These numbers are nationwide averages as shown in Table B-2, Appendix IIB.

The VOC weighting factor (F) is calculated as the sum of VOC factors of autos, trucks, and buses. The calculation is expressed as the following:

$$F = (VOC_{auto} * i_{auto} + VOC_{truck} * i_{truck} + VOC_{bus} * i_{bus}) \quad (8)$$

where i_{auto}, i_{truck}, and i_{bus} are the percentages of ETC transactions by automobiles, trucks, and buses. Total weighted passenger time saving can be obtained by multiplying total vehicle timesaving by vehicle occupancy weighing factor above. The time saving is then converted to dollar values using an assumed value of time.

The value of passenger time saving is the product of total passenger timesaving and a unit value of time, usually measured by dollars per hour. The value of travel time is influenced by many factors, such as alternative uses of time, income, trip purpose, productivity of alternative activities that time will otherwise be used for, *etc*. (Lee and Pickrell, 1997). Where information on travelers' characteristics is available, those factors should be incorporated into the determination of time value. Alternatively, one can also adopt time indices used in other sources as references, as long as there is a justification for the adoption. The time indexes for different years should be adjusted for inflation.[6] In this case study, we convert the passenger time saving to dollar value with a formula of multiplying the time saving by a factor of time value (F_t). The F_t is created by the following equation:

$$F_t = U_{t\_auto} * i_{auto} * VOC_{auto} + U_{t\_truck} * i_{truck} * VOC_{truck} + U_{t\_bus} * i_{bus} * VOC_{bus} \quad (9)$$

Where U_{t_auto}, U_{t_truck}, and U_{t_bus} are units of time value for automobiles, trucks, and buses. The value of time is assumed to be $12.75 per hour for automobiles and buses, and $33.41 per hour for 3- or more axle trucks. The hourly values are computed by taking the estimates

[5]This information was obtained from a conversation with Mr. Miller, manager of the ETC Project at Caltrans, on April 22, 1998.
[6]Currently inflation is a non-issue since it is negligible but should it become an issue it must be factored into the calculation.

of the value of hourly travel time (in 1988 dollars) used by Highway Economic Requirements System (HERS),[7] and converted to 1995 dollars by applying a factor of 1.33. The factor is based on employment cost index published by the U.S. Bureau of Labor Statistics. The value of 3- or more axle trucks is the average value of 3-4 axle, 4-axle, and 5-axle trucks indicated in the HERS document. A completed description of the assumptions and estimation procedure is presented in Appendix B and the estimates of passenger timesavings are displayed in Table 9.

1.3.4.3 Vehicle Emission Changes [Reductions]

Vehicle emission reductions per ETC transaction under free flow condition include cutbacks due to eliminating vehicle idling and acceleration in a toll transaction cycle. Vehicle emissions during deceleration events can be neglected because the flow of fuel through the engine is small. Total annual emission reductions can be obtained by multiplying emission rates by the amount of fuel reduction times the amount of pollution of each type per unit time times the time savings from ETC. The calculations can be written as:

$$TE_{NOx} = E_{NOx\_a} * G \qquad (10)$$

$$TE_{HC} = (E_{HC\_i} * T) + (E_{HC\_a} * G) \qquad (11)$$

$$TE_{CO} = (E_{CO\_i} * T) + (E_{CO\_a} * G) \qquad (12)$$

where:

TE_{NOx}:	total annual NOx emissions reduced by the use of ETC;
E_{NOx_a}:	NOx emission rate for acceleration events;
TE_{HC}:	total annual HC emission reduced by the use of ETC;
E_{HC_i}:	HC emission rate for idling events;
E_{HC_a}:	HC emission rate for acceleration events;
TE_{CO}:	total annual CO emission reduced by the use of ETC;
E_{CO_i}:	CO emission rate for idling events;
E_{CO_a}:	CO emission rate for acceleration events;
G:	total annual fuel reduction;
T:	total annual timesaving of toll transactions.

[7]The HERS is a computer model designed to simulate improvement selection decisions based on the relative benefit-cost merit of alternative improvement options by U.S. DOT (U.S. DOT, 1996).

Table 9
Estimates of Passenger Time Savings

Year	Time Saving of Toll Transactions		Time Saving of Movement	Total Time Saving	VOC Factor	Total Time Saving	Factor of Time Value	Value of Time
	ETC vs. Ticket	ETC vs. Cash						
	(Hours, unweighted)	(Hours, unweighted)	(Hours, unweighted)	(Hours, unweighted)		(Hours, weighted)	($/H)	(FY95$)
95/96	0	0	0	0	1.80	0	$22.95	$0
96/97	0	0	0	0	1.80	0	$22.95	$0
97/98	591	348	8,569	9,508	1.80	17,115	$22.95	$218,210
98/99	1,623	529	22,065	24,218	1.79	43,298	$23.96	$580,117
99/00	2,090	1,231	30,302	33,624	1.79	60,116	$23.96	$805,520
00/01	2,153	3,533	39,014	44,700	1.79	79,919	$23.96	$1,070,878
_	2,218	5,972	48,221	56,411	1.79	100,857	$23.96	$1,351,432
02/03	2,284	8,554	57,946	68,784	1.79	122,979	$23.96	$1,647,856
_	2,353	11,286	68,211	81,849	1.79	146,337	$23.96	$1,960,849
04/05	2,423	14,174	79,039	95,636	1.79	170,986	$23.96	$2,291,139
05/06	2,496	17,225	90,456	110,176	1.79	196,983	$23.96	$2,639,481

The NOx, HC, and CO emission rates are listed in Table 10. Total time saving of toll transactions includes those resulting from changing cash to ETC payments and from tickets to ETC payments. The calculation is expressed as the following:

$$T = T_{(ETC\ vs.\ Cash)} + T_{(ETC\ vs.\ Ticket)} \qquad (13)$$

Fuel reduction (G) is estimated by multiplying time saving from eliminating acceleration by the unit of fuel consumption in gallons per hour. The time saving (ΔT) realized by eliminating acceleration is the product of total number of vehicles equipped with ETC transponders ($\#Veh_{ETC}$) and the time saving per vehicle (U_t), which is the time difference between acceleration time that a vehicle takes from idling to normal speed within a distance and the time that a vehicle travels at a normal speed in the same distance. It is expressed as:

$$\Delta T = \#Veh_{ETC} * U_t \qquad (14)$$

Dividing average travel speed derives the unit fuel consumption in gallons per hour (g) by the fuel consumption factor of miles per gallon. Total fuel reduction from eliminating vehicle acceleration is computed by equation (15):[8]

$$G = \Delta T * g \qquad (15)$$

[8] Special attention should be given to converting the time measure from second or minute to hour or vice versa, so that the units of calculation are consistent.

Table 10

Emission Rates of All Vehicles

	Pollutant		
	NOx	**HC**	**CO**
Acceleration Emission Rates (grams/gallon)	24.7	9.5	209
Idle Emission Rates (grams/minute)	N/A	0.1 ~ 0.2	2 ~ 3

Source: Kirchstetter, *et al.* 1998.

There are a number of ways to determine the value of pollution reduction. One is direct damage costing method. This method determines the value of pollution on the basis of the amount of economic or health damages caused by pollution (Small and Kazimi, 1995; Ottinger, *at al*., 1990; and Fuller *et al.*, 1983). According to Small and Kazimi, the unit costs of health damage are $0.0063 per kilogram of CO, $1.22 ~ $1.33 per kilogram of HC and NOx in the 1995 dollars. Another method is to determine the value on the basis of costs to remove the pollutants (Wang and Santini, 1993; IEPA, 1993; and Bernard and Thorpe, 1994). Wang and Santini determined the unit costs based on the cost of replacing typical gasoline powered cars with electric vehicles. The values provided by the Illinois EPA were based on the costs of buying older, high polluting cars and destroying them. The unit estimates of Bernard and Thorpe were taken from studies of railroad electrification for emission reductions. Those unit costs are presented in Table 11. In this study, we use the average costs of health damage provided by Small and Kazimi since the environmental effect of pollution on health is more tangible to daily life. The estimates of annual value of environmental benefits are presented in Table 12.

1.3.4.4 Benefits from Changes in Safety

Safety levels may rise or fall with ITS projects but with ETC there is generally an improvement in safety. It can be measured by the reduction in number of accidents/incidents and monetizing these for property, injury and life savings. For the evaluation of existing ETC systems, the improvement in safety can be obtained from field observations or it may be modeled. In particular safety will be a function of the number of accidents and accidents will be related to a number of factors including the type of toll collection method. This can be estimated as the function of toll collection method (M), traffic volume (TV), travel speed (SP), time of the day (T), and other possible causes (X) of vehicle accidents and an error term (ε) as expressed by equation (16). The toll collection method can be measured by a dummy variable with 1 indicating ETC and 0 representing manual toll collection. It hypothesis that the higher travel speed, the higher number of accidents because the probability of having accidents may be higher when vehicles are crossing lanes at a higher speed to look for toll booths without or with shorter queues. The relationship between number of accident and traffic volume is expected to be nonlinear. On the one hand, more vehicles increase the chance of collision. On the other hand, a higher traffic volume increases traffic congestion and forces vehicles to slow down, therefore reducing the possibility of vehicle collision or/and the severity of accidents. It is presumed that by controlling other factors, the ETC will reduce the number of accidents.

$$\#Accidents = a + b*TV + c*SP + d*T + f*M + X + \varepsilon \qquad (16)$$

Table 11

Unit Cost of Air Pollution($/kg of pollutant)

Source	Pollutant		
	NOx	HC	CO
Bernard and Thoroe (1994)	8.21 3.04	6.70 3.63	1.10 3.04
Wang and Santini (1993)	27.84	22.69	0.00
Illinois EPA (1993)	24.16	3.81	N/A
Small & Kazimi (1995)	1.22 ~ 1.33	1.22 ~ 1.33	0.0063
Value used (FY95$)	1.28	1.28	0.0063

Table 12

Estimates of Vehicle Emissions

Year	Emission Reduction from idling (grams)			Emission Reduction from Acceleration (grams)			Total Emission Reduction (grams)			Value of Emission Reduction (95$)			
	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	Total
95/96	0	0	0	0	0	0	0	0	0	$0	$0	$0	$0
96/97	0	0	0	0	0	0	0	0	0	$0	$0	$0	$0
97/98	140,894	0	8,454	1,969,963	232,814	89,544	2,110,857	232,814	97,997	$13	$297	$125	$435
98/99	322,940	0	19,376	5,072,655	599,496	230,575	5,395,595	599,496	249,952	$34	$764	$319	$1,117
99/00	498,248	0	29,895	6,966,447	823,307	316,657	7,464,695	823,307	346,552	$47	$1,050	$442	$1,539
00/01	852,942	0	51,177	8,969,300	1,060,008	407,695	9,822,242	1,060,008	458,872	$62	$1,352	$585	$1,998
01/02	1,228,469	0	73,708	11,086,055	1,310,170	503,912	12,314,523	1,310,170	577,620	$78	$1,670	$736	$2,485
02/03	1,625,759	0	97,546	13,321,743	1,574,388	605,534	14,947,502	1,574,388	703,079	$94	$2,007	$896	$2,998
03/04	2,045,782	0	122,747	15,681,594	1,853,279	712,800	17,727,376	1,853,279	835,547	$112	$2,363	$1,065	$3,540
04/05	2,489,543	0	149,373	18,171,047	2,147,487	825,957	20,660,590	2,147,487	975,329	$130	$2,738	$1,244	$4,112
05/06	2,958,088	0	177,485	20,795,754	2,457,680	945,262	23,753,842	2,457,680	1,122,747	$150	$3,134	$1,432	$4,715

In this study, accident data in the period between September 1996 and December 1996 were compared with those between September 1997 and December 1997 -- months after one dedicated ETC lane was opened. As shown in , the total number of accidents in the latter period is higher than those in the period of 1996, though the numbers of accidents in Figure 1. September and December 1997 were lower than those in the same months in 1996. Data also indicate that the total number of personal injuries in 1997 was 13, as compared to 5 in 1996 However, non-personal injuries in 1997 were lower than that in 1996. Due to the lack of data, we cannot use the above model to estimate the number of accidents in the future years. We instead developed a simple model using traffic and accident data between September 1996 and December 1997 (Equation 17). However, the model is not statistical significant. Hence, we did not estimate safety benefit or dis-benefit in this study.

$$\#Accidents = a + b*TV + c*M \quad (17)$$

Figure 2

Total Number of Accidents at the Carquinez Bridge
(A Comparison before and after the Installation of the ETC)

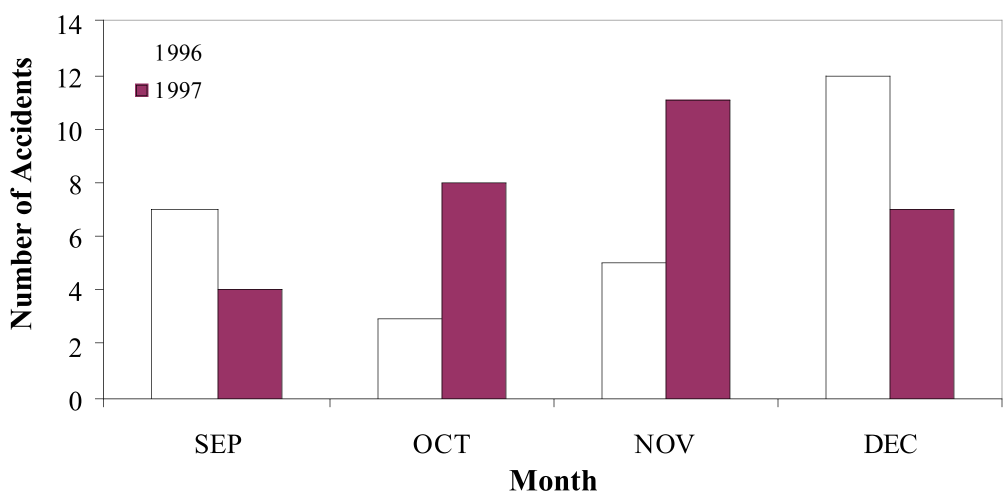


Figure 3

The Number of Personal Injuries at the Carquinez Bridge

(A Comparison before and after the Installation of the ETC)

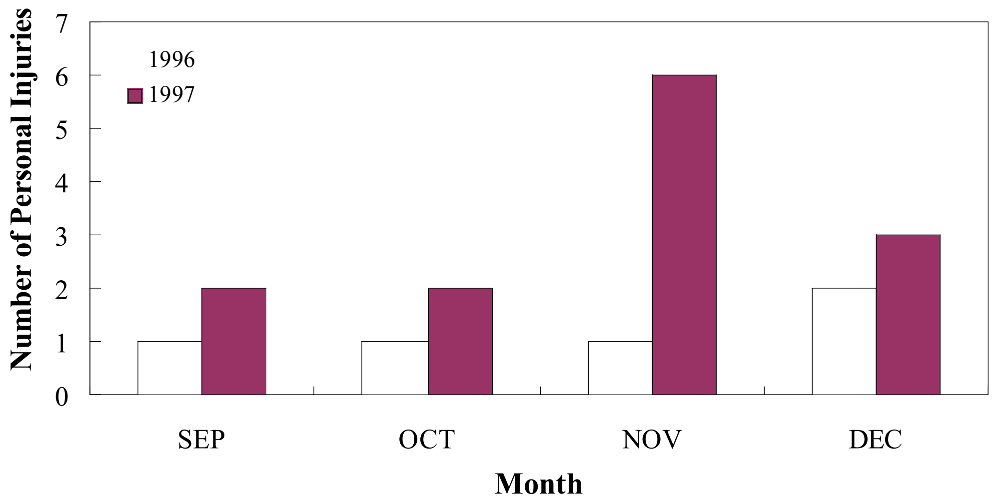
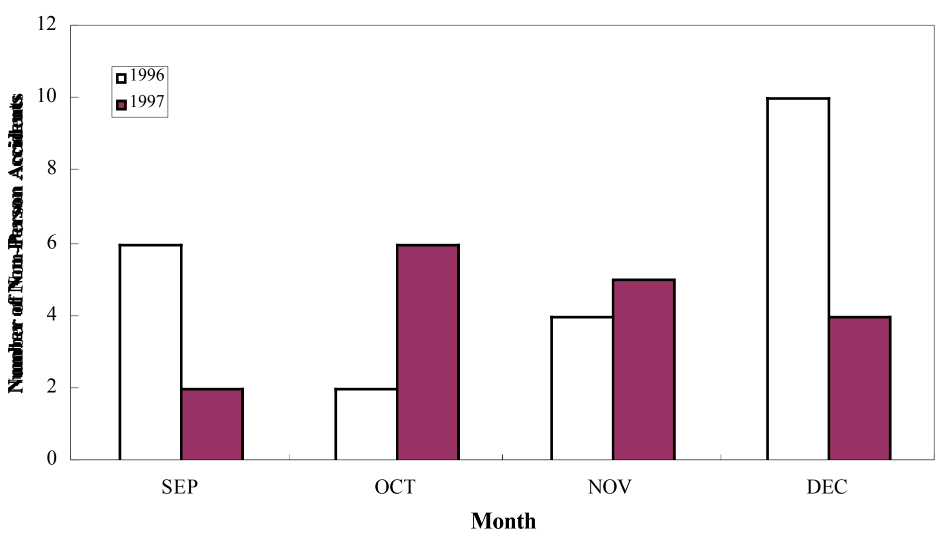


Figure 4

Number of Non-Person Accidents at the Carquinez Bridge

(A Comparison before and after the installation of the ETC)



1.3.5 Analytical Results

This section analyzes the value of total net effect of the ETC project and the distribution of the values among the toll agency, ETC users, and society. The effects of assumptions with respect to ETC market share, time value, and emission rate are examined, and their implications are also discussed.

1.3.5.1 Total net effect and its distribution

Table 13 shows the cost streams of the baseline and the ETC project. The data indicate that total costs of the ETC project in the first four years are higher than those of the baseline. The costs of ETC system would be lower than the baseline in the rest of the years in the evaluation period. However, the lifetime cost of the ETC system would be about $2.7 million more than that of the baseline. The cost is equivalent to $2.9 million after discounted at a rate of 5 percent to FY95 present value.

The streams of benefit values (in FY95 dollars) are shown in Table 14. Data show that as the ETC market share expands the annual value of total benefit increases. Total benefit value in the lifetime of the ETC system would be about $13.7 million. As a result, the total net present value of the ETC benefit would be about $11.2 million as shown in Table 15. The benefit-cost ratio would be 4.7 and the internal rate of return (IRR) would be about 24 percent, indicating the ETC project is certainly worth pursuing.

Table 13

Total Cost Streams of Baseline and ETC

Year	TC_Base	TC_ETC	_TC	PVC (in FY95$)
0	$4,310,198	$7,324,178	$3,013,980	$3,013,980
1	$4,436,974	$4,460,014	$23,040	$21,943
2	$4,567,997	$4,638,797	$70,800	$64,218
3	$4,703,243	$4,903,735	$200,492	$173,192
4	$4,843,180	$4,830,359	($12,821)	($10,548)
5	$4,987,803	$4,958,037	($29,766)	($23,323)
6	$5,139,174	$5,086,107	($53,067)	($39,600)
7	$5,295,398	$5,218,357	($77,041)	($54,752)
8	$5,456,680	$5,355,022	($101,658)	($68,806)
9	$5,623,243	$5,487,878	($135,365)	($87,258)
10	$5,795,332	$5,625,174	($170,158)	($104,462)
Total	$55,159,221	$57,887,656	$2,728,435	$2,884,585

Table 14

Total Benefit Streams (in FY95$)

Year	_Fuel Value	_Time Value	__Env. Value	_Operation Revenue	Total Benefit Value
0	$0	$0	$0	$0	$0
1	$0	$0	$0	$0	$0
2	$12,641	$218,210	$435	$6,601	$237,887
3	$31,908	$580,177	$1,117	$16,997	$630,199
4	$44,704	$805,520	$1,539	$23,342	$875,105
5	$60,968	$1,070,878	$1,998	$30,053	$1,163,897
6	$78,167	$1,351,432	$2,485	$37,145	$1,469,229
7	$96,343	$1,647,856	$2,998	$44,636	$1,791,834
8	$115,540	$1,960,849	$3,540	$52,543	$2,132,472
9	$135,802	$2,291,139	$4,112	$60,884	$2,491,936
10	$157,175	$2,639,481	$4,715	$69,679	$2,871,049
Total	$733,248	$12,565,543	$22,938	$341,879	$13,663,608

Table 15

Total Net Benefit (in FY95$)

Year	PVB	PVC	NPV
0	$0	$3,013,980	($3,013,980)
1	$0	$21,943	($21,943)
2	$237,887	$64,218	$173,669
3	$630,199	$173,192	$457,007
4	$875,105	($10,548)	$885,652
5	$1,163,897	($23,323)	$1,187,220
6	$1,469,229	($39,600)	$1,508,829
7	$1,791,834	($54,752)	$1,846,585
8	$2,132,472	($68,806)	$2,201,278
9	$2,491,936	($87,258)	$2,579,194
10	$2,871,049	($104,462)	$2,975,512
Total	$13,663,608	$2,884,585	$10,779,023

The toll agency is responsible for almost all the direct cost of the ETC project. Table 16 indicates that although the annual operating cost of the ETC system would be less than that of the baseline after four years in operation, the operating cost savings could not offset the capital investment.

Table 16
Cost Streams of Toll Agency (in FY95$)

Year	TC_Base	TC_ETC	_TC	PVC (in FY95$)
0	$4,310,198	$7,324,178	$3,013,980	$3,013,980
1	$4,436,974	$4,460,014	$23,040	$21,943
2	$4,567,997	$4,631,520	$63,523	$57,617
3	$4,703,243	$4,884,059	$180,816	$156,196
4	$4,843,180	$4,801,987	($41,193)	($33,889)
5	$4,987,803	$4,919,681	($68,122)	($53,375)
6	$5,139,174	$5,036,329	($102,845)	($76,745)
7	$5,295,398	$5,155,549	($139,849)	($99,388)
8	$5,456,680	$5,277,392	($179,288)	($121,349)
9	$5,623,243	$5,393,426	($229,817)	($148,142)
10	$5,795,332	$5,511,674	($283,658)	($174,141)
Total	$55,159,221	$57,395,809	$2,236,588	$2,542,706

Table 17

Net Benefit of Toll Agency (in FY 95$)

Year	_Operation Cost	_Operation Revenue	Total Net Savings
0	($3,013,980)	$0	($3,013,980)
1	($21,943)	$0	($21,943)
2	($57,617)	$6,601	($51,017)
3	($156,196)	$16,997	($139,199)
4	$33,889	$23,342	$57,231
5	$53,375	$30,053	$83,428
6	$76,745	$37,145	$113,890
7	$99,388	$44,636	$144,024
8	$121,349	$52,543	$173,892
9	$148,142	$60,884	$209,026
10	$174,141	$69,679	$243,820
Total	($2,542,706)	$341,879	($2,200,827)

If the cost of transponders could be transferred to ETC users and there is no deposit required for transponders, the ETC project would save the agency about $0.8 million over its lifetime. These arise from saving in labor and maintenance costs. However, if the cash flow is adjusted at a 5 percent discount rate to present value in the FY95 dollars, the ETC project would still cost the agency about $0.3 million more than the baseline in the evaluation period. But the net loss can be partially offset by the increase in operation revenue, yielding in an approximate net cost of $0.14 million, about $2 million less than the agency would pay for the ETC transponders.

ETC users are the main beneficiaries of the ETC project. According to estimates shown in Table 18 and Table 19, the values of saving in fuel and time would be greater than the costs paid by ETC users. Annual net benefit of ETC users ranges from $0.2 million to $2.8 million in the FY95 dollar as the market share of ETC usage increases. Total value of the net user benefit in the evaluation period would be about $13 million.

The benefit-cost ratio for the ETC users would be about 38. Even if the ETC users would be responsible for the cost of their transponders, the benefit would surpass the cost, resulting a net benefit of $10.5 million in the FY95 dollar.

Table 18
Cost Streams of ETC Users (in FY95$)

Year	TC_Base	TC_ETC (in FY95$)	_TC (in FY95$)
0	$0	$0	$0
1	$0	$0	$0
2	$0	$6,601	$6,601
3	$0	$16,997	$16,997
4	$0	$23,342	$23,342
5	$0	$30,053	$30,053
6	$0	$37,145	$37,145
7	$0	$44,636	$44,636
8	$0	$52,543	$52,543
9	$0	$60,884	$60,884
10	$0	$69,679	$69,679
Total	$0	$341,879	$341,879

Table 19

Net Benefit of ETC Users (in FY95$)

Year	_Cost	_Fuel Value	_Time Value	Total Net Savings
0	$0	$0	$0	$0
1	$0	$0	$0	$0
2	($6,601)	$12,641	$218,210	$224,251
3	($16,997)	$31,908	$580,177	$595,089
4	($23,342)	$44,704	$805,520	$826,882
5	($30,053)	$60,968	$1,070,878	$1,101,793
6	($37,145)	$78,167	$1,351,432	$1,392,454
7	($44,636)	$96,343	$1,647,856	$1,699,563
8	($52,543)	$115,540	$1,960,849	$2,023,846
9	($60,884)	$135,802	$2,291,139	$2,366,056
10	($69,679)	$157,175	$2,639,481	$2,726,977
Total	($341,879)	$733,248	$12,565,543	$12,956,912

As exhibited in Table 20, the ETC system would provide positive environmental benefits to the society, though the magnitude of the benefit would be limited. In brief, overall the ETC project would result in a net present value of $10.8 million in the entire evaluation period. However, the distribution of the net benefit is quite uneven (Figure 5). Since most of the benefits come from saving in time and fuel reduction, user benefit accounts for more than the total net quantifiable benefit. Even if the ETC users pay for transponder cost, they are still the winners. On the other hand, if the toll agency would be responsible for the transponder cost, it would have to spend about $2.2 million for its welfare in data collection and operation improvement, as compared to a net cost of $0.14 million if the transponder cost is paid by the ETC users.

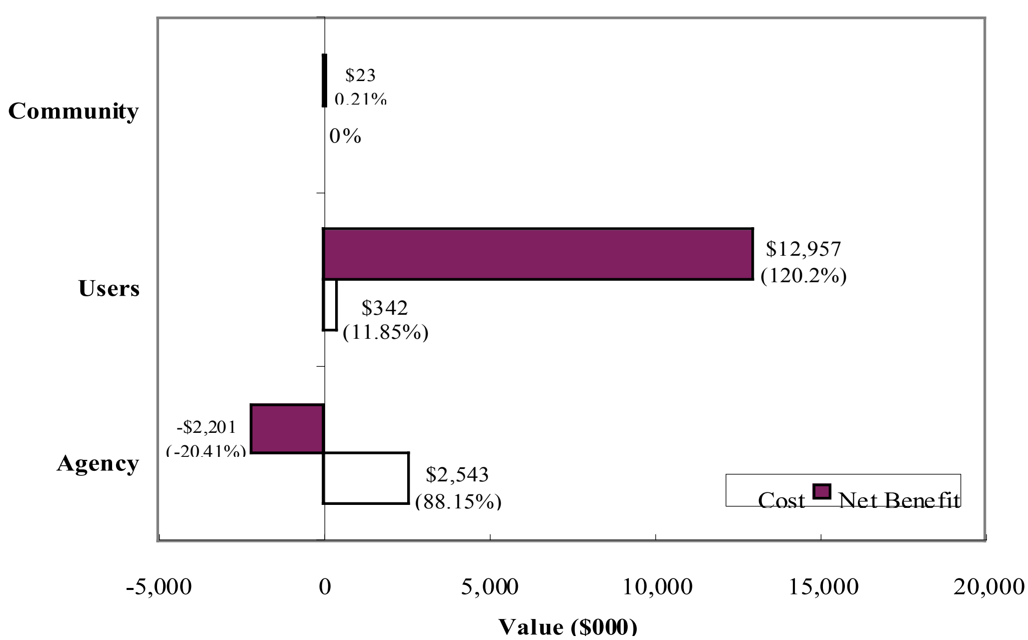
Table 20

Net Benefit of Community (in FY95$)

Year	_CS	_Env. Value	Total Net Savings
0	$0	$0	$0
1	$0	$0	$0
2	$0	$435	$435
3	$0	$1,117	$1,117
4	$0	$1,539	$1,539
5	$0	$1,998	$1,998
6	$0	$2,485	$2,485
7	$0	$2,998	$2,998
8	$0	$3,540	$3,540
9	$0	$4,112	$4,112
10	$0	$4,715	$4,715
Total	$0	$22,938	$22,938

Figure 5

Distribution of Cost and Net Benefit



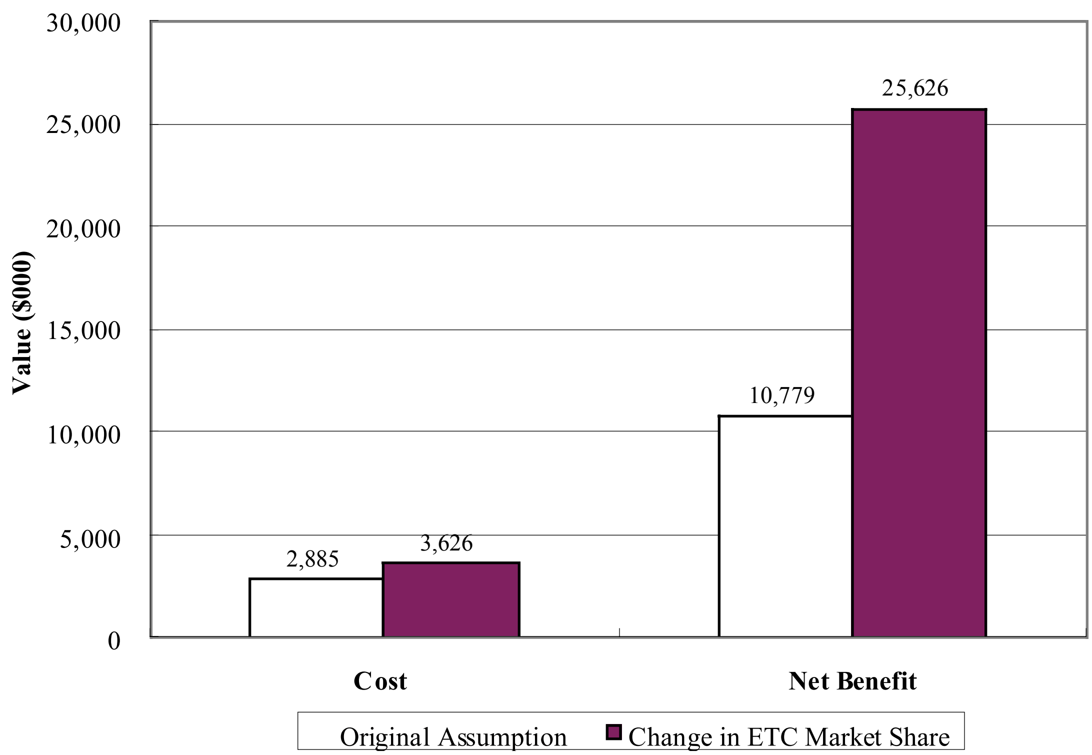
1.3.6 Sensitivity analysis

1.3.6.1 Effect of ETC market share

If the ETC market share were 10 percent of total toll transactions in FY97/98, escalated to 50 percent in FY98/99, and increased 5 percent each year until 85 percent in the last year of the evaluation period, what would be the total net effect and how would this assumption affect the distribution of the net effect, holding other assumptions constant? The analysis shows that if the ETC market share is 35 percent more than originally assumed, the life time cost of the ETC project would be about $3.4 million more than the baseline line, which is equivalent to about $3.6 million in the FY95 dollar. Total value of time saving, fuel saving, emission reduction, and operation revenue, would increase to $29.2 million over the analysis period. As a result, the total net benefit would be about $25.6 million in the FY95 dollar, more than double the net benefit under the previous assumptions (Figure 6). Total benefit-cost ratio would be about 8.1 with an internal rate of return of 42 percent, more than half of the IRR under the previous assumption of ETC market share.

Figure 6

Effect of ETC Market Share on Total Cost & Net Benefit



The increase in ETC market share would not reduce the financial burden of the toll agency. Although the toll agency would be able to reduce labor cost since a larger proportion of the toll transactions would be performed automatically, the cost of transponders also increases.

The reduction of labor cost and increase in operation revenue would not offset the increase in transponder cost. As a result, the toll agency would lose about $2.2 million in the FY95 dollar over the entire evaluation period (Figure 7). However, if the cost of transponders can be transferred to ETC users, the toll agency would benefit from the increase of ETC market share. That is, instead of giving out free transponders or holding deposit for transponders, the toll agency has ETC users pay for their transponders. By doing so, the agency would save about $1.4 million in constant dollars for operation instead of losing money in comparison with the baseline in real terms, in spite of some reductions in operation revenue (Figure 8). In addition, benefit cost ratio would increase to 1.4 and IRR would escalate to about 6 percent. The agency would be able to collect more data due to the more frequent use of ETC. Hence, the toll agency would benefit significantly from increasing ETC usage and transferring the cost of transponders to ETC users.

Users would still be the major beneficiaries of the ETC project. As more toll transactions are performed automatically, ETC users would save more in travel time and fuel cost. The total net benefit over the evaluation period would be about $27.8 million in constant dollars, more than double of the net benefit under previous assumption on ETC market share (Figure 9). User net benefit would be about $23.1 million if the cost of transponders were born by the ETC users.

Figure 7
Effect of Market Shares on Cost & Net Benefit of Toll Agency

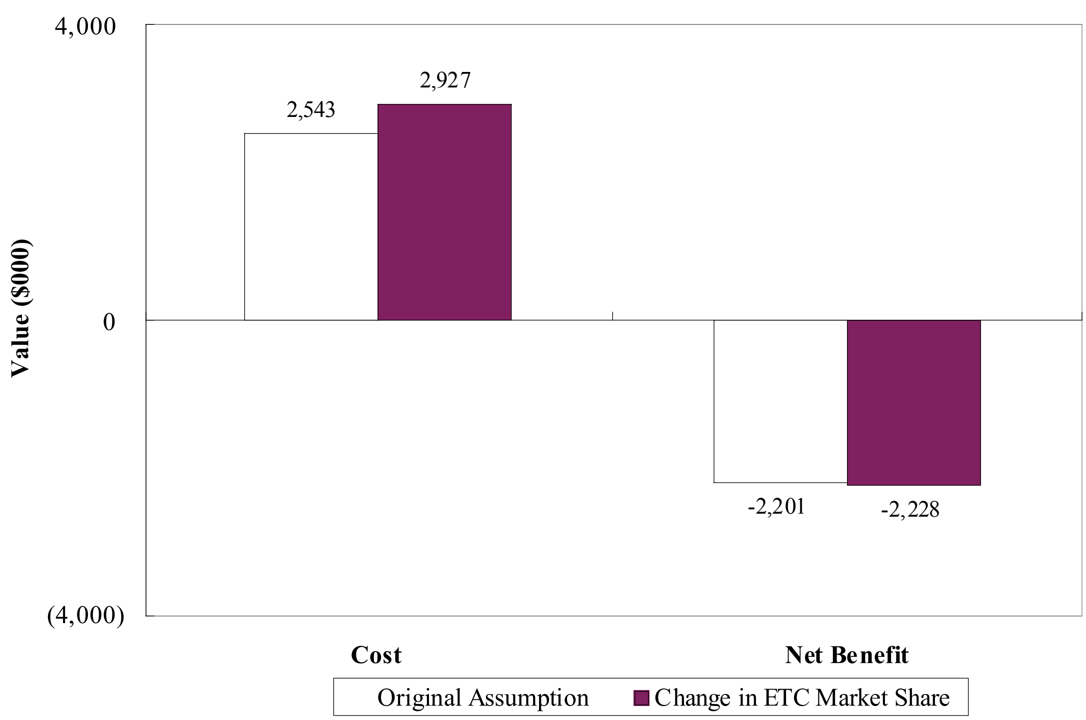
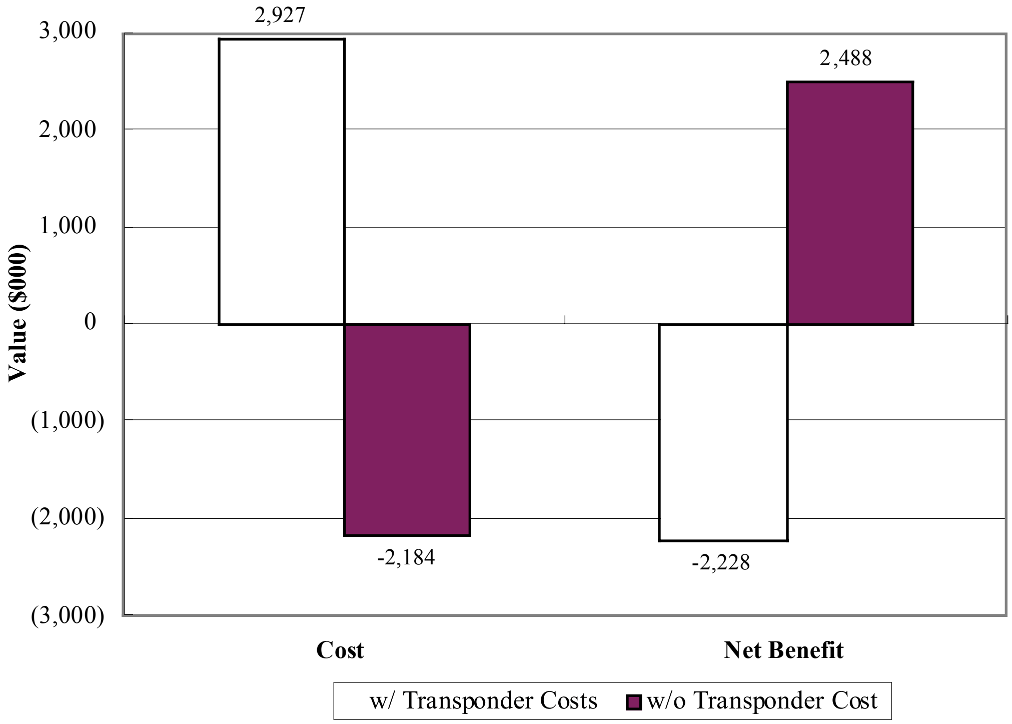


Figure 8
Effect of Transponder expenses on Cost & Net Benefit of Toll Agency



Similarly, the net benefit of the society in the evaluation period, as shown in Figure 10, would also increase to $47,514 in the FY95 dollar, more than double of the benefit under the original assumption.

In short, the analysis shows that if the ETC market share is 35 percent more than what is previously presumed the entire society would be better off. However, the distribution of benefit would depend on who pays for the cost of the ETC transponders. If the cost is born by ETC users, all the groups would have positive net benefits and the net present value of benefits would be more evenly distributed as shown in Figure . Otherwise, the toll agency would bear slightly more financial responsibility for the project than that under the previous assumption of ETC market share.

Figure 9

Effect of ETC Market Share on Cost & Net Benefit for ETC Users

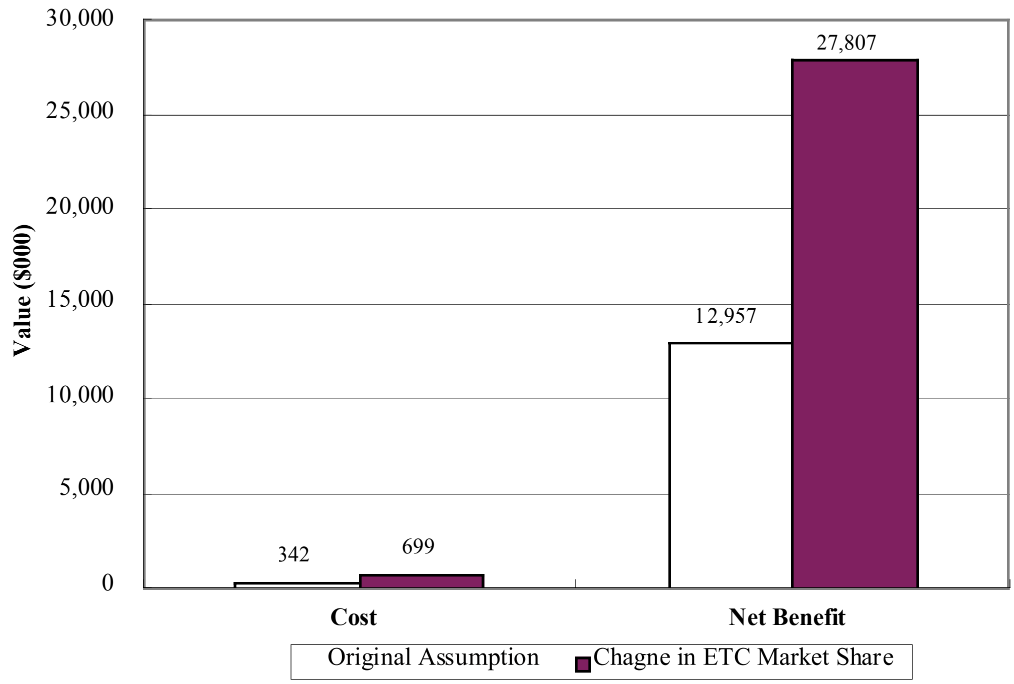


Figure 10

Effect of ETC Market Share on Cost & Net Benefit for the community

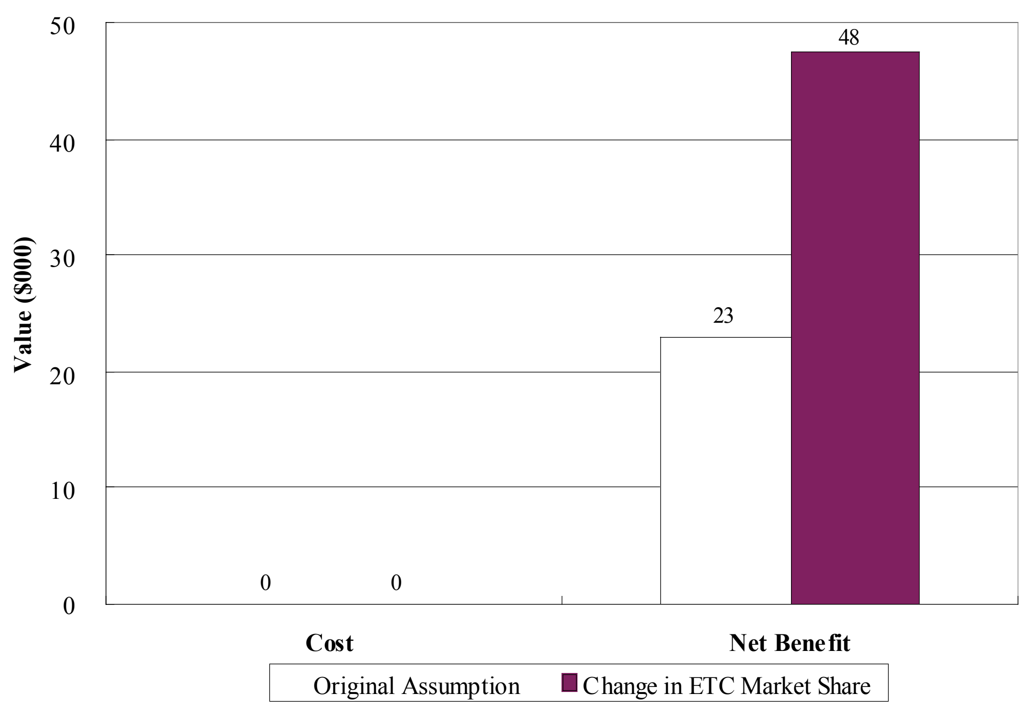
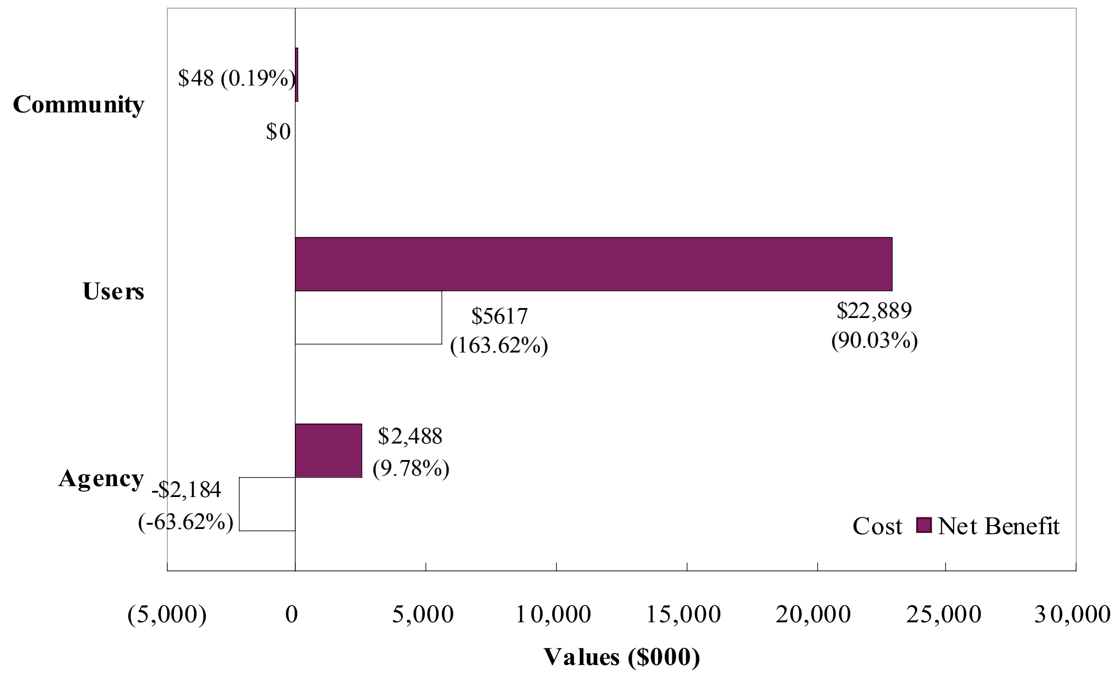


Figure 11

Re-distribution of Cost & Net Benefit
(Effect of ETC Market Share & Transponder Cost)



1.3.6.2 Effect of time value

Under the previous assumption, the hourly time value was assumed to be $12.75 for auto and bus travelers and $33.41 for truck drivers. Due to the lack of information on traveler profiles, such an assumption may over-estimate the effect of ETC project. To investigate the magnitude of such an effect, we substituted the previous assumption with a more conservative time value: $9.00 per hour for auto and bus travelers and $23.40 per hour for truck drivers.[9] As shown in, Figure 12 total benefit reduces by about $3.7 million from previous $12.6 million to current $8.9 million. The benefit-cost ratio declines to 3.5 and internal rate of return drops 6 percent.

The change of assumption on time value does not affect the net benefits and benefit-cost ratios of the toll agency and community. It does bring down the net benefit of ETC users to about $9.3 million, as compared to $13 million of previous estimates. The benefit-cost ratio

[9] In Caltrans' CAL/B-C model, the value of time is assumed to be $0.15/minute for cars and $0.39/minute for trucks. These assumptions are equivalent to $9.00/hr and $23.40/hr respectively.

of ETC users also reduces to 27.4 as compared to previous ratio of 40. However, As seen in, Figure 13 ETC users are still the majority winners of the ETC project among the three groups.

1.3.6.3 Effect of fuel consumption

Assumptions regarding fuel consumption also effects the outcome of the analysis. As stated earlier, we assume that the average fuel economy is 25 miles per gallon. This is a typical assumption for vehicles traveling on city streets. It may be low for a situation where vehicles are accelerating, especially for those light-duty trucks and spot utility vehicles, as well as large cars. To examine the possible effect of underestimating emission benefits and fuel savings, we assume a higher fuel consumption value of 15 miles per gallon. Under this assumption, the excess fuel used for a typical car accelerating from 0 to 55 mph in 13 seconds relative to a car traveling same distance at a steady speed of 55 mph would be about 50.5 ml. As a result, the estimate of total benefit increases to $14.2 million, $0.5 million higher than the estimate under the conservative assumption. The increase is largely due to fuel saving. The environmental benefit composes only a small proportion of the total increase, though it does rise by about 60 percent as compared to the earlier (Figure 14). Because of this reason, the distribution of net effect among the toll agency, the ETC users, and society will remain the same, namely the ETC users would benefit from the ETC service the most (Figure 15).

Figure 12

Effect of Time Value on Net Benefit

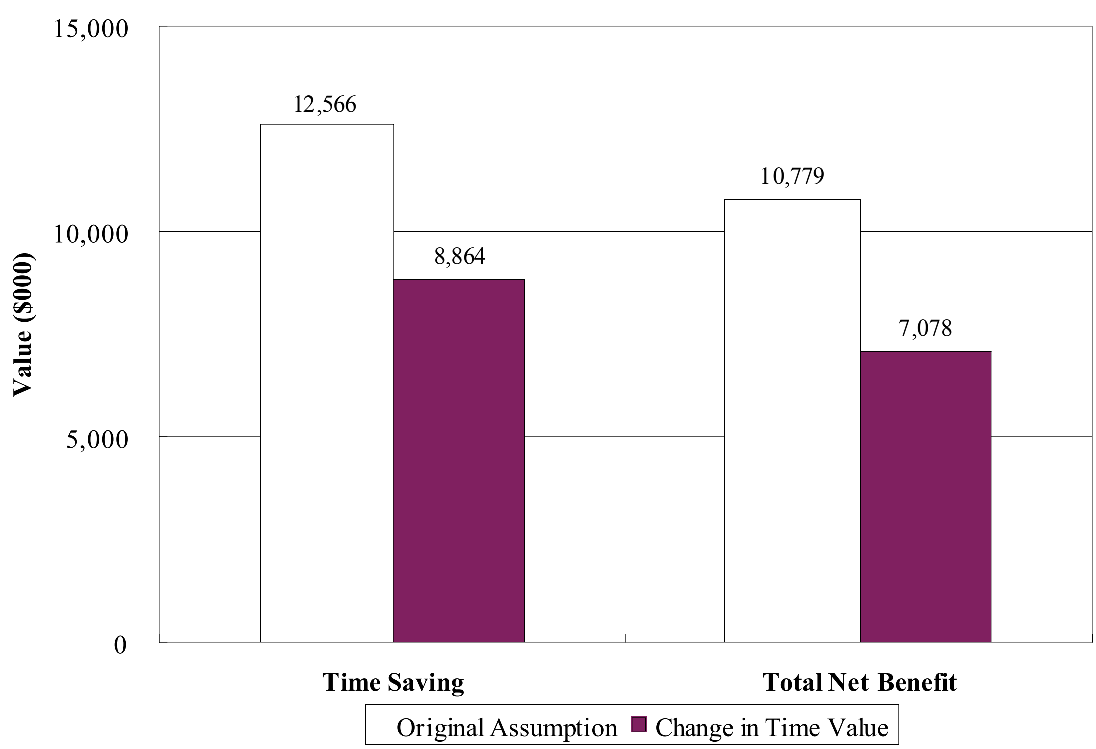


Figure 13
Effect of Time Value on Net Benefit Distribution

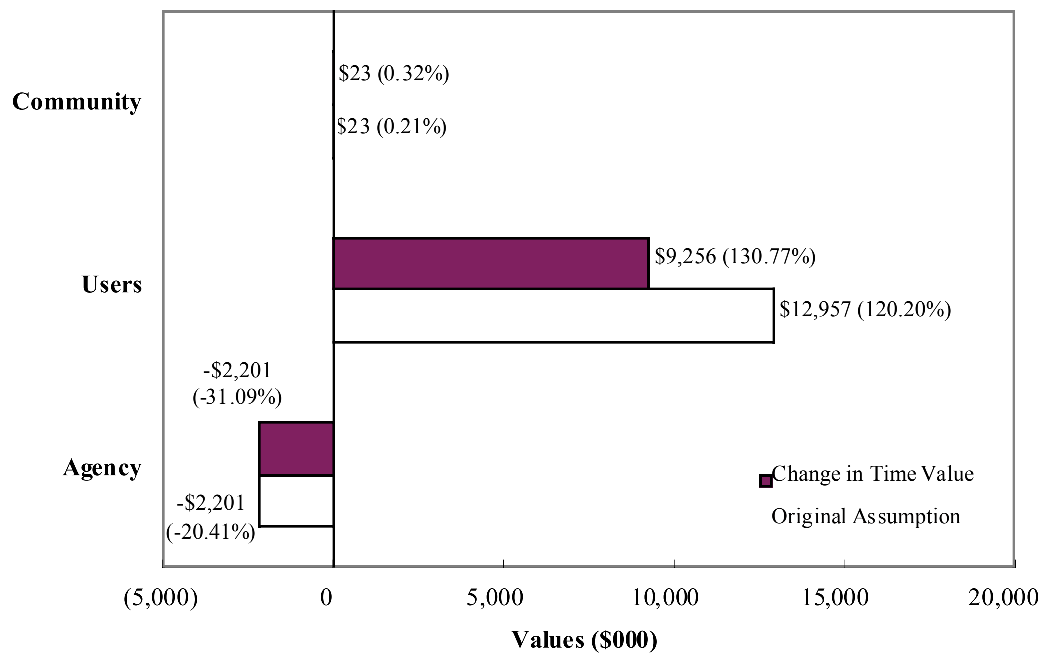


Figure 14
Effect of Fuel Consumption on Net Benefit

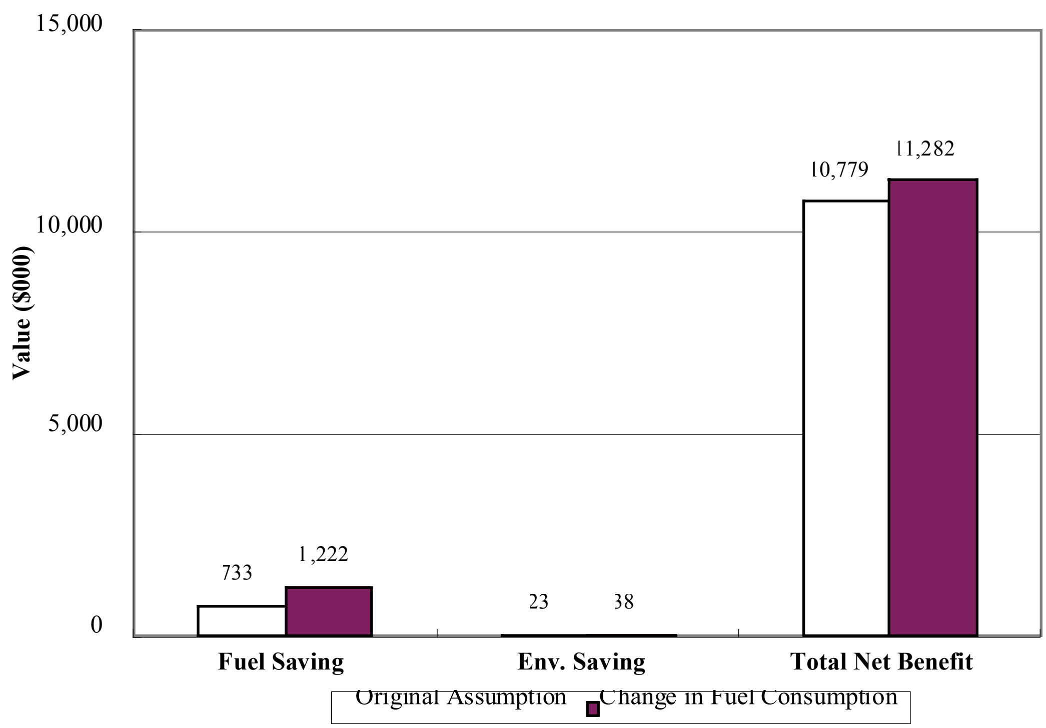
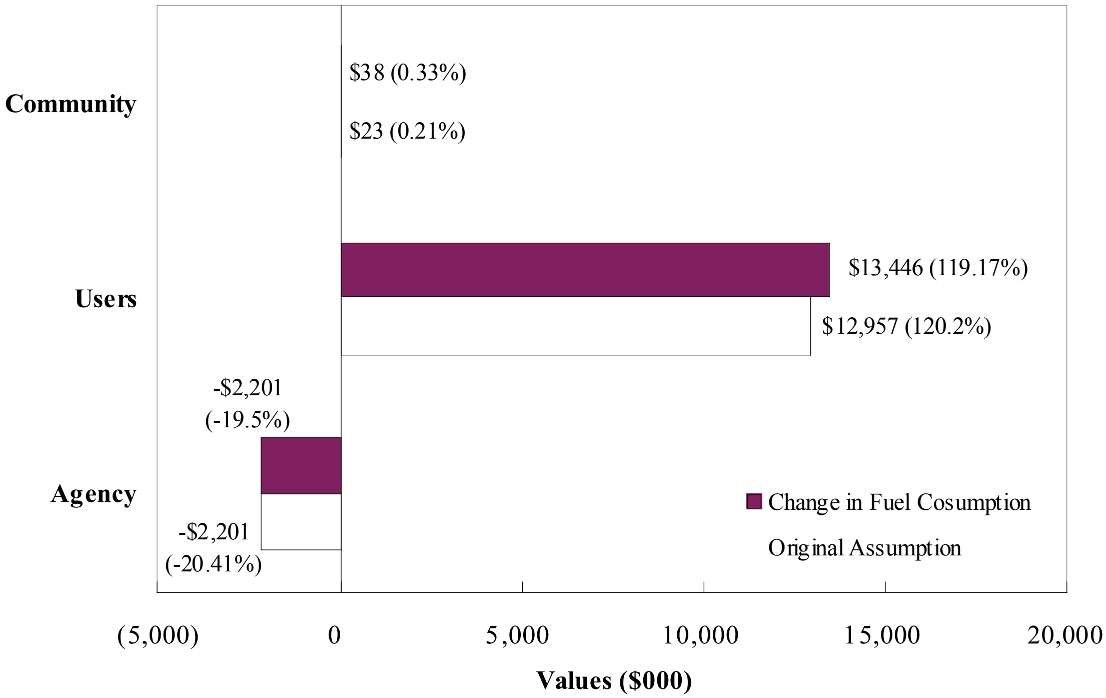


Figure 15

Effect of Fuel Consumption on Net Benefit Distribution



In sum, by examining the effects of ETC market share, time value, and fuel consumption and comparing the results with those under the previous assumptions, we found that in general, ETC users are the group that would benefit from the ETC project the most. The toll agency, on the other hand, would improve its facility and data collection with a cost of $2.2 million in the FY95 dollar over the evaluation period. If the cost of transponders can be transferred to the ETC users, the cost of the toll agency would be significantly reduced to about $0.14 million. The change of ETC market share would have a relatively large effect on the total net benefit and benefit distribution among the toll agency, ETC users, and community. In comparison, the changes of assumptions on time value and fuel consumption would have some effects on total net benefits, but almost no effect on the benefit distribution among the three groups.

2.0 CONCLUSION

In this report, we have followed steps provided in the Evaluation Methodologies for ITS Applications and conducted a benefit-cost analysis for the ETC project in Carquinez Bridge. We laid out the temporal and spatial framework for the evaluation, identified and quantified the benefits and costs of the ETC project based on established assumptions, and finally analyzed the total effect and its distribution among the toll agency, users, and society. In addition, we examined the effects of ETC market share, time value, and fuel consumption on the net benefits of the ETC project.

A number of conclusions can be drawn from this study. First, the evaluation framework provides basic guidelines for conducting a benefit-cost analysis. The lists of ITS benefits and costs are useful in helping evaluators identify the specific benefits and cost of a specific ITS project. While the cost estimation is relatively easy, the benefit estimations are difficult tasks. They require sophisticated assumptions and modeling techniques to provide inputs for the estimations. Difference assumptions and modeling techniques will result in different inputs for calculation of benefits. They can alter the outcomes of the evaluation. This implies that ITS project evaluators should be fully aware of these limitations. Great effort should be placed in making and disclosing the assumptions for estimations of benefits and costs. There is an urgent need for collecting data from ITS deployments and developing models that can be used to accurately predict demands and benefits of ITS applications.

Secondly, this study found that based on our assumptions, total benefit of the ETC project would exceed its costs over the evaluation period. The total net benefit would be about $10.5 million in the FY95 constant dollar. Major benefits are time saving and fuel reductions. The project also generates environmental benefit, though the magnitude is relatively small. The finding suggests that from the viewpoint of whole society, the ETC project is worth pursuing.

Third, ETC users are the major winners of the ETC project. Although ETC users would have to pay for renting transponders and forego the interests generated in deposits, the benefits resulting from time saving and fuel reduction far exceed than those costs. In addition, the ETC increases travel convenience. Hence, the ETC project certainly fulfills one of its objectives: "provide an acceptable level of service for toll patrons."

Fourth, the evaluation results indicate that while the ETC system will save the toll agency operating and maintenance cost after the fourth year, the saving in subsequent years could not offset the initial capital cost in constant dollars. Although the ETC project does generate additional operation revenue to the agency, the cost saving and operation revenue would not offset the cost of the ETC project over the entire evaluation period. From this point of view, the ETC system does not meet the original expectation about reducing the overall toll collection cost. However, the ETC system would enable the toll agency to collect data on traffic volume, traffic speed, and type of vehicles from vehicles equipped with ETC transponders. It will also allow the toll agency to set real time tolls. Hence, it does "increase the quality of data collection and provide information currently not available."

Fifth, the study reveals that the cost of ETC transponders is a significant expenditure for the toll agency. If the cost can be reduced or transferred to the ETC users without affecting the demand for ETC, it would reduce the agency cost substantially.

Finally, sensitivity analyses indicate that the change of assumption on ETC market share would have a relatively large effect on the result of the benefit-cost analysis. It alters not only the total net benefit, but also the distribution of the net present value among the toll agency, ETC users, and society. In comparison, the effects of changing assumptions on time value and fuel consumption are relatively minor. They affect the total net benefit, but not the distribution of the benefit. The finding implies that the market share of ETC usage is an important factor for success. Toll agency should place great efforts in marketing.

To summarize, the findings of this study suggest that overall, the ETC project will meet most of its objectives. It will provide a higher level of service quality to toll patrons, improve the quantity and quality of data collection, increase traffic flow on toll bridges, and reduce vehicle emissions and fuel consumption. However, the environmental benefit of the ETC project may be small. In addition, saving in toll collection may not offset the initial capital investment if the demand for ETC usage is limited and the cost of transponders is high. Hence, promoting ETC while reducing cost are essential for cost recovery and benefit enlargement.

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Appendices

An Illustration of Benefit-Cost Method for the ETC System at Carquinez Bridge

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Appendix A:

Cost Estimation: Assumptions and Methodology

This paper presents the procedures of cost estimation for the baseline and ETC alternatives. The cost estimates of the toll agency and users under each alternative are provided separately. Since the installation of ETC system does not involve direct cost from society other than the toll agency, though it represents the state government in this particular case, the cost of society is not the subject of cost estimation here.

1. Baseline Costs:

The operation cost of the toll agency for continuing the current service is the major tangible cost of the baseline. User and society costs of the baseline can be considered to have a zero base and any additional or reduction in user and/or society costs generated by ETC will be calculated as net cost or benefit. Hence, this section focuses on agency cost estimation only.

- *Agency cost*

The ATCAS Feasibility Study Report provides aggregated cost estimations for the nine bridges owned by Caltrans (Caltrans, 1995). To estimate cost for the Carquinez Bridge, the data must be disaggregated and re-assembled. In general, the costs that are shared by all nine bridges are divided by the proportion of toll lanes or number of bridges, depending on whether the cost is most likely to be associated with lane or with bridge.

Since there will be no major capital improvement, the cost of baseline involves only ***continuing existing (M&O) costs***. The *total information technology cost and total program cost* are the two major components of the M&O costs. The *information technology cost* consists of the costs of "continuing staff" and "hardware/software."

"Cost of continuing staff" is the cost of one-person year (PY) for the computer service support to assist the personnel of the accounting center at District 4 with problems downloading and storing toll data. Since the center serves all nine bridges, the share of this cost for the Carquinez bridge is computed as one-ninth of the PY cost. The unit cost of a PY is assumed to be $65,000 per year. The cost is assumed to increase at an annual inflation rate of 3%.

"Cost of continuing hardware/software" are materials and operation costs, such as the costs of printer paper, ribbons, diskettes, troubleshooting, recovering lost data, and locating parts and service vendors. According to Caltrans' Feasibility Study Report, such costs were assumed to be half of the materials and operations costs shown in Appendix F of the feasibility study report. The cost of materials was estimated to increase by 20% a year because of the increasing difficulty in finding replacement parts. The cost of operation is estimated to increase at 7% a year. In our analysis, we calculated the cost of this category for the Carquinez Bridge by multiplying the total cost of this category by the proportion of toll lanes (12) at the Carquinez

Bridge over the total number of toll lanes (75) for all the nine bridges. This approach assumes a correlation between materials and operation costs and the number of toll lanes.

The *program cost* consists of the "cost of toll collecting and accounting staff," and "other costs" such as the commute ticket booklet contract, and maintenance costs for the existing system. In recent year, total PYs required for the management and operation of Carquinez bridge have been 42 full-time and 23 part-time employees, equivalent to 61.5 full-time PYs after converting the number of part-time employees (1,500 hours per year per person) to full-time PYs (1,768 hours per person per year).[1] In Caltrans' report, it was assumed that the number of PYs with the baseline will remain the same over the whole evaluation period. The maintenance and other miscellaneous costs for the Carquinez bridge are parted from the system total by its ratio of toll lanes (12/75) since those costs are mostly related to number of toll lanes.

2. The costs of ETC project

Tangible costs of ETC alternative include expenditures for acquiring ETC equipment and those for ETC operation and maintenance. The capital and operation costs for providing ETC service are those of toll agency. Since ETC users are required to prepay for setting up an ETC account and maintain a certain amount of balance in their accounts, there is a user cost involved under the ETC alternative. These costs are estimated as follows.

- *Agency cost*

Table A-1: Summary of ETC System Costs

Summary of ETC Process Control Cost	
In_Lane Subsystems	$786,560
ETC Addition to In-Lane Subsystems	$1,113,265
Sub-total	$1,899,825
Contingencies 5%	$94,991
Total Process Control Costs	$1,994,816
Summary of Data Processing Cost	
Plaza Computer Subsystems	$310,638
Host Computer Subsystem	$65,414
Documentation, Training & Installation - Carquinez Bridge (1/9)	$90,915
ETC Account & Patron Service - Carquinez Bridge (1/9)	$423,019
TC Software Development & Licensing - Carquinez Bridge (1/9)	$76,228
Subtotal	$960,639
Contingencies 5%	$48,032
Total Data Processing Costs	$1,014,525

[1]The number is provided by the Captain of Carquinez bridge on April 14, 1998.

Table A-2: ETC Process Control Components

In-Lane Subsystems			
Item Description	**Unit ($)**	**Quantit y**	**Subtotal ($)**
Lane Controller	18,846	12	226,152
Ergonomic Toll Terminal	2,739	12	32,868
Touch Screen Terminal	10,794	12	129,528
Magnetic Card Reader	270	12	3,240
Receipt Printer	956	12	11,472
Receipt Printer Enclosure	717	12	8,604
Mounting Plates	62	12	744
Booth "A" Cabinet	3,252	12	39,024
Heater/Cooling Unit	2,157	12	25,884
Cabinet Light	140	12	1,,680
VTDM Camera (color)	3,882	3	11,646
Hi-Fi VCR	717	3	2,151
Male F/O RS-232C Transceiver	340	12	4,080
80486-33 MHz Computer	6,570	1	6,570
16-Port RS-232 Board	1,448	1	1,448
16-Port DB25	412	1	412
Modem-9600 Baud	878	1	878
Audio Data Interface	2,369	1	2,369
80 Column Character Generator	2,743	1	2,743
16 Channel Serial I/O Board	3,182	1	3,182
Misc. Cables & Connectors	1,425	1	1,425
12" Color Monitor	1,151	1	1,151
Video Switcher	2,362	1	2,362
VCR Cabinet	1,754	1	1,754
Misc. Hardware & Connectors	1,317	1	1,317
Misc. Materials (Conduit, Cables...)	7,261	1	7,261
Lane Controller Software Development	412,193	0.16	65,951
Lane Controller Software Licensing	237,377	0.16	37,980
In-Lane Subsystem Freight/Installation	954,271	0.16	152,683
Total In-Lane Subsystems Costs			**$786,560**

Table A-2: ETC Process Control Components (Cont'd.)

ETC Addition to In-Lane Subsystems			
Item Description	**Unit ($)**	**Quantity**	**Subtotal ($)**
ETC Reader & Antennae	17,531	12	210,372
VDS Color Camera	2,415	12	28,980
VDS Color Camera High Resolution	2,358	12	28,296
Camera Accessories	11,740	12	140,880
VDS Server	20,207	1	20,207
Review Monitor	2,653	1	2,653
Ethernet Adapter & Hub	7,982	1	7,982
Audio Codec	253	1	253
Network Router	7,577	1	7,577
Optical WORM Disk Drive	7,313	1	7,313
VDS Cabling	5,051	1	5,051
VDS Light Source	478	12	5,736
Enforcement System	32,019	1	32,019
AVC Fiber Optic Axle Counter	3,553	12	42,636
AVC Scanning Infra-red Sensor	19,082	12	228,984
Patron Toll Display	5,204	12	62,448
In-Lane ETC Freight/Installation	1,761,737	0.16	281,878
Total ETC Additional Costs			**$1,113,265**

Table A-3: Data Processing Components

Plaza Computer Subsystems			
Item Description	**Unit ($)**	**Quantit y**	**Subtotal ($)**
DEC Alpha Model 400 Workstation	26,073	1	26,073
System Disk Enclosure	1,708	1	1,708
Dual Disk Drives	5,117	2	10,234
Disk Shadowing Software	4,838	1	4,838
Optical Worm Drive	10,293	1	10,293
Worm Drive Cartridge	196	4	784
Optical Worm Jukebox Software	4,286	1	4,286
Synchronous Display Port	2,938	1	2,938
Synchronous Modem	4,092	1	4,092
Four Port Ethernet Module	2,455	4.67	11,457
FO Fault Tolerant Transceiver	1,361	12	16,332
17-Slot Rack Mount Concentrator	5,574	1	5,574
Ethernet Backplane	1,251	1	1,251
Ethernet Server	2,146	2	4,292
Ethernet Repeater	1,829	2	3,658
FO Repeater	831	1	831
Cartridge Tape Subsystem	6,326	1	6,326
Portable Maintenance Computer	3,767	1	3,767
System Printer	8,140	1	8,140
Portable Equipment Racks	706	1	706
VDT's w/ Computers	2,606	4	10,424
Operating System Software	499	4	1,996
Sergeants / Observation Printer	994	2	1,988
Captain Printer	475	1	475
Maintenance Printer	2,073	1	2,073
Large Format Pen Plotter	5,349	1	5,349
50 KVA Uninterruptible Power Supply	84,357	1	84,357
Plaza Subsystem Software Licensing	549,856	0.11	61,095
Plaza Subsystem Software Licensing	137,707	0.11	15,301
Total Plaza Computer System Costs			**$310,638**

Table A-3: Data Processing Components (Cont'd.)

Host Computer Subsystem			
Item Description	**Unit ($)**	**Quantity**	**Subtotal ($)**
DEC Alpha Model 500 workstation	37,990	1	37,990
Memory Expansion Modules	7,493	1	7,493
System Console Printer	846	1	846
System Console Terminal	748	1	748
Operating System Software License	3,257	1	3,257
Dual Disk Drives	4,614	2	9,228
Disk Shadowing Software	4,493	1	4,493
9-Track System Tape Drive	11,382	1	11,382
Tape Controller Card	1,751	1	1,751
Transportable Tape Subsystem	5,874	1	5,874
Optical Worm Drive	9,558	1	9,558
Worm Cartridge	182	4	7,28
Optical Worm Jukebox Software	3,980	1	3,980
2000 LPM Printer	42,968	1	42,968
Print Server	4,309	1	4,309
Laser Printer	7,558	1	7,558
VDT w/ Personal Computer	2,156	16	34,496
Ethernet Cards	264	16	4,224
Operating System Software	422	16	6,752
Personal Character Printers	877	16	14,032
Communication Cabinet	3,161	1	3,161
Synchronous Communication Router	24,790	1	24,790
Router Communication Software	567	1	567
Synchronous Ports-WAN	9,641	2	19,282
Modem Control Panel	1,156	1	1,156
Modem Rack	4,154	2	8,308
Synchronous Modems	3,229	16	51,664
Asynchronous VDT Hub	1,162	2	2,324
Asynchronous VDT Repeater	1,698	4	6,792
Asynchronous Communication Server	1,551	4	6,204
Asynchronous Modem Rack	134	4	536
Asynchronous Modems	1,988	8	15,904
Multiplexer Server	3,987	3	11,961
Portable Maintenance Computer	3,498	1	3,498
Cash Room 8-Port Serial Interface	1,551	1	1,551
20 KVA Uninterruptible Power Supply	59,243	1	59,243
Host Subsystem Software Licensing	123,648	1	123,648
Host Subsystem Freight/Installation	36,468	1	36,468
Total Host Computer Subsystem Costs			**$588,724**

The agency cost for the ETC alternative includes three major categories: ***one-time capital costs of the process control components, data processing costs; and continuing existing (M&O)***

costs. The ETC process control and data processing costs are summarized in Table A-1. The cost components are described below.

The ***process control costs*** contain capital investments for the "*In-Lane Subsystems*" and the "*ETC Addition to In-Lane Subsystems*." Basic components of the process control are ETC reader, lane controller, automatic vehicle classification system, violator detection system, patron toll display, and terminals. A complete list of the process control components, unit cost of each component, number of unit associated with each component, is shown in Table A-2. The cost of each component is calculated by multiplying the number of units and the unit cost. Shared cost of all bridges is multiplied by 0.16, the ratio (12/75) to obtain the cost for the Carquinez bridge because most of component costs are related to the number of toll lanes. The sum of those costs is the total process control costs for the Carquinez Bridge.

Data processing costs are expenditures for *ETC hardware/software and services*. The data processing components are listed in Table A-3. The annual cost of transponders is the product of the number of newly issued transponders in a year and the unit cost of transponders. According to Caltrans' feasibility study report, the unit cost of an interior transponder is about $28 and that of an exterior transponder is about $41. Since the hardware and software at the center office and PY of service support are for all nine bridges, the cost for the Carquinez Bridge is derived as one-ninth of
the total data process costs.

The ***continuing existing (M&O) costs*** contain both *total information technology costs* and *total program cost*. *Total information technology costs* include recurrent costs of staff and hardware/software for the support and operation of ETC data process at the center office. As indicated earlier, the cost of continuing staff allocated to the Carquinez bridge is calculated as one-ninth of the PY cost, since the PY at the district account center serves all nine bridges. Cost of continuing hardware/software for Carquinez Bridge is assumed to be 16%[2] of the information technology cost of all nine bridges since materials and operation costs are most likely to be associated with number of lanes.

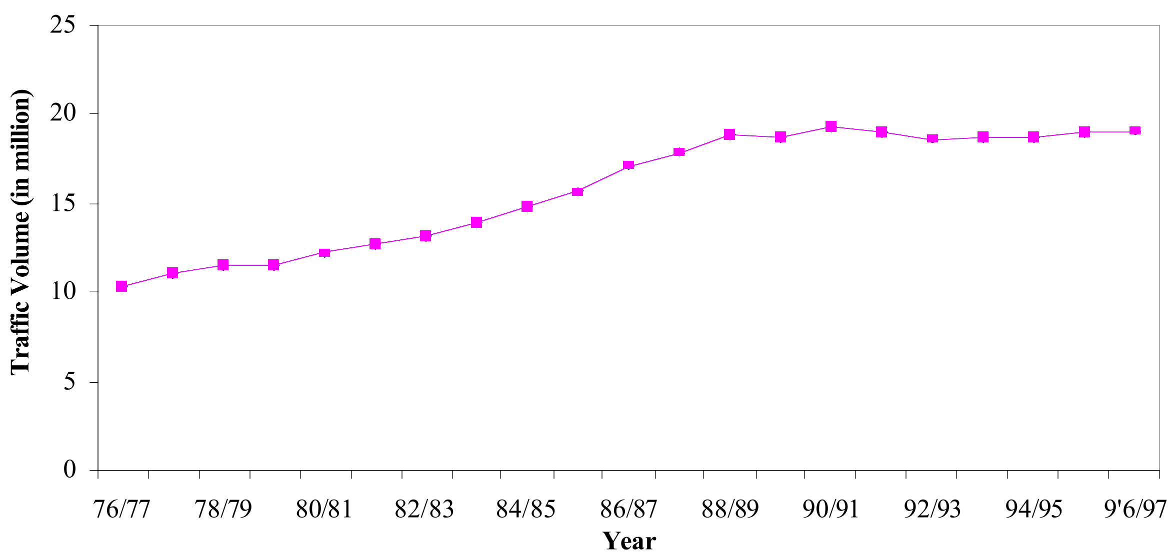
Total program costs are expenditures occurring at the toll plaza, such as toll collectors, administrative PYs, material and maintenance costs, and other miscellaneous operation costs such as expenditure for service contracts, credit card transaction fees, *etc*. The costs other than PYs are proportioned from the total cost estimates of the nine bridges by Caltrans, based on the share of lanes. Travel volume and the market share of ETC usage largely determine the cost of PYs. The more travelers using ETC and the more dedicated ETC lanes are opened, the fewer PY's necessary. In order to estimate travel volume, ETC demand, and PY costs in the coming years, we made the following assumptions:

[2]This is the ratio of number of lane (12) in the Carquinez Bridge over total number of lane (75) in the nine bridges.

(1) traffic demand will be grow at an average rate of 3% per year[3];
(2) ETC use rate will be 6% for the first year, 15% for the second year, and increase 5% per year after then.
(3) toll transaction time is assumed to be 2.4 seconds per ETC transaction; 10 seconds per cash transaction; and 4.5 seconds per ticket transaction;
(4) all ETC transactions are concentrated in certain time period of a day so that the toll agency can open dedicated ETC lanes for the transactions; and
(5) the toll agency has complete flexibility for hiring part-time employees who are paid on hourly basis.

The assumption of traffic demand is made on the basis of historical data of traffic volume in Carquinez Bridge. According to the data, traffic on the bridge has increased at an average rate of 3 percent per year over the last 20 years (Figure A-1). This study presumes that such a trend will remain the same in the next 10 years.

Figure A-1: Annual Traffic Volume at the Carquinez Bridge (FY77 - FY 96)



The assumption on ETC demand is made on the basis of several considerations. First, according to the Daily Traffic Reports for Carquinez Bridge from September 1997 to April 1998, the average ETC usage is about 3.7 percent of total traffic volume (Table A-4). Considering that ETC usage may increase in the period between May and June 1998, the average annual rate of

[3] This assumption exceeds the actual growth traffic on the Bridge but reflects the growth in traffic in general.

ETC usage in FY97/98 is adjusted to 6 percent. Second, since the ETC systems are expected to be installed for public use in all bridges in the Bay Area,[4] it is expected that there may be a surge in ETC usage in Carquinez Bridge in FY98/99, and most of the ETC users may be previous ticket users. In FY96/97, ticket trips counted for about 17 percent of total trips at Carquinez Bridge (Caltrans, 1997). It may be realistically expected that about 80 percent of the previous ticket users and 1 to 2 percent of cash users will use ETC when ETC is available on all the bridges in the Bay Area. A result of this assumption is 15 percent increase in ETC usage in FY98/99. Third, the longer the ETC system is in operation and the more familiar the public is with the ETC and its benefits, the more likely motorists will become ETC users. The annual ETC growth rate of 5 percent after FY98/99 is crosschecked with reference to ETC market shares of ETC systems in other regions throughout the U.S. According to Electronic Toll and Traffic Management (ETTM), , the market share of ETC usage for ETC systems in the United States ranges between 2% ~ 65% of annual average daily trips except the SR91 in California, which requires ETC transponders for the use of the toll facility (Table A-5).

Table A-4: Monthly Traffic at the Carquinez Bridge

Time	Total Transaction	E.T.C. Transaction	% of E.T.C.
Aug 1997	1,777,931	3,472	0.20%
Sep 1997	1,591,046	27,169	1.71%
Oct 1997	NA.	NA.	NA.
Nov 1997	1,536,173	44,828	2.92%
Dec 1997	1,518,552	54,411	3.58%
Jan 1998	1,453,338	67,698	4.66%
Feb 1998	1,437,066	74,915	5.21%
Mar 1998	1,617,304	91,586	5.66%
Apr 1998	1,631,233	89,925	5.51%
Average		56,751	3.7%

[4]Caltrans plans to install ETC on all the bridges, with one dedicated ETC lane per bridge, in the Bay Area by September, 1998 (conversation with Mr. Wyne Miller, ETC project manager, April 22, 1998).

Table A-5: ETC System in the United States

Facility/ Agency	System Name	No. Tags Market Share (% of avg. daily peak)	Date Opened
Transportation Corridor Agencies Los Angeles (CA) Foothill Corridor (SR 241) San Joaquin Hills Corridor (SR 73)	FasTrak	75,000 58% (70%) 33%(68%)	1995
California Private Transportation Company Orange County (CA) State Route 91	91 Express Lanes	80,000 100%	1995
E-471 Public Highway Authority Denver (CO) State Route 470 Extension	EXPRESS TOLL	7,000 33%	1991
Orlando – Orange county Expressway Authority Orlando (FL) Beeline Expressway Central Florida Expressway East – West Expressway Seminole Expressway Southern Connector Extension	E Pass	76,000 12% (23%) 27% (36%) 29% (39%) NA. NA.	1995
Osceola County Kissimmee (FL) Osceola Parkway	O-Pass	1,500 10%	1995
Georgia State Tollway Authority Atlanta (GA) State Route 400	Cruise-Card	75,000 32% (48%)	1993
Illinois State Toll Highway Authority Chicago (IL) TriState Tollway East - West Tollway North - South Tollway	I-PASS	23,000 2% 3% 5%	1994
Kansas Turnpike Authority Kansas Kansas Turnpike	K-TAG	68,000 22% (60%)	1995
Greater New Orleans Expressway Commission New Orleans (LA) Lake Pontchartrain Causeway	TollTag	19,000 60% (90%)	1990
Louisiana Department of Transportation and Development New Orleans (LA) Crescent City Connection Bridge	TollTag	80,000 40% (50%)	1989
Massachusetts Turnpike Authority Massachusetts Third Harbor Tunnel	MassPass	2,200 10% (15%)	1995

Source: ETTM on the Web

Table A-5: ETC System in the United States (Cont'd.)

Facility/ Agency	System Name	No. Tags Market Share (% of avg. daily peak)	Date Opened
New York State Thruway Authority (NY) Tappan Zee Bridge, Grand Island Bridges, Buffalo plazas, New York City to Albany plazas	E-Z Pass	200,000 10% (15%)	1993-95
Metropolitan Transportation Authority of Bridges and Tunnels New York City (NY) Bronx-Whitestone Bridge Brooklyn Battery Tunnel Cross Bay Bridge Henry Hudson Bridge Marine Parkway Bridge Queens Midtown Tunnel Throgs Neck Bridge Triborough Bridge Verrazano Narrows Bridge	E-Z Pass	570,000 34% (40%) 39% (40%) 38% (22%) 45% (42%) 49% (34%) 37% (38%) 41% (44%) 31% (33%) 46% (55%)	1995
Port Authority of New York and New Jersey New York City (NY) Lincoln Tunnel Exclusive Bus Lane		3,500 3%	1989
Oklahoma Turnpike Authority Oklahoma Cimarron Turnpike Cherokee Turnpike Chickasaw Turnpike H.E. Bailey Turnpike Indian Nation Turnpike Kilpatrick Turnpike Muskogee Turnpike Turner Turnpike Will Rogers Turnpike	PIKEPASS	332,300 36% 28% 22% 54% 31% 25% 69% 35% 40% 31%	1991
Texas Turnpike Authority Dallas (TX) Dallas North Tollway	TollTag	120,000 43% (57%)	1989
Harris County Toll Road Authority Houston (TX) Hardy Toll Road Sam Houston Tollway Sam Houston Tollway Ship Channel Bridge	EZ Tag	65,000 15%	1992
Virginia Department of Transportation and the Toll Road Investment Partnership II Virginia Dulles Toll Road Coleman Bridge Dulles Greenway	FasToll	80,000 19% (34%) 65% (75%) 24% (30%)	1996

Source: ETTM on the Web

The assumption on toll transaction times is adopted from Caltrans' feasibility study report. Based on the above assumptions, the annual traffic volume, ETC demand, and PY reductions are calculated by the following formulas:

$$TV_n = TV_{(n-1)} * (1 + i) \qquad (1)$$
$$ETC_n = TV_n * i_{ETC} \qquad (2)$$
$$PYs_n = (ETC_n / ETC) / U_{PY} \qquad (3)$$

Where:

TV_n: Total annual traffic volume in year n;
$TV_{(n-1)}$: Total annual traffic volume in prior year (n-1);
iTV Average annual traffic increase rate;
ETC_n: Total ETC transactions in year n;
i_{ETC}: Assumed percentage of ETC transactions in a year;
ETC_{Cap}: The capacity of an ETC lane, which equals 1500 (3600/2.4) transactions per hour;
PYs_n: Annual PY savings in year n;
U_{PY}: Unit of PY, which is assumed to be 1768 hours per PY by Caltrans.

The annual PY savings are listed in Table A-6. However, it should be noted that if the ETC transactions are dispersed during the time of a day, the toll agency may not be able to open more dedicated ETC lanes or operate ETC lanes for a longer time period, and have to operate toll lanes in mixed mode. As a result, the toll agency may not be able to save as many PYs as it would have been.

The annual costs are calculated as the sum of process control costs, data process costs, and continuing existing costs. The cash flows of the baseline and ETC project are discounted at 5% to FY95 dollars in order to compare with benefits.

Table A-6: Estimates of Annual Personal Year Saving

Year	Traffic /Y	% ETC Transactions	Total ETC Transactions	Yearly Hour Reduction	Yearly PY Reduction
95/96	19,016,173	0%	0	0	0.0
96/97	19,064,849	0%	0	0	0.0
97/98	19,636,794	6%	1,178,208	785	0.4
98/99	20,225,898	15%	3,033,885	2,023	1.1
99/00	20,832,675	20%	4,166,535	2,778	1.6
00/01	21,457,656	25%	5,364,414	3,576	2.0
01/02	22,101,385	30%	6,630,416	4,420	2.5
02/03	22,764,427	35%	7,967,549	5,312	3.0
03/04	23,447,360	40%	9,378,944	6,253	3.5
04/05	24,150,780	45%	10,867,851	7,245	4.1
05/06	24,875,304	50%	12,437,652	8,292	4.7

◆ *User cost*

Under ETC alternative, the main user cost is the loss of interest, the opportunity cost of holding money in a balance with Caltrans rather than in an interest earning instrument. The money is generated from deposits for ETC transponders and balance in users' ETC accounts. According to Caltrans in FY97, users are required to establish an account with Caltrans and to maintain a minimum balance of \$5 ~ \$10 in their accounts, depending on the type of payment selected. Those who pay cash for their ETC accounts are required to deposit \$30 for each transponder. The initial prepayment for an account is \$40 and a minimum balance for the cash account is \$10. Once the balance drops below \$10, users are required to prepay and bring their account balance up to at least \$30. Those using a credit card do not pay the \$30 deposit for transponders. Their minimum account balance is \$5. Once the account balance falls below the minimum requirement, an automatic recharge from their credit cards will bring the balance up to \$30. Based on such requirements, it is assumed that an ETC account has an average balance of \$20. Hence, a \$50 balance is assumed for the cash or check accounts and \$20 for credit card accounts. These average balances, after discounted to FY95 dollars at a rate of 5 percent, are \$29.28 and \$19.52 respectively. It is also assumed that among the ETC accounts, 64 percent are established with cash or checks and 36 percent are opened with credit cards. This assumption is based on a survey conducted by PATH in 1990 regarding users' response for ETC payments. In addition, it is presumed that the average tags per account is 1.35 and the average use rate is 160 per ETC account per year. The last two suppositions were made on the basis of FasTrak statistics provided by Caltrans since July 30, 1997 (Table A-7). Based on the above assumptions, annual user cost is calculated by the following steps:

1. Estimate the number of annual ETC transactions by multiplying the projected annual toll transactions by percentage of ETC transactions.
2 Estimate the number of ETC accounts established by cash and credit card respectively. This is done by first dividing the number of ETC transactions by the average ETC usage rate to derive the total number of ETC accounts (#ETC). The number (#ETC) is then multiplied by percentages of cash and credit card payment to obtain the numbers of ETC accounts established by cash and credit card. The equations are listed below:

$$ETC_{cash} = ETC * \%\ cash\ payment \quad (4)$$

$$ETC_{credit} = ETC * \%\ credit\ card\ payment \quad (5)$$

3. Compute the balances in cash and credit card accounts in FY95 dollars. That is:

$$B_{cash} = ETC_{cash} * (\$19.52 + \$29.28 * 1.35) \quad (6)$$

$$B_{credit} = ETC_{credit} * \$19.52 \quad (7)$$

4. Calculate total balance by summing up the balance of cash and credit card accounts; and
5. Assess annual interest revenue, which is the product of total balance and interest rate

Table A-7: FasTrack Statistics

Month	Account Opened/M	Com. Accounts	Transponders Issued/M	Com. Transponders
Jul-97	73	73	108	108
Aug-97	1,191	1,264	1,580	1,688
Sep-97	1,491	2,755	2,186	3,874
Oct-97	479	3,234	690	4,564
Nov-97	317	3,551	510	5,074
Dec-97	866	4,417	1,103	6,177
Jan-98	974	5,391	965	7,142
Feb-98	479	5,870	812	7,954
Mar-98	401	6,271	522	8,476
Apr-98	274	6,545	353	8,829
AVG./M	654.5	3,937.1	882.9	5,388.6
Tags/Account	1.35			
AVG./M (Aug-97 ~ Mar-98)	774.75	4,094.125	1,046	5,618.625
Tags/Account (Aug-97 ~ Mar-98)	1.35			

Source: Caltrans

Table A- 8: User Cost Estimates

Year	*(VII) Traffic/Y*	% ETC Users	# ETC Trans.	# ETC Accnt.	Minimum ETC Account Balance			
					Cash Account	Credit Card Account	Total ETC account balance	Annual interest
95/96	19,016,173	0%	0	0	$0	$0	$0	$0
96/97	19,064,849	0%	0	0	$0	$0	$0	$0
97/98	19,636,794	6%	1,178,208	7,364	$278,283	$51,747	$330,030	$6,601
98/99	20,225,898	15%	3,033,885	18,962	$716,579	$133,248	$849,828	$16,997
99/00	20,832,675	20%	4,166,535	26,041	$984,102	$182,994	$1,167,096	$23,342
00/01	21,457,656	25%	5,364,414	33,528	$1,267,032	$235,605	$1,502,637	$30,053
01/02	22,101,385	30%	6,630,416	41,440	$1,566,051	$291,208	$1,857,259	$37,145
02/03	22,764,427	35%	7,967,549	49,797	$1,881,871	$349,935	$2,231,806	$44,636
03/04	23,447,360	40%	9,378,944	58,618	$2,215,231	$411,923	$2,627,155	$52,543
04/05	24,150,780	45%	10,867,851	67,924	$2,566,899	$477,316	$3,044,216	$60,884
05/06	24,875,304	50%	12,437,652	77,735	$2,937,674	$546,262	$3,483,936	$69,679

The results are shown in Table A-8. No charge is included in the user cost calculation because the price of toll is not affected by the introduction of ETC. In general, user cost also includes time. Since it is presumed that the use of ETC system will reduce users' travel time for passing toll facilities, the difference between times for passing a manual toll plaza and an ETC toll facility will be a benefit.

- *Community cost*

Social cost is the resource that a society may use for environmental improvement. Since ETC is expected to allow vehicles travel at a normal speed without stopping, it would reduce vehicle emissions. Hence, the savings for environmental cost will be calculated as an environmental benefit.

Appendix B

Estimation of Time Saving

Since an ETC system allows toll transactions to be performed while vehicles travel at a normal travel speed, it will reduce travel time. This time saving is the difference between times for passing a manual toll plaza and an ETC toll facility. Users will be the main beneficiaries of timesavings.

Like any other benefits, the basic estimation process includes establishing assumptions, quantifying timesavings, and converting timesavings to dollar terms. These steps are explained in the following sections.

- **Assumptions**

The effect and value of timesavings by ETC system are affected by a number of factors. These factors include the total number of ETC transactions and the distributions among various travel modes. It also includes the payment methods that the ETC patronage would have used if tolls are collected manually. In addition traffic volume, speed, and delays in different travel time periods under the scenarios of manual toll collection and ETC, vehicle occupancies of various modes, transaction time by types of payment, and the value of time are all included. Those assumptions are listed in Table B-1 and explained below.

1. Total traffic volume in the Carquinez Bridge is assumed to increase at an average rate of 3 percent per year.

2. The percentage of ETC transactions over total toll transactions is assumed to be 6 and 15 percent in FY97/98 and FY98/99 respectively, and increase 5 percent annually afterward.
3. The split among the ETC users is supposed to be 94.76 percent for automobiles, 5.11 percent for trucks, and 0.13 percent for buses. These numbers are derived from the "1996-97 Annual Financial Report: State Owned Toll Bridges." The split is applied to the calculations after FY98/99 because in FY97/98, only 2-axle vehicles are allowed to use the ETC lane.[5] Since most 2-axle vehicles are automobiles, the timesaving in FY97/98 include only those from automobiles.[6]

4. Average vehicle occupancy is assumed to be 1.8 for automobiles, 1.1 for trucks, and 20 for buses. These numbers are nationwide averages as shown in Table B-2.

5. According to Caltrans' FY97 financial report, about 17 percent of the toll payments were tickets and about 83 percent were cash. We assume that about 30 percent of the ticket transactions change to ETC payments in FY97/98, about 80 and 100 percent of ticket

[5] This information was obtained from a conversation with Mr. Miller, manager of the ETC Project at Caltrans, on April 22, 1998.

[6] This is treated as constant for this application but the ETC split should reflect the general traffic split as ETC approaches 100 %.

users will utilize ETC in FY98/99 and FY99/00 respectively. The rest of the ETC users would be previous cash users. This assumption is necessary for the calculation of timesaving as a result of switching to ETC payment from ticket and cash payments.

Table B- 1: Assumptions for Calculation of TimeSaving

Items	Assumptions
Annual traffic growth rate (i_{TV})	3%
Annual growth rates of ETC transactions (i_{ETC})	6% in FY97/98, 15% in FY98/99, 5% annually afterward
% automobiles (i_{auto})	94.76%
% trucks (i_{truck})	5.11%
% buses (i_{bus})	0.13%
Average auto VOC (VOC_{auto})	1.8
Average truck VOC (VOC_{truck})	1.1
Average bus VOC (VOC_{bus})	20
Percent change from ticket to ETC ($i_{ETC-ticket}$)	30% in FY97/98; 80% in FY98/99; 100% afterward
Seconds/cash transaction	10
Seconds/ticket transaction	4.5
Seconds/ETC transaction	2.4
Normal travel speed (mph)	55
Average speed of deceleration/acceleration (mph)	27.5
Ramp distance prior to or leading from the toll plaza (mile)	0.2
Time Value ($/hour) for autos (in 95$)	$12.75
Time Value ($/hour) for trucks (in 95$)	$33.41
Time Value ($/hour) for buses (in 95$)	$12.75

6. Toll transaction time is assumed to be 10 seconds per cash transaction, 4.5 seconds per ticket transaction, and 2.4 seconds per ETC transaction respectively. These assumptions are adopted from Caltrans' feasibility report.

7. It is assumed that vehicles travel through the toll plaza at an average speed of 55 miles per hour under ETC alternative while with deceleration and acceleration the average speed is 27.5 mile per hour under manual toll collection system.

8. The distance on ramps prior to or leading from the toll plaza is about 0.2 miles. Total distance on both sides of the toll plaza is about 0.4 miles.

9. Value of time is assumed to be $12.75 per hour for automobile travelers and $33.41 per hour for 3- or more axle trucks. The hourly values are computed by taking the estimates of the value of hourly travel time (in 1988 dollars) used by Highway Economic Requirements System (HERS),[7] and convert them to the FY 1995 dollar by applying a factor of 1.33. The factor is based on employment cost index published by the U.S. Bureau of Labor Statistics. The average value of 3-4 axle, 4-axle, and 5-axle trucks indicated in the HERS document is used for the value of 3- or more axle trucks.

Table B- 2: Nationwide Average VOC (1995)

Type of Vehicle		Vehicle-Miles (millions)	Passenger-Miles (millions)	Average Occupancy
Automobile[a]	Passenger Cars & Taxis	1,541,458	2,834,653	1.84
Truck[b]	Other 2-Axle 4 Tire Vehicles, Single-Unit	686,977	904,979	1.32
	2-Axle 6-Tire or More	62,706	62,706	1
	Combination Trucks	115,454	115,454	1
	Average			1.1
Bus	All Buses	6,383	135,320	21.2
	School Buses	5,000[c]	95,000[c]	190

a. U.S. DOT/FHWA, Highway Statistics, 1996.
b. U.S. DOT/FHWA, Highway Statistics, 1996.
c. National Safety Council, Accident Facts, annual issues, pp.94, 95, 1996
Source: BTS on the Web

- **Quantification of Time Saving**

Timesaving are calculated by the following steps:

[7] The HERS is a computer model designed to simulate improvement selection decisions based on the relative benefit-cost merit of alternative improvement options by U.S. DOT (U.S. DOT, 1996).

1. Projection of annual traffic volume (TV) by equation (1).

$$TV_n = TV_{(n-1)} * (1 + i_{TV}) \qquad (1)$$

Where:
TV_n: the annual traffic volume in year n;
$TV_{(n-1)}$: the annual traffic volume in the year prior to year n;
i_{TV}: the average annual traffic increase rate.

2. Projection of annual ticket ($Ticket_n$) and cash ($Cash_n$) transactions.

$$Ticket_n = TV_n * i_{ticket} \qquad (2)$$
$$Cash_n = TV_n * i_{cash} \qquad (3)$$

Where:
i_{ticket} and i_{cash} are percentages of ticket and cash transactions, which are assumed to be about 17 and 83 percent respectively.

3. Projection of annual ETC usage by equation (4).

$$ETC_n = TV_n * i_{ETC\_n} \qquad (4)$$

Where:
ETC_n: the annual ETC usage in year n;
i_{ETC_n}: the ETC usage rate as a percent of total traffic volume in year n.

4. Estimation of ETC transactions changing from ticket and cash transactions based on assumption #5 above.

$$ETC_{ticket\_n} = Ticket_n * i_{ETC\_ticket} \qquad (5)$$
$$ETC_{cash\_n} = ETC_n - ETC_{ticket\_n} \qquad (6)$$

5. Estimation of toll transaction time saving (T_{m_etc}, in hours) resulting from the changes of ticket and cash to ETC payments by equation (7), based on assumption #6.

$$T_{m\_etc} = \frac{1}{3600} * [ETC_{ticket\_n} * (4.5 - 2.4) + ETC_{cash\_n} * (10 - 2.4)] \qquad (7)$$

6. Estimation of time saving (T_{a_l}, in hours) resulted from eliminating deceleration and acceleration based on assumptions #7 and #8.[8]

$$T_{a\_l} = ETC_n * [(T_a + T_l) - T] / 3600 \quad (8)$$

$$T_a = D_a/V_d \quad (9)$$

$$T_l = D_l/V_a \quad (10)$$

$$T = (D_a + D_l)/V \quad (11)$$

Where:

T_a: time for approaching the toll plaza. This is the time that a vehicle travels between the point where the vehicle begins to decelerate and the toll plaza where the vehicle stops.

T_l: time for leaving the toll plaza. This is the time that a vehicle travels between toll plaza and the point where the vehicle has reached normal speed.

T: time for each vehicle traveling between the points where lanes are split and merged at normal travel speed.

D: distances on ramps prior to (D_a) or leading from (D_l) the toll plaza. The distance in Carquinez Bridge is about 0.2 mile.

V: average travel speeds; where V is the normal travel speed assumed to be 55 miles per hour; V_a and V_d are average speeds of acceleration or deceleration. It is assumed to be 27.5 miles per hour - half of the normal travel speed.

7. Calculation of total time saving (TS, in hours), which is the function of time reductions from toll transaction, deceleration, acceleration, vehicle headway -- the time between two consecutive vehicles as one leaves and another stops at the toll plaza, and queuing delays.

$$TS = T_{a\_l} + T_{m\_etc} + H + Q \quad (12)$$

Where:

H: total headway (in hours), which is the product of average headway per vehicle and total vehicles.

Q: total queuing delays (in hours). It is derived by multiplying average reduction in queuing time per vehicle by total vehicles.

[8] Note this assumption implies there is no congestion at the ETC lanes. This can easily be modified as ETC usage approaches 100%.

Estimating T_{a_l}, H, and Q requires substantial data. For the purpose of this study, we simplify the calculation to include T_{a_l} and T_{m_etc} only, because of the limitation of time for field data collection. Hence, the calculation of timesaving in this study is simplified as the following:

$$TS = (T_{a\_l} + T_{m\_etc}) \quad (13)$$

8. Calculation of vehicle occupancy (VOC) weighing factor (F), which equals the sum of VOC factors of autos, trucks, and buses expressed as the following:

$$F = (VOC_{auto} * i_{auto} + VOC_{truck} * i_{truck} + VOC_{bus} * i_{bus}) \quad (14)$$

   As indicated in assumption #3 above, the VOC factor is applied only for the years after FY98/99.

9. Computation of total weighted time saving by multiplying total time saving by vehicle occupancy weighing factor obtained from steps 7 and 8.

- **Valuation of Time Saving**

Time value is calculated by multiplying total timesaving with a unit value of time, usually measured by dollars per hour. The value of travel time is influenced by many factors, such as alternative uses of time, income, trip purpose, productivity of alternative activities that time will otherwise be used for, *etc*. (Lee and Pickrell, 1997). Where information on travelers' characteristics is available, those factors should be incorporated into the determination of time value. Alternatively, one can also adopt time indexes used in other sources as references, as long as there is a justification for the adoption. The time indexes of different year may be adjusted for inflation. In this case study, we create a factor of time value (F_t) based on assumptions #3 and #9. The factor (F_t) is calculated by the following formula:

$$F_t = U_{t\_auto} * i_{auto} * VOC_{auto} + U_{t\_truck} * i_{truck} * VOC_{truck} + U_{t\_bus} * i_{bus} * VOC_{bus} \quad (15)$$

Where U_{t_auto}, U_{t_truck}, and U_{t_bus} are units of time value for automobiles, trucks, and buses. As stated earlier, the value of time is assumed to be $12.75 per hour for automobiles and buses, and $33.41 per hour for 3- or more axle trucks. The hourly values are computed by taking the estimates of the value of hourly travel time (in 1988 dollars) used by Highway Economic Requirements System (HERS),[9] and converted to 1995 dollars by applying a factor of 1.33. The factor is based on employment cost index published by the U.S. Bureau of Labor Statistics. The value of 3- or more axle trucks is the average value of 3-4 axle, 4-axle, and 5-axle trucks indicated in the HERS document. The results of timesaving and value are shown in Table B-3.

[9]The HERS is a computer model designed to simulate improvement selection decisions based on the relative benefit-cost merit of alternative improvement options by U.S. DOT (U.S. DOT, 1996).

Table B-3: Estimates of Passenger Time Savings

IX.	Toll Transactions			ETC Transactions				Time Saving of Toll Transactions		Time Saving of Movement	Total Time Saving	VOC Factor	Total Time Saving	Factor of Time Value	Value of Time
	Total	Ticket	Cash	%	Total	ETC vs. Ticket	ETC vs. Cash	ETC vs. Ticket	ETC vs. Cash						
								(Hours, unweighted)	(Hours, unweighted)	(Hours, unweighted)	(Hours, unweighted)		(Hours, weighted)	($/H)	(FY95$)
95/96	19,016,173	3,270,782	15,745,391	0%	0	0	0	0	0	0	0	1.80	0	$22.95	$0
96/97	19,064,849	3,279,154	15,785,695	0%	0	0	0	0	0	0	0	1.80	0	$22.95	$0
97/98	19,636,794	3,377,529	16,259,266	6%	1,178,208	1,013,259	164,949	591	348	8,569	9,508	1.80	17,115	$23.96	$218,210
98/99	20,225,898	3,478,855	16,747,044	15%	3,033,885	2,783,084	250,801	1,623	529	22,065	24,218	1.79	43,298	$23.96	$580,177
99/00	20,832,675	3,583,220	17,249,455	20%	4,166,535	3,583,220	583,315	2,090	1,231	30,302	33,624	1.79	60,116	$23.96	$805,520
00/01	21,457,656	3,690,717	17,766,939	25%	5,364,414	3,690,717	1,673,697	2,153	3,533	39,014	44,700	1.79	79,919	$23.96	$1,070,878
01/02	22,101,385	3,801,438	18,299,947	30%	6,630,416	3,801,438	2,828,977	2,218	5,972	48,221	56,411	1.79	100,857	$23.96	$1,351,432
02/03	22,764,427	3,915,481	18,848,945	35%	7,967,549	3,915,481	4,052,068	2,284	8,554	57,946	68,784	1.79	122,979	$23.96	$1,647,856
03/04	23,447,360	4,032,946	19,414,414	40%	9,378,944	4,032,946	5,345,998	2,353	11,286	68,211	81,849	1.79	146,337	$23.96	$1,960,849
04/05	24,150,780	4,153,934	19,996,846	45%	10,867,851	4,153,934	6,713,917	2,423	14,174	79,039	95,636	1.79	170,986	$23.96	$2,291,139
05/06	24,875,304	4,278,552	20,596,751	50%	12,437,652	4,278,552	8,159,100	2,496	17,225	90,456	110,176	1.79	196,983	$23.96	$2,639,481

Appendix C

Estimation of Environmental Benefit

Vehicles with more frequent deceleration and acceleration contribute significantly to the production of emissions (LeBlanc, *et al.*, 1994; Darlington, *et al*. 1992; CARB, 1991; Groblicki, 1990; Benson, 1989). It was also suggested that one sharp acceleration may cause as much as pollution as does the entire remaining trip (Carlock, 1992). Because the ETC system can eliminate deceleration, idling, and acceleration, it can reduce vehicle emissions. Additional emission reduction can be achieved since ETC system can increase overall throughput at the toll facility and shorten traffic queues for other non-ETC transactions. The environmental benefit is usually considered as an externality to society or the community.[10]

- **Brief review of emission estimation methods**

Vehicle emissions can be estimated by several approaches. A common method is modeling. Examples of emission models include the various versions of MOBILE by U.S Environmental Protection Agency (EPA), EMFACs by California Air Resource Board (CARB), and CALINE by the California Department of Transportation (Caltrans). Emission models estimate emission factors for Carbon Monoxide (CO), Hydrocarbon (HC), and Nitrogen Oxide (NOx). Besides speed and other vehicle operating characteristics, site specific data, such as ambient temperature, operating conditions, *etc*. are needed as inputs to the models. A number of studies employed the MOBILE models for estimations of emission reduction by ETC technologies. For instance, Pesesky and Marin (1990) used MOBILE4 to estimate CO, NOx, and HC emissions under different Automatic Vehicle Identification (AVI) application scenarios at New Jersey Turnpike Interchange. Klodzinski, *et al,* (1998) applied MOBILE5a for the estimations of the same pollutants before and after the development of ETC system in the Holland East Toll Plaza, Florida.

Washington and Guensler (1994) developed a Modal Model, a derivative of the CALINE, and used it to predict CO emission differences between toll-plaza and AVI scenarios with different driving behavior. The model incorporates relative contributions of CO emissions from idle, acceleration, cruise, and deceleration events.

Vehicle emissions can also be estimated by following specific guidelines. For example, the "Transportation Project-Level Carbon Monoxide Protocol" by Garza, *et al.* from UC Davis provides procedures and guidelines for the evaluation of potential local level CO impacts of a project. Similar to many emission estimation models, various characteristic data of the evaluated project are required to estimate the CO concentrations. However, this method does not require complicated computer programming. Many correction factors can be found from the protocol. Following the steps provided by the guideline, users could approximate CO emissions.

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[10] Some might argue this is an externality that is internal to the highway system. It would therefore an externality to drivers or the agency. Since this externality refers to air quality, we would argue the benefits of any reduction would flow more broadly than the highway system.

Under circumstances where data are limited, one can apply emission factors produced by previous studies to estimate vehicle emissions. For example, based on results provided in Table C-1, one can roughly approximate the amounts of pollutants if information on the number of cars in acceleration and the age of those cars are known. Similarly, emissions can be estimated using factors presented in Tables C-2 to C-4 respectively if information on type of vehicles and their travel mileage, or cars in acceleration, or idle time of vehicles is given.

Table C-1: Grams emitted per 0-65 acceleration by car age

Car Age		Pollutant	
	NOx	HC	CO
1989-1994	.75	.95	33
1980-1988	2.36	7.07	196
1979 and older	7.20	25.41	686

Sources: (1989-1994) Cicero-Fernandez and Long, 1993; (1988 and older) Sisson, 1995.

Table C- 2: Emission Rate during average Driving (FTP Cycle) (in grams per km)

Auto Type	Pollutant		
	NOx	HC	CO
New Cars (1980-1990)	.034	.268	2.01
Older Cars (1968-1979)	3.22	7.17	41.81

Sources: New cars (Cicero-Fernandez and Long, 1993); Older cars (IEPA, 1993).

Table C- 3: Acceleration Emissions of "Fleet Average" (in grams per acceleration)

Auto Type		Pollutant	
	NOx	HC	CO
Fleet Average	2.21	6.50	181

Source: Sisson, 1995.

Table C- 4: Emission Rates of All Vehicles

	Pollutant		
	NOx	HC	CO
Acceleration Emission Rates (grams/gallon)	24.7	9.5	209
Idle Emission Rates (grams/minute)	N/A	0.1 ~ 0.2	2 ~ 3

Source: Kirchstetter, *et al.* 1998.

- **Calculation of Environmental Benefit**

Given the purpose and data limitation of this study, we apply emission factors listed in Table C-4 provided by Kirchstetter, *et al.* to evaluate the environmental benefit of ETC system. Vehicle emission reduction per ETC transaction under free flow condition includes cutbacks due to eliminating vehicle idling and acceleration in a toll transaction cycle. Vehicle emissions during deceleration events can be neglected because flow of fuel through engine is small. Total annual emission reduction can be obtained by multiplying emission rates by the numbers of fuel reductions and timesaving resulted from ETC transactions respectively. The calculation can be written as:

$$TE_{NOx} = E_{NOx\_a} * G \quad (1)$$

$$TE_{HC} = (E_{HC\_i} * T) + (E_{HC\_a} * G) \quad (2)$$

$$TE_{CO} = (E_{CO\_i} * T) + (E_{CO\_a} * G) \quad (3)$$

Where:

TE_{NOx}: total annual NOx emission reduced by the use of ETC;
E_{NOx_a}: NOx emission rate for acceleration events;
TE_{HC}: total annual HC emission reduced by the use of ETC;
E_{HC_i}: HC emission rate for idling events;
E_{HC_a}: HC emission rate for acceleration events;
TE_{CO}: total annual CO emission reduced by the use of ETC;
E_{CO_i}: CO emission rate for idling events;
E_{CO_a}: CO emission rate for acceleration events;
G: total annual fuel reduction;
T: total annual time saving;

To estimate timesaving of toll collection, it is assumed that the time for toll transaction is 10 seconds per cash transaction, 4.5 seconds per ticket transaction, and 2.4 seconds per ETC transaction respectively. Additional assumptions include that:

(1) average fuel consumption is 25 miles per gallon;
(2) normal travel speed is 55 miles per hour;
(3) vehicles travel at an average speed of 27.5 miles per hour during acceleration and deceration; and
(4) the distance that a vehicle accelerates from idling to normal speed is assumed to be the ramp distance between toll plaza and the point where the number of lanes are reduced to normal ones. In the case of Carquinez Bridge, the distance is about 0.2 miles.

Toll transaction time saving of changing from cash to ETC payments can be obtained by multiplying the time difference between cash and ETC transactions, which equals 7.6 seconds per transaction based on the above assumption, by the total number of such changes. Similarly, the time savings from ticket to ETC transactions is the product of time difference between ticket and

ETC transactions, which equals 2.1 seconds per transaction, and the total number of changes from ticket to ETC payments. The sum of the two is the total timesaving of toll collection resulting from ETC usage. The calculation is expressed as the following:

$$T = T_{(ETC\ vs.\ Cash)} + T_{(ETC\ vs.\ Ticket)} \quad (4)$$

Fuel reduction (G) is estimated by multiplying time saving from eliminating accelerations by the unit of fuel consumption in gallons per hour. The time saving resulting from the elimination of accelerations is the product of total number of vehicles equipped with ETC transponders ($\#Veh_{ETC}$) and the time saving per vehicle (U_t). This amounts to the time difference between acceleration time that a vehicle takes from idling to normal speed within a distance and the time that a vehicle travels at a normal speed in the same distance. It is expressed as:

$$\Delta T = \#Veh_{ETC} * U_t \quad (5)$$

The unit fuel consumption in gallons per hour (g) is derived by dividing average travel speed by the fuel consumption factor of miles per gallon. Total fuel reduction from eliminating vehicle acceleration is computed by equation (6):

$$G = \Delta T * g \quad (6)$$

Special attention should be given to converting the time measure from second or minute to hour or vise versa so that the units of calculation are consistent.

- **Valuation of Environmental Benefits**

There are a number of ways to determine the value of pollution reduction. One is direct damage costing method. This method determines the value of pollution on the basis of the amount of economic or health damages caused by pollution (Small and Kazimi, 1995; Ottinger, *at al*., 1990; and Fuller *et al.*, 1983). According to Small and Kazimi, the unit costs of health damage are \$0.0063 per kilogram of CO, \$1.22 ~ \$1.33 per kilogram of HC and NOx in 1995 dollars. Another method is to determine the value on the basis of costs to remove the pollutants (Wang and Santini, 1993; IEPA, 1993; and Bernard and Thorpe, 1994). Wang and Santini determined the unit costs based on the cost of replacing typical gasoline powered cars with electric vehicles. The values provided by the Illinois EPA were based on the costs of buying older, high polluting cars and destroying them. The unit estimates of Bernard and Thorpe were taken from studies of railroad electrification for emission reductions. Those unit costs are presented in Table C-5. In this study, we use the average costs of health damage provided by Small and Kazimi since the environmental effect of pollution on health is more tangible to daily life. Table C-6 reports the estimates of annual value of environmental benefits.

Table C- 5: Cost Estimates of Air Pollution

($/kg of pollutant)

Source	Pollutant		
	NOx	HC	CO
Bernard and Thoroe (1994)	8.21 3.04	6.70 3.63	1.10 3.04
Wang and Santini (1993)	27.84	22.69	0.00
Illinois EPA (1993)	24.16	3.81	N/A
Small & Kazimi (1995)	1.22 ~ 1.33	1.22 ~ 1.33	0.0063
Value used	1.28	1.28	0.0063

Table C-6: Estimates of Vehicle Emissions

Year	Toll Transactions			ETC Transactions				Time Saving of Toll Transactions			Time Saving from Acceleration	Emission Reduction from idling (grams)			Emission Reduction from Acceleration (grams)			Total Emission Reduction (grams)			Value of Emission Reduction (95$)			
	Total	Ticket	Cash	%	Total	ETC vs. Ticket	ETC vs. Cash	ETC vs. Ticket	ETC vs. Cash	Total		CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx	HC	Total
95/96	19,016,173	3,270,782	15,745,391	0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$0	$0	$0	$0
96/97	19,064,849	3,279,154	15,785,695	0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$0	$0	$0	$0
97/98	19,636,794	3,377,529	16,259,266	6%	1,178,208	1,013,259	164,949	591	348	939	4,284	140,894	0	8,454	1,969,963	232,814	89,544	2,110,857	232,814	97,997	$13	$297	$125	$435
98/99	20,225,898	3,478,855	16,747,044	15%	3,033,885	2,783,084	250,801	1,623	529	2,153	11,032	322,940	0	19,376	5,072,655	599,496	230,575	5,395,595	599,496	249,952	$34	$764	$319	$1,117
99/00	20,832,675	3,583,220	17,249,455	20%	4,166,535	3,583,220	583,315	2,090	1,231	3,322	15,151	498,248	0	29,895	6,966,447	823,307	316,657	7,464,695	823,307	346,552	$47	$1,050	$442	$1,539
00/01	21,457,656	3,690,717	17,766,939	25%	5,364,414	3,690,717	1,673,697	2,153	3,533	5,686	19,507	852,942	0	51,177	8,969,300	1,060,008	407,695	9,822,242	1,060,008	458,872	$62	$1,352	$585	$1,998
01/02	22,101,385	3,801,438	18,299,947	30%	6,630,416	3,801,438	2,828,977	2,218	5,972	8,190	24,111	1,228,469	0	73,708	11,086,055	1,310,170	503,912	12,314,523	1,310,170	577,620	$78	$1,670	$736	$2,485
02/03	22,764,427	3,915,481	18,848,945	35%	7,967,549	3,915,481	4,052,068	2,284	8,554	10,838	28,973	1,625,759	0	97,546	13,321,743	1,574,388	605,534	14,947,502	1,574,388	703,079	$94	$2,007	$896	$2,998
03/04	23,447,360	4,032,946	19,414,414	40%	9,378,944	4,032,946	5,345,998	2,353	11,286	13,639	34,105	2,045,782	0	122,747	15,681,594	1,853,279	712,800	17,727,376	1,853,279	835,547	$112	$2,363	$1,065	$3,540
04/05	24,150,780	4,153,934	19,996,846	45%	10,867,851	4,153,934	6,713,917	2,423	14,174	16,597	39,519	2,489,543	0	149,373	18,171,047	2,147,487	825,957	20,660,590	2,147,487	975,329	$130	$2,738	$1,244	$4,112
05/06	24,875,304	4,278,552	20,596,751	50%	12,437,652	4,278,552	8,159,100	2,496	17,225	19,721	45,228	2,958,088	0	177,485	20,795,754	2,457,680	945,262	23,753,842	2,457,680	1,122,747	$150	$3,134	$1,432	$4,715

Appendix D

Analytical Results of Changing ETC Market Share Assumptions

Table D-1: Total Cost Streams of Baseline and ETC

Year	TC_Base	TC_ETC	ΔTC	PVC (in FY95$)
0	$4,310,198	$7,324,178	$3,013,980	$3,013,980
1	$4,436,974	$4,460,014	$23,040	$21,943
2	$4,567,997	$4,812,836	$244,840	$222,077
3	$4,703,243	$6,279,249	$1,576,006	$1,361,413
4	$4,843,180	$4,733,821	($109,358)	($89,969)
5	$4,987,803	$4,846,089	($141,714)	($111,036)
6	$5,139,174	$4,973,566	($165,608)	($123,579)
7	$5,295,398	$5,097,437	($197,961)	($140,687)
8	$5,456,680	$5,225,475	($231,205)	($156,488)
9	$5,623,243	$5,349,461	($273,782)	($176,482)
10	$5,795,332	$5,477,653	($317,679)	($195,027)
Total	$55,159,221	$58,579,780	$3,420,559	$3,626,143

Table D-2: Total Benefit Streams (in FY95$)

Year	ΔFuel Value	ΔTime Value	ΔEnv. Value	ΔOperation Revenue	Total Benefit Value
0	$0	$0	$0	$0	$0
1	$0	$0	$0	$0	$0
2	$23,566	$387,369	$738	$11,001	$422,674
3	$130,370	$2,171,605	$3,847	$56,655	$2,362,477
4	$146,120	$2,444,691	$4,350	$64,190	$2,659,351
5	$165,426	$2,759,224	$4,894	$72,127	$3,001,670
6	$185,759	$3,090,428	$5,467	$80,481	$3,362,136
7	$207,163	$3,439,022	$6,070	$89,272	$3,741,528
8	$229,684	$3,805,750	$6,704	$98,518	$4,140,657
9	$253,370	$4,191,387	$7,371	$108,239	$4,560,367
10	$278,271	$4,596,736	$8,072	$118,454	$5,001,533
Total	$1,619,730	$26,886,212	$47,514	$698,937	$29,252,393

Table D-3: Total Net Benefit (in FY95 $)

Year	PVB	PVC	NPV
0	$0	$3,013,980	($3,013,980)
1	$0	$21,943	($21,943)
2	$422,674	$222,077	$200,597
3	$2,362,477	$1,361,413	$1,001,064
4	$2,659,351	($89,969)	$2,749,320
5	$3,001,670	($111,036)	$3,112,707
6	$3,362,136	($123,579)	$3,485,715
7	$3,741,528	($140,687)	$3,882,215
8	$4,140,657	($156,488)	$4,297,145
9	$4,560,367	($176,482)	$4,736,849
10	$5,001,533	($195,027)	$5,196,560
Total	$29,252,393	$3,626,143	$25,626,250

Table D-4: Cost Streams of Toll Agency (in FY95 $)

Year	TC_Base	TC_ETC	ΔTC	PVC (in FY95$)
0	$4,310,198	$7,324,178	$3,013,980	$3,013,980
1	$4,436,974	$4,460,014	$23,040	$21,943
2	$4,567,997	$4,800,708	$232,711	$211,076
3	$4,703,243	$6,213,663	$1,510,420	$1,304,758
4	$4,843,180	$4,655,798	($187,382)	($154,160)
5	$4,987,803	$4,754,036	($233,768)	($183,163)
6	$5,139,174	$4,865,714	($273,460)	($204,060)
7	$5,295,398	$4,971,822	($323,576)	($229,959)
8	$5,456,680	$5,079,919	($376,761)	($255,007)
9	$5,623,243	$5,181,547	($441,695)	($284,721)
10	$5,795,332	$5,284,704	($510,628)	($313,481)
Total	$55,159,221	$57,592,102	$2,432,881	$2,927,205

Table D-5: Net Benefit of Toll Agency (in FY95$)

Year	ΔOperation Cost	ΔOperation Revenue	Total Net Savings
0	$3,013,980	$0	($3,013,980)
1	$21,943	$0	($21,943)
2	$211,076	$11,001	($200,075)
3	$1,304,758	$56,655	($1,248,103)
4	($154,160)	$64,190	$218,350
5	($183,163)	$72,127	$255,290
6	($204,060)	$80,481	$284,541
7	($229,959)	$89,272	$319,232
8	($255,007)	$98,518	$353,525
9	($284,721)	$108,239	$392,960
10	($313,481)	$118,454	$431,935
Total	$2,927,205	$698,937	($2,228,268)

Table D-6: Cost Streams of ETC Users (in FY95 $)

Year	TC_Base	TC_ETC (FY95$)	ΔTC (FY95$)
0	$0	$0	$0
1	$0	$0	$0
2	$0	$11,001	$11,001
3	$0	$56,655	$56,655
4	$0	$64,190	$64,190
5	$0	$72,127	$72,127
6	$0	$80,481	$80,481
7	$0	$89,272	$89,272
8	$0	$98,518	$98,518
9	$0	$108,239	$108,239
10	$0	$118,454	$118,454
Total	$0	$698,937	$698,937

Table D-7: Net Benefit of ETC Users (in FY95 $)

Year	Δ Cost	ΔFuel Value	ΔTime Value	Total Net Savings
0	$0	$0	$0	$0
1	$0	$0	$0	$0
2	($11,001)	$23,566	$387,369	$399,934
3	($56,655)	$130,370	$2,171,605	$2,245,320
4	($64,190)	$146,120	$2,444,691	$2,526,620
5	($72,127)	$165,426	$2,759,224	$2,852,523
6	($80,481)	$185,759	$3,090,428	$3,195,706
7	($89,272)	$207,163	$3,439,022	$3,556,913
8	($98,518)	$229,684	$3,805,750	$3,936,916
9	($108,239)	$253,370	$4,191,387	$4,336,518
10	($118,454)	$278,271	$4,596,736	$4,756,553
Total	($698,937)	$1,619,730	$26,886,212	$27,807,004

Table D-8: Net Benefit of Community (in FY95 $)

Year	ΔC S	ΔEnv. Value	Total Net Savings
0	$0	$0	$0
1	$0	$0	$0
2	$0	$738	$738
3	$0	$3,847	$3,847
4	$0	$4,350	$4,350
5	$0	$4,894	$4,894
6	$0	$5,467	$5,467
7	$0	$6,070	$6,070
8	$0	$6,704	$6,704
9	$0	$7,371	$7,371
10	$0	$8,072	$8,072
Total	$0	$47,514	$47,514

Appendix E

Analytical Results of Changing Time Value Assumptions

Table E-1: Total Cost Streams of Baseline and ETC

Year	TC_Base	TC_ETC	ΔTC	PVC (in FY95$)
0	$4,310,198	$7,324,178	$3,013,980	$3,013,980
1	$4,436,974	$4,460,014	$23,040	$21,943
2	$4,567,997	$4,638,797	$70,800	$64,218
3	$4,703,243	$4,903,735	$200,492	$173,192
4	$4,843,180	$4,830,359	($12,821)	($10,548)
5	$4,987,803	$4,958,037	($29,766)	($23,323)
6	$5,139,174	$5,086,107	($53,067)	($39,600)
7	$5,295,398	$5,218,357	($77,041)	($54,752)
8	$5,456,680	$5,355,022	($101,658)	($68,806)
9	$5,623,243	$5,487,878	($135,365)	($87,258)
10	$5,795,332	$5,625,174	($170,158)	($104,462)
Total	$55,159,221	$57,887,656	$2,728,435	$2,884,585

Table E-2: Total Benefit Streams (in FY95$)

Year	ΔFuel Value	ΔTime Value	Δ Env. Value	ΔOperation Revenue	Total Benefit Value
0	$0	$0	$0	$0	$0
1	$0	$0	$0	$0	$0
2	$12,641	$154,031	$435	$6,601	$173,708
3	$31,908	$409,287	$1,117	$16,997	$459,309
4	$44,704	$568,256	$1,539	$23,342	$637,840
5	$60,968	$755,453	$1,998	$30,053	$848,472
6	$78,167	$953,370	$2,485	$37,145	$1,071,167
7	$96,343	$1,162,483	$2,998	$44,636	$1,306,460
8	$115,540	$1,383,284	$3,540	$52,543	$1,554,907
9	$135,802	$1,616,288	$4,112	$60,884	$1,817,085
10	$157,175	$1,862,026	$4,715	$69,679	$2,093,595
Total	$733,248	$8,864,478	$22,938	$341,879	$9,962,544

Table E-3: Total Net Benefit (in FY95$)

Year	PVB	PVC	NPV
0	$0	$3,013,980	($3,013,980)
1	$0	$21,943	($21,943)
2	$173,708	$64,218	$109,490
3	$459,309	$173,192	$286,117
4	$637,840	($10,548)	$648,388
5	$848,472	($23,323)	$871,794
6	$1,071,167	($39,600)	$1,110,767
7	$1,306,460	($54,752)	$1,361,212
8	$1,554,907	($68,806)	$1,623,713
9	$1,817,085	($87,258)	$1,904,343
10	$2,093,595	($104,462)	$2,198,057
Total	$9,962,544	$2,884,585	$7,077,958

Table E-4: Cost Streams of ETC Users (in FY95$)

Year	TC_Base	TC_ETC (in FY95$)	ΔTC (in FY95$)
0	$0	$0	$0
1	$0	$0	$0
2	$0	$6,601	$6,601
3	$0	$16,997	$16,997
4	$0	$23,342	$23,342
5	$0	$30,053	$30,053
6	$0	$37,145	$37,145
7	$0	$44,636	$44,636
8	$0	$52,543	$52,543
9	$0	$60,884	$60,884
10	$0	$69,679	$69,679
Total	$0	$341,879	$341,879

Table E-5: Net Benefit of ETC Users (in FY95$)

Year	ΔCost	ΔFuel Value	ΔTime Value	Total Net Savings
0	$0	$0	$0	$0
1	$0	$0	$0	$0
2	($6,601)	$12,641	$154,031	$160,072
3	($16,997)	$31,908	$409,287	$424,199
4	($23,342)	$44,704	$568,256	$589,618
5	($30,053)	$60,968	$755,453	$786,368
6	($37,145)	$78,167	$953,370	$994,392
7	($44,636)	$96,343	$1,162,483	$1,214,190
8	($52,543)	$115,540	$1,383,284	$1,446,281
9	($60,884)	$135,802	$1,616,288	$1,691,205
10	($69,679)	$157,175	$1,862,026	$1,949,523
Total	($341,879)	$733,248	$8,864,478	$9,255,847

Appendix F

Analytical Results of Changing the Assumption of Fuel Consumption

Table F-1: Total Cost Streams of Baseline and ETC

Year	TC_Base	TC_ETC	ΔTC	PVC (in FY95$)
0	$4,310,198	$7,324,178	$3,013,980	$3,013,980
1	$4,436,974	$4,460,014	$23,040	$21,943
2	$4,567,997	$4,638,797	$70,800	$64,218
3	$4,703,243	$4,903,735	$200,492	$173,192
4	$4,843,180	$4,830,359	($12,821)	($10,548)
5	$4,987,803	$4,958,037	($29,766)	($23,323)
6	$5,139,174	$5,086,107	($53,067)	($39,600)
7	$5,295,398	$5,218,357	($77,041)	($54,752)
8	$5,456,680	$5,355,022	($101,658)	($68,806)
9	$5,623,243	$5,487,878	($135,365)	($87,258)
10	$5,795,332	$5,625,174	($170,158)	($104,462)
Total	$55,159,221	$57,887,656	$2,728,435	$2,884,585

Table F-2: Total Benefit Streams (in FY95$)

Year	ΔFuel Value	ΔTime Value	Δ Env. Value	ΔOperation Revenue	Total Benefit Value
0	$0	$0	$0	$0	$0
1	$0	$0	$0	$0	$0
2	$21,069	$218,210	$717	$6,601	$246,597
3	$53,180	$580,177	$1,844	$16,997	$652,198
4	$74,507	$805,520	$2,537	$23,342	$905,905
5	$101,613	$1,070,878	$3,284	$30,053	$1,205,827
6	$130,278	$1,351,432	$4,073	$37,145	$1,522,929
7	$160,572	$1,647,856	$4,907	$44,636	$1,857,971
8	$192,567	$1,960,849	$5,787	$52,543	$2,211,746
9	$226,336	$2,291,139	$6,715	$60,884	$2,585,075
10	$261,959	$2,639,481	$7,695	$69,679	$2,978,813
Total	$1,222,081	$12,565,543	$37,559	$341,879	$14,167,061

Table F-3: Total Net Benefit (in FY95$)

Year	PVB	PVC	NPV
0	$0	$3,013,980	($3,013,980)
1	$0	$21,943	($21,943)
2	$246,597	$64,218	$182,379
3	$652,198	$173,192	$479,006
4	$905,905	($10,548)	$916,453
5	$1,205,827	($23,323)	$1,229,150
6	$1,522,929	($39,600)	$1,562,528
7	$1,857,971	($54,752)	$1,912,723
8	$2,211,746	($68,806)	$2,280,552
9	$2,585,075	($87,258)	$2,672,332
10	$2,978,813	($104,462)	$3,083,275
Total	$14,167,061	$2,884,585	$11,282,476

Table F-4: Cost Streams of ETC Users (in FY95$)

Year	TC_Base	TC_ETC (in FY95$)	ΔTC (in FY95$)
0	$0	$0	$0
1	$0	$0	$0
2	$0	$6,601	$6,601
3	$0	$16,997	$16,997
4	$0	$23,342	$23,342
5	$0	$30,053	$30,053
6	$0	$37,145	$37,145
7	$0	$44,636	$44,636
8	$0	$52,543	$52,543
9	$0	$60,884	$60,884
10	$0	$69,679	$69,679
Total	$0	$341,879	$341,879

Table F-5: Net Benefit of ETC Users (in FY95$)

Year	ΔCost	ΔFuel Value	ΔTime Value	Total Net Savings
0	$0	$0	$0	$0
1	$0	$0	$0	$0
2	($6,601)	$21,069	$218,210	$232,679
3	($16,997)	$53,180	$580,177	$616,361
4	($23,342)	$74,507	$805,520	$856,685
5	($30,053)	$101,613	$1,070,878	$1,142,438
6	($37,145)	$130,278	$1,351,432	$1,444,565
7	($44,636)	$160,572	$1,647,856	$1,763,792
8	($52,543)	$192,567	$1,960,849	$2,100,873
9	($60,884)	$226,336	$2,291,139	$2,456,590
10	($69,679)	$261,959	$2,639,481	$2,831,761
Total	($341,879)	$1,222,081	$12,565,543	$13,445,744

Table F-6: Net Benefit of Community (in FY95$)

Year	ΔCS	ΔEnv. Value	Total Net Savings
0	$0	$0	$0
1	$0	$0	$0
2	$0	$717	$717
3	$0	$1,844	$1,844
4	$0	$2,537	$2,537
5	$0	$3,284	$3,284
6	$0	$4,073	$4,073
7	$0	$4,907	$4,907
8	$0	$5,787	$5,787
9	$0	$6,715	$6,715
10	$0	$7,695	$7,695
Total	$0	$37,559	$37,559

Appendix G: Measuring Cost Savings/Productivity Improvements from ITS Projects

The introduction of an ITS project may allow firms to utilize more transportation and lower their costs. This 'productivity' impact is not captured by the lower costs of maintaining production in its present form. If the firm re-organizes its' production to take advantage of the 'new' transportation investment the gains should be counted. The model below outlines an approach for developing such measures.

The measure of impact can be accomplished in a number of alternative ways. One would be the impact on a firm's costs if transportation costs or prices were to fall. This model relies on information from the current economic literature on the own and cross price elasticities of demand and elasticity of substitution to determine the impact of changes in transportation prices-costs. The reason it is limited to the manufacturing sector is the information on all the required input prices and quantities are available only for the manufacturing sector. Information on transportation cost shares is drawn from the input/output tables for Ontario (most recent). Elasticities of substitution for transportation and other inputs are taken from studies in the US and Canada.[11]

The evaluation of the impact of changes in transportation prices or costs is based upon the following model. Assume the cost function for a firm or industry can be represented in a general way as:

$$C = \varphi(p_1, p_2, ..., p_n, Q) = \sum_{i=1}^{n} p_i x_i^* \qquad \text{(A1)}$$

where p_i's are the input prices, Q is output and x's are measures of input quantities. This representation of the cost function is one that exhibits constant returns to scale and is separable in the input arguments. This assumption is not as strong as it sounds. It is merely saying that constant returns characterize the cost relationship in the neighborhood of the current output. This means unit costs are constant at some given level over a range of outputs. For a single price or cost change of one of the input factors one can show, using equation A1 that the firm's (or industry's) costs will change as

$$\%\Delta C = \left\{ S_i \left[1 + \eta_i \right] + \sum_{i=1}^{n-1} S_i \cdot \eta_1^i \right\} \cdot (\%\Delta p) \qquad \text{(A2)}$$

where %Δ is the percentage change, S_i is the ith cost share, η_1 is the output constant own price elasticity of demand for factor 1 with respect to a change in the price of factor 1 and η_1^i is the output constant cross elasticity of input demand for factor i with respect to a change in p_1. In the absence of any cross price effects, equation (21) becomes

$$\%\Delta C = \{ S_i ? [1 + \eta_i]\} ? (\%\Delta p) \qquad \text{(A3)}$$

[11] These studies include Holleyman (1996, Gillen (1996), Morrison and Schwartz (1992) and Nadirri (1993).

Once the proportionate change in costs has been established, the demand elasticity for the product could be used to assess how output markets would be affected and hence economic welfare.[12]

An explanation is in order as to how this model is used to assess the impact of changes in the transportation system in California. A reduction in the cost of highway transportation services to firms in the economy can occur through a number of means; increasing speeds, improving the reliability of trips via better maintenance and pavement smoothness, for example. This is equivalent to a change in relative factor prices, the effective relative price of transportation to the firm is lower. Firms in the industry therefore have an incentive to substitute transportation for other inputs. As a result they are able to produce the same output but at a lower cost. The research, see summary in Gillen (1996), has found that transportation and labor are substitutes, private capital can be a substitute or complement -the evidence is mixed. The inputs required to measure the impact are the own and cross price elasticities and the share of each factor cost in total cost.

[12] The manufacturing data reports expenditures on fuel and electricity, labor and materials as well as value added.. To develop a cost approximation we assumed that the industries were competitive so they were earning just a normal rate of return. We know value added is essentially the payments to labor and capital. If we add payments to fuel and electricity and materials to value added it should approximate total costs since in a competitive industry total revenue equals total cost (recognizing capital costs include a normal return).