HOMEWORK #3

Review the attached paper and prepare a short write up in your own words, which should contain at least the following components:

• Scope of the study and methodology used
• Results and conclusion
• Your evaluation of the contents of the paper
Benefit-Cost Evaluation of the Electronic Toll Collection System

A Comprehensive Framework and Application

JIANLING LI, DAVID GILLEN, AND JOY DAHLGREN

Although electronic toll collection (ETC) technologies are fairly mature and many ETC systems have been implemented, there is a dearth of comprehensive and systematic assessment of their benefits and costs. Most previous studies have focused only on one or two short-term benefits or costs and have not translated the benefits into dollar values. A comprehensive framework is proposed, incorporating various benefit and cost components, and decomposing the benefits and costs by affected groups. The framework also is tested using data for the ETC system at the Carquinez Bridge in the San Francisco Bay Area. The results of the analysis show that while the Carquinez ETC project would generate a benefit-cost ratio of 40 over the entire evaluation period, the distribution of costs and benefits would be uneven. Time saving is a major direct benefit of ETC. Other benefits include energy saving, emission reduction, and service improvement. Toll patrons would be the primary beneficiaries. However, cost savings to the agency would depend largely on the demand for use of the ETC system and the cost of transponders. Implications of the findings are discussed.

Electronic toll collection (ETC) is an application of several technologies—such as automatic vehicle identification, classification, and communication technologies—to toll collections. ETC replaces manual in-lane collections with automatic toll transactions that can be performed while vehicles travel at highway speeds. Because of the advantages provided by ETC technologies, an ETC system can generate potentially significant economic and environmental benefits.

Although ETC technologies are fairly mature and many ETC systems have been implemented, there is a dearth of comprehensive and systematic assessment of ETC benefits and costs. Most previous studies, either hypothetical or empirical, have focused on a specific aspect of ETC benefits or costs. Furthermore, few studies have investigated who benefits and who loses from instituting ETC systems. In addition, most studies have focused on short-term benefits or costs rather than lifetime ones, and have not transferred the benefits into dollar values. For example, Pietrzyk and Mierejewski (1) studied the costs of the ETC systems on the Dallas North Tollway and the Oklahoma Turnpike. Al-Deck et al. (2) evaluated ETC benefits in increasing throughput and reducing delay through the reduction of transaction time at a toll plaza in Orlando, Florida. Delozer (3) focused on ETC benefits in enhancing audit control. The bulk of the literature also has been devoted to the assessment of the environmental benefits of the ETC systems. For instance, Pesesky and Marin (4) estimated the potential reductions of carbon monoxide, nitrogen oxides, and nonmethane hydrocarbons by vehicles due to the use of automatic vehicle identification (AVI) technology in a toll plaza operated by the New Jersey Turnpike Authority. Similar studies were conducted by Lennon (5) for the ETC system at the Tappan Zee Bridge in New York, Sisson (6) for Chicago, and Klodzinski et al. (7) for the Holland East Toll Plaza in Orlando. These studies concluded that ETC technologies reduced air pollution both on an annual average basis and in the peak-hour period only. Although these previous studies collectively provided rich information on the costs and benefits of the ETC systems, there were some limitations in the assessment of an ETC system in terms of breadth and depth.

The purposes of this study are twofold. First, it proposes a comprehensive framework that incorporates various benefit and cost components as well as lifetime costs and benefits of an ETC system, and it decomposes the benefits and costs to the extent possible. Second, it tests the framework using data for the ETC system at the Carquinez Bridge in the San Francisco Bay Area in California. Issues that arose in the evaluation process also are discussed.

This study will overcome the limitations of previous studies by providing a comprehensive framework and therefore will contribute to a better understanding of the trade-offs between the forgone resources and gains from ETC technologies. By assessing the full lifetime costs and benefits of an ETC system and allowing comprehensive comparisons with competing investment alternatives, this study also will facilitate efficient decision making and promote economic efficiency in public investment. In addition, by decomposing the costs and effects of an ETC system on affected parties, our study provides an alternative for addressing issues of who pays and who benefits, as well as the redistributive effects of transportation alternatives. Furthermore, the comprehensive nature of our framework also might have broader applications in the evaluation of other intelligent transportation systems (ITS) projects.

In the following sections, a comprehensive framework for ETC evaluation is presented and tested using data for the ETC system at the Carquinez Bridge. Implications of the findings are discussed.

COMPREHENSIVE EVALUATION FRAMEWORK

**Brief Review of Benefit-Cost Analysis and Life-Cycle Costing Analysis**

Benefit-cost analysis is a tool for evaluating and choosing investment options based on economic efficiency criteria. Benefit-cost analysis measures the resources forgone for an investment alternative and the returns from the investment, and values the costs and benefits in terms of the opportunity costs of inputs and the
beneficiary's willingness to pay. By examining the positive and negative effects of investment options on a common basis, it helps decision makers select a better alternative among a set of options.

Life-cycle costing is a method of calculating the total cost of ownership over the life span of an asset or a project (8). It includes not only the initial capital investment and subsequent operating and maintenance costs but also the necessary costs of rehabilitation and reconstruction. Like benefit-cost analysis, all life-cycle cost analyses must be performed in terms of compatible dollars. Costs-flows in different years are discounted to present values or future values at a discount rate. Although life-cycle costing focuses only on costs, it can be incorporated into the process of estimating cost-flows in benefit-cost analysis.

Evaluation Framework

The evaluation framework is based on the principles of benefit-cost analysis and life-cycle costing. The framework for the evaluation of ETC systems is shown in Figure 1. The framework outlines the tasks to be performed in the evaluation process. These tasks include the following:

1. Identifying the goals and objectives of the proposed ETC system—an important step for selecting the evaluation criteria for decision making;
2. Defining a temporal and spatial horizon to provide a frontier for benefit and cost assessments;
3. Classifying and measuring cost differences between the baseline—usually defined as a toll facility without an ETC system—and the ETC system, as well as the incremental benefits to affected parties;
4. Computing the evaluation indices, such as net present value, benefit-cost ratio, and internal rate of return;
5. Conducting a sensitivity analysis to determine risk and uncertainty; and
6. Presenting analytical results.

Decomposition of Benefits and Costs

The most challenging but important task in ETC evaluation is to identify and distinguish the costs and benefits of the baseline and the proposed ETC system among affected parties. In this framework, the affected parties are classified into three groups: toll patrons, toll agencies, and the community.

Toll patrons include both individual and business users, such as commuters, nonwork trip-makers, trucking companies, shippers, carriers, and other service trip-makers. Toll agencies refer to all public or private agencies that plan, fund, build, and operate toll services. They could be governmental transportation departments at various levels or metropolitan planning organizations (MPOs). They also could be private transportation investors, private or public partners, or other nonprofit agencies. The community, if defined narrowly, is a geographic area that is directly or indirectly affected by an ETC project. It also can refer broadly to a higher level jurisdiction, such as a city, county, region, state, or country, depending on the scale of the project. The costs and benefits to the three groups, including quantifiable and identifiable benefits, are outlined in Figure 2.

All the quantifiable costs and benefits can be grouped into five major categories: direct monetary costs or savings, accident costs or savings, time costs or savings, environmental costs or savings, and others that are not included in the previous four categories. Direct monetary cost includes vehicle operating costs and life-cycle costs of toll service. For toll agencies, the cost of a manual or automatic toll-collection system encompasses some or all of the following: initial capital investment; labor and material costs for service operation and maintenance; and other service expenditures, such as insurance cost, interest payment on debt, taxes, contract services, and so on. Monetary savings of toll agencies include the increase of operating revenue—such as interest generated from deposits—and reduction of operating costs due to fewer toll collectors and maintenance workers, as well as to fewer cash-handling mistakes and risks.

For toll patrons, costs include vehicle operation and maintenance costs (mainly fuel costs), as well as any service charges associated

![FIGURE 1 Evaluation framework.](image1)

![FIGURE 2 Overview of benefit-cost of ETC.](image2)
with a manual or automatic toll-collection system. Note that the service charges of toll patrons—such as tolls and costs for establishing ETC accounts (including interest forgone from deposits on ETC transponders and for maintaining an account balance), and the cost of transponders—transfer to the toll agency as operation revenues or cost reductions. From society's perspective, these are not net benefits in a benefit-cost evaluation. However, they matter when examining the distribution of benefits and costs. The direct monetary savings for toll patrons are reductions in fuel and vehicle maintenance costs due to improved traffic conditions and the elimination of decelerations and accelerations.

Accident costs to toll patrons are the medical expenses, wage losses, vehicle repairs, and other expenditures due to personal injury or death. Accident cost to toll agencies refers to the resources used for repairing property damage caused by accidents. Community cost due to accidents includes support services provided by other sectors of the society. Time cost is the loss of time in using the toll facility. Environmental cost refers to expenditures by the community for cleaning vehicle emissions. The differences in the costs of accident, time, and environment between an ETC system and the baseline are benefits or disbenefits. Other nonquantifiable benefits include increases in travel convenience and data collection capability, improvements in data quality and service quality, and other induced impacts on travel demand, traffic congestion, productivity, and the like.

Generic Estimation Models

Another complex task is estimating the cost and benefit flows of the baseline and an ETC system. As seen in Figure 1, this estimate requires—but is not limited to—information on service provision and demand, the time frame, and the geographic boundaries affected by the proposed project. The effects of these dimensions are interactive. A good demand model is essential for providing basic inputs for benefit and cost estimates.

Many factors could influence total demand for a toll facility and the market segments of ETC. These include economic and population growth in the region, fees or deposits for transponders and the balance requirement for ETC accounts, ETC payment policies, travel frequency, trip purpose of toll patrons, time saving, value of time, and other socioeconomic attributes of toll patrons ($Q_{t,0}$). If $D_t$ represents travel demand for the ETC market segment in a year, and $X_n$ denotes the factors affecting demand, then $D_t$ can be defined as:

$$D_t = f(X_1, X_2, \ldots, X_n)$$

In addition to a demand model, there is a need for a set of models that can estimate cost, travel time, safety, and environment impacts of the baseline and the ETC scenario to provide inputs for benefit and cost estimates. A key variable in estimating these impacts is the toll plaza configuration—the combination of manual and ETC lanes and the duration of operation time. An optimal toll plaza configuration is one that can minimize the average travel delay at the toll plaza. Under a specific toll plaza configuration, the average travel delay ($T_{ave}$) is equivalent to the sum of delays of ETC and manual toll patrons over total traffic volume, and can be expressed as the following:

$$T_{ave} = \frac{T_{ave, ETC} \cdot Q_{ETC} + T_{ave, M} \cdot Q_M}{Q_{ETC} + Q_M}$$

where

- $T_{ave, ETC}$ = average delays in ETC lanes;
- $T_{ave, M}$ = average delays in manual lanes;
- $Q_{ETC}$ = trips made by ETC; and
- $Q_M$ = trips made by regular toll patrons.

Travel delay at the toll plaza includes both time for toll transactions and time waiting in a queue. In theory, a vehicle with an ETC transponder under a free-flow traffic condition does not suffer time loss. However, if the vehicle is stuck in a queue, the only time saving is the toll transaction time, although the time waiting in a queue may be shorter compared with a manual toll transaction. Average travel delays for using ETC and manual lanes are the functions of lane capacity and traffic volume and can be estimated by queuing models.

Traffic volume, temporal distribution of traffic flow, travel behavior of drivers, weather conditions, and type of toll payments may have effects on safety. Capacities and design configuration of transportation infrastructure, travel speed and traffic conditions, type and age of vehicles, temperature, wind direction and speed, and other geographic location factors can determine environmental impacts. The generic models for projecting the impacts on safety and environment can be expressed as the following:

$$A = f(Q, SP, t, W, i)$$

$$E_i = f(Temp, W, Loc, V_i, V_{age}, SP, Q, i)$$

where

- $A$ = number of accidents;
- $E_i$ = number of emissions;
- $Q$ = traffic volume;
- $SP$ = vehicle travel speed;
- $t$ = time of day;
- $W$ = weather conditions;
- $i$ = type of toll system;
- $Loc$ = locational geographic attributes;
- $V_i$ = vehicle type;
- $V_{age}$ = vehicle age; and
- $Temp$ = temperature.

Specific models must be developed on the basis of available data. In the absence of data, one can forecast demands and impacts based on historical data from the site or on references from other similar situations using a case-based reasoning method.

Once the technical features of the baseline and an ETC system are determined and their impacts are estimated, costs and benefits can be estimated with the following models.

$$C_i = KC_i + OC_i + MC_i - R_i + SC_i$$

$$T_i = (T_{ave, ETC} + T_{ave, M}) \cdot VOC \cdot U_t$$

$$F_i = (T_{ave, ETC} + T_{ave, M}) \cdot g \cdot P$$

$$EC_i = [F_{EC_i} \cdot T_{ave, ETC} + F_{EC_i} \cdot T_{ave, M}] \cdot U_{[t, \text{year}, \text{BC}]}$$

$$S_i = A_i \cdot U_{[t, \text{cost}, \text{agency}, \text{community}]}$$
where

\[ C = \text{net cost}; \]
\[ KC = \text{capital cost}; \]
\[ OC = \text{operating cost}; \]
\[ MC = \text{maintenance cost}; \]
\[ SC = \text{service charges}; \]
\[ R = \text{operating revenue}; \]
\[ T = \text{time cost or saving}; \]
\[ T_d = \text{time for toll transaction}; \]
\[ T_{del} = \text{traffic delay, including time lost in deceleration, queue, and acceleration}; \]
\[ T_{acc} = \text{transaction time and queuing time}; \]
\[ VOC = \text{average vehicle occupancy (people per vehicle)}; \]
\[ F = \text{fuel cost}; \]
\[ G = \text{gasoline consumed (liters)}; \]
\[ P = \text{gasoline price (cost per liter)}; \]
\[ EC = \text{emission cost}; \]
\[ S = \text{accident cost}; \]
\[ A = \text{number of accidents}; \]
\[ U = \text{time value (cost per hour), or a unit cost of air pollution (cost per kilogram of pollution), or accident (cost per accident on user, agency, and community)}; \]
\[ g = \text{a unit of hourly gasoline consumption (liters per hour)}; \]
\[ E_{idle} = \text{emission rate (grams per minute) while vehicles are idling}; \]
\[ E_{acc} = \text{emission rate (grams per liter) while vehicles are accelerating}. \]

**APPLICATION TO THE EVALUATION OF THE ETC SYSTEM AT CARQUINZ DE BRIDGE**

**Carquinez Bridge ETC Project**

Caltrans owns and operates nine toll bridges statewide. The current toll collection systems on the bridges are known as Toll Registration, Audit and Collection (TRAC), installed in the early 1980s. Tolls have been collected manually by toll collectors since then. With the significant growth in traffic volume and deterioration of the toll facilities, Caltrans decided to replace the manual TRAC system with the ETC system on all bridges. The Carquinez Bridge ETC project is a pilot project of this statewide toll-bridge improvement project.

Carquinez Bridge was selected as the site for ETC pilot implementation because it has sufficient capacity to handle peak traffic demand with a few bottlenecks out of service for ETC demonstration. The project started in 1995. It was planned to equip all the toll lanes with automatic toll collection devices. A dedicated lane has been open since Aug. 21, 1997, to users who have established an ETC account with Caltrans. In addition, two lanes are open for the use of both manual toll collection and ETC. The ETC system will be completed in 1999.

Given this background, the baseline of the evaluation is defined as the existing manual TRAC system. The evaluation compares the baseline conditions that presently occur and will occur in the future in the absence of the ETC system with the conditions of the ETC system during the evaluation period. According to Caltrans, the major objectives of the ETC project are to

- Reduce overall toll collection cost;
- Provide an acceptable level of service for toll patrons;
- Increase data quality and provide information currently not available in the planning and operation of transportation facilities; and
- Reduce traffic congestion, air pollution, and fuel consumption on toll bridges.

Because of these objectives, it is important to examine the distribution of costs and benefits among the toll agency, toll patrons, and the community in which the ETC facility is situated over the life cycle of ETC equipment. Since most ETC components have a life span of 10 years, the temporal framework of the analysis is set to be 10 years. Due to the unique geographic location of the bridge, which is relatively isolated from other bridges and highways, the spatial effect of the ETC system is limited to the bridge itself. [The nearest bridge—Benicia Martinez Bridge—is about 14 km (9 mi) away and will be equipped with the ETC system right after the completion of the project at Carquinez Bridge. The installation of an ETC system at Carquinez Bridge should not affect or reduce traffic from Benicia Martinez Bridge.]

**Basic Assumptions and Estimation Procedures**

Based on data provided by Caltrans and drawn from the existing literature and national statistics (1±15), a number of assumptions were made, and the annual direct costs and benefits in a 10-year period were estimated. The primary parameters of the estimations are listed in Table 1.

The average annual traffic growth rate of 3 percent was derived from traffic data for the bridge for the past 20 years (12). The ETC market share was assumed to be 5 percent in fiscal year (FY) 1997–1998 and 15 percent in FY 1998–1999, increasing 5 percent annually thereafter, reaching 50 percent in the 14th year. The assumption of the annual ETC market share was made on the basis of current usage of the ETC system on the bridge and on other ETC systems (1±15). According to the daily traffic reports for Carquinez Bridge in FY 1997–1998, ETC transactions on average accounted for about 4 percent of the total toll transactions. To include the possible missing data and to simplify calculation, 5 percent was used as the rate of ETC market share for the first year after the opening of the ETC system. The assumption was that there will be an upsurge in ETC usage in FY 1998–1999 when ETC systems are installed at all the bridges in the Bay Area, and most previous ticket users and some of the cash users will switch to ETC payment. In FY 1996–1997, ticket trips accounted for about 17 percent of the total trips at Carquinez Bridge (11). The 5 percent annual increase rate of ETC market share over total travel volume was based on the consideration that the longer the ETC system in operation, the more familiar the public becomes with ETC and its benefits, and the more likely that toll patrons will become ETC users. This assumption was also cross-checked with reference to the ETC market share in other regions in the United States. According to Electronic Toll and Traffic Management (ETTM) on the Web, the market shares of ETC systems in other regions of the United States range between 2 percent and 65 percent, except for Southern California's SR91, which requires ETC transponders.

The assumptions of times for different toll transactions made by Caltrans were adopted in this study (12). The rates and unit costs of emissions provided by the existing literature (16–20) also were used. Due to the lack of vehicle occupancy information for vehicles using the toll bridge, the assumption was made that the vehicle occupancy rates of automobiles, trucks, and buses were the
same as the national average and that their market shares would remain the same over the evaluation period. The average time value was based on the hourly values used in the Highway Economic Requirements System—a computer model employed by the U.S. Department of Transportation—and adjusted by factors such as inflation and the market share of automobiles, trucks, and buses for Carquinez Bridge. The average fuel consumption, measured in liters per hour, was derived by dividing the travel speed limit on the bridge, 88.5 km/h, by a proximate fuel consumption factor of 10.6 km/L. The peak period is defined in this study as 4:00 p.m. to 8:00 p.m., Monday through Friday, because the Carquinez Bridge is a one-way toll road, and traffic volume during this period usually accounts for about 30 percent to 40 percent of the total daily trips (73). It was also assumed that queuing delay occurs only when demand exceeds capacity.

Based on these assumptions and data provided by Caltrans, the monetary costs, time saving, and environmental benefits of the toll agency, toll patrons, and the community were estimated using Equations 5 to 8. The estimation procedure includes several steps. First, the future annual traffic demands and the ETC and manual market segments were projected at the presumed growth rates. Second, based on the projections, the assumptions of average time for toll collection and traffic flow distribution and for the average queue delays of the ETC and manual lanes under various toll operation configurations were estimated using a queuing model. The average delay of total traffic under each toll operation configuration was estimated using Equation 2, and the optimal configuration of the toll plaza was determined. The estimates for the average delay and toll operation configuration were then used as inputs to compute the annual travel time, labor cost of toll operation, vehicle operation cost, and emissions of the baseline and the ETC system. Travel time was further adjusted by incorporating the vehicle occupancy rate. The time value and emission costs were computed by factoring the appropriate mode split, types of delays—such as idling and acceleration or deceleration—and unit costs. Other capital and operation costs, as well as operation revenue from the baseline and the ETC system, were estimated using data provided by Caltrans.

After the annual costs, time value, and emission costs of the baseline and the ETC system for the toll agency, toll patrons, and the community were estimated and discounted at a 5 percent rate to FY 1995 dollars separately, the differences between the baseline and the ETC system were calculated by subtracting the costs, time value, and environmental costs of the ETC system from those of the baseline. The total costs and benefits, as well as their distributions, were obtained by summing the negative and positive differences. Finally, the net benefits or disbenefits were obtained by subtracting the total costs from the total benefits.

The safety benefit or disbenefit of an existing ETC system can be obtained from field observations. Future safety benefit or disbenefit can be estimated by Equation 3, developed on the basis of available data. In this study, accident data in the period between September 1996 and December 1996 were compared with those between September 1997 and December 1997, the months after one dedicated ETC lane was opened. (The accident report of December 1997 was the latest data available when this study was conducted.) The data show that the total number of accidents on the bridge in the latter period was 30, compared with 27 in 1996. The data also indicate that the number of personal injuries in 1997 was 13, compared with 5 in the same period of 1996, and nonpersonal injuries (i.e., damage to property only) in 1997 were lower than those in 1996. In short, available safety data show that the numbers of accidents and personal injuries after the opening of the ETC system were higher than those before the ETC system, although nonpersonal injuries were lower.

In addition to analyzing observed data, a model also was tested using the available traffic volume and accident data provided by Caltrans. It was hypothesized that the ETC system would reduce the number of accidents and that there is a nonlinear relationship between the number of accidents and traffic volume, because on the one hand, the probability of collision increases as traffic volume increases. On the other hand, when traffic volume exceeds the bridge capacity, the possibility of collision decreases, because traffic congestion forces vehicles to slow down. However, neither of the parameters (toll collection method and traffic volume) in the model is statistically significant. Since the ETC has been operating only for a short time, and there is a lack of information on travel speed associated with traffic flows for this particular location, it is difficult to establish a causal relationship between safety benefit and the ETC system. For this reason, the safety benefit or disbenefit is not estimated in this study.

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<tr>
<th>TABLE 1: Estimation Parameters (41,55-20)</th>
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<td>Items</td>
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<td>-------------------------------------------</td>
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<tr>
<td>Average annual traffic growth rate</td>
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<td>ETC market share</td>
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<td>Time per ETC transaction</td>
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<td>Time per ticket transaction</td>
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<td>Time per cash transaction</td>
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<td>Average vehicle occupancy</td>
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<td>Average fuel consumption</td>
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<tr>
<td>Emission rate &amp; unit cost of NOx</td>
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<td>Emission rate &amp; unit cost of HC</td>
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<td>Emission rate &amp; unit cost of CO</td>
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Results of the Benefit-Cost Analysis

The sum and distribution of the direct costs and net benefits in the evaluation period are shown in Table 2. The data indicate the following:

- Overall, the ETC project would result in a net present value of $129 million and a benefit-to-cost ratio of 40.3 over the evaluation period. The value of users' time saving would account for about 90 percent of the total direct benefits.
- Distributions of direct costs and net benefits are uneven. The toll patrons are the winners. Collectively, all the toll patrons would benefit from the ETC system, since it reduces traffic congestion. The ETC system not only would save the travel time and fuel consumption of ETC and manual users, but also would increase the travel convenience for ETC users. The net present value of toll patrons' benefit would be about $130 million in FY 1995 dollars, if transponders were provided by the toll agency with or without a deposit requirement.
- Although the ETC system would save the toll agency labor and operation costs in later years, it would cost the agency a net present value of about $1 million during the evaluation period, because the operating cost savings and revenues would not offset the initial capital investment for the ETC system. However, the agency's ability to set tolls would be enhanced. The agency would also have access to more data with higher quality—potential benefits that are not included in this analysis.
- The ETC project would generate environmental benefits for the community, but the magnitude would be relatively small.

Sensitivity Analysis

To investigate the effects of changing assumptions on the net benefits and the distribution of benefits and costs, a series of sensitivity analyses was conducted by changing assumptions of the discount rate, ETC market share, time value, and fuel consumption, respectively. Those changes are relative to the assumptions of the benefit-cost analysis. The results of the analyses are shown in Table 3 and can be summarized as follows:

- A change in the discount rate from 5 percent to 7 percent while holding other assumptions constant would reduce the total net benefit to $113 million. The present value of the agency's net cost would be about $1.1 million, higher than the value at a discount rate of 5 percent. A higher discount rate of 7 percent would lead to lower present values of the net benefits for toll patrons and the community—about $113.8 million and $66,000, respectively. However, despite changes in absolute terms, the use of a higher discount rate would not alter significantly the distribution of net benefits (or disbenefit) among the toll agency, toll patrons, and the community (Scenario 1, Table 3).
- As stated in the previous section, it is assumed that the ETC market share is 5 percent in FY 1997–1998, 15 percent in FY 1998–1999, and increases 5 percent annually afterward. If more vehicles use the ETC system, how would such a change affect the total and the distribution of the net benefit? To examine the effects of ETC market share, it can be assumed that the annual ETC market share is 5 percent in FY 1997–1998, 10 percent in FY 1998–1999, and increases 5 percent annually afterward, holding other assumptions constant. The results show that the present value of the total net benefit would be about $168 million in FY 1995 dollars, about $39 million more than under the original assumptions. The net benefits for toll patrons and the community would increase as more toll payments are processed by the ETC system. However, the present value of net loss to the toll agency would increase by about $0.4 million if the cost of ETC transponders is borne by the toll agency (Scenario 2, Table 3). If the cost of transponders is borne by ETC users, the benefits would be more evenly distributed and all three groups would be better off. As seen in Scenario 3 of Table 3, toll patrons would still be the major beneficiaries, with a net benefit of $166 million in the entire evaluation period. The toll agency, on the other hand, would save about $2.4 million when compared with the baseline, in spite of some reduction in interest generated from transponder deposits. The savings would account for about 1.4 percent of the total net benefit.
- A decrease in the assumed time value while holding everything else constant would not affect the outcomes of net benefits of the toll agency and the community, but it would reduce the total and toll patrons' net benefits. For example, under the previous assumption, hourly time value was presumed to be $12.75 for automobile and

| TABLE 2 | Total Distribution of Direct Costs and Benefits (Fiscal Year 1995 Dollars) |
|----------|-----------------|-----------------|-----------------|-----------------|
| Direct Costs | Total | Toll Agency | Toll Patrons | Community |
| Monetary Savings | $13,645,462 | $2,652,699 | $11,992,764 | $ - |
| Time Saving | $118,272,376 | $ - | $118,272,376 | $ - |
| Emission Reduction | $75,789 | $ - | $ - | $75,789 |
| Safety Improvement | N/A | N/A | N/A | N/A |
| Subtotal | $131,993,627 | $2,652,699 | $129,865,140 | $75,789 |
| Net Benefits | $128,716,757 | $984,722 | $129,625,691 | $75,789 |
| B/C Ratio | 49.28 | - | - | - |
bus travelers and $33.41 for truck drivers. With a mode split of 5.11 percent for trucks and 94.89 percent for automobiles and buses \((f_t)\), the average rate of $13.80 was used to compute time saving. In this sensitivity analysis, we used the time value of $9.00/h for automobile and bus travelers and $23.40/h for truck drivers. [In Caltrans' CAL/B-C model, the value of time is assumed to be $0.11/h for cars and $0.39/h for trucks. These assumptions are equivalent to $9.00/h and $23.40/h, respectively \((2\times)\).] With the same mode split, the average time value of $9.73/h was used in the calculation. While changing the assumption of time value has no effect on the net benefits for the toll agency and the community, it would reduce the total and the toll patrons' net benefits. The time saving of toll patrons would decrease from $118.5 million to $83.4 million, resulting in a net benefit of $94.7 million as compared with $129.6 million under the previous time value assumption. Total net benefit would decline by about 27 percent. However, toll patrons would still be the primary beneficiaries (Scenario 4, Table 3).

- The assumption regarding fuel consumption also affects the analytical outcomes. A higher fuel consumption value would generate higher estimates for fuel savings and vehicle emission reduction. In the previous benefit-cost analysis, we assumed an average fuel consumption rate of 10.6 km/L. This assumption may be low for accelerating vehicles, especially for light-duty trucks and sport utility vehicles. To examine the possible effect of underestimating emission benefit and fuel saving, we used a higher fuel consumption value of 6.4 km/L—40 percent higher than the previous assumption. Under this assumption, the excessive fuel used for a typical car accelerating from 0 to 88.5 km/h in 0.3 km or 13 s relative to a car traveling the same distance at a steady speed of 88.5 km/h would be about 50.5 mL. As a result, a 40 percent increase in fuel consumption would cause about a 65 percent increase in fuel saving and emission reduction. The estimate of total net benefit is about $7.7 million higher than the estimate based on the assumption of 10.6 km/L. The increase is largely due to fuel saving. The environmental benefit accounts for only a small proportion of the total increase. However, since fuel saving and emission reduction make up only about 9 percent of the total benefit estimated under the previous assumption, a change in the assumption about fuel consumption would result in about a 6 percent increase in total benefits (Scenario 5, Table 3). The change would not have a significant effect on the distribution of net benefits among the toll agency, toll patrons, and the community. Toll patrons would still be the primary beneficiaries.

**CONCLUSIONS**

The findings of this study have several important implications. First, in assessing costs and impacts of ITS projects, it is important to measure not only the total costs and impacts of the projects, but also the distribution of costs and impacts among affected parties. An overall positive net benefit does not necessarily mean positive net benefits to all the affected parties. Issues such as who loses and who benefits are crucial in decision making.

Second, different assumptions and modeling techniques will lead to different inputs for the calculations of costs and impacts, which can alter the outcomes of evaluation and affect decision making. Since most ITS technologies are relatively new, and there are few well-developed empirical databases on costs and benefits, ITS project evaluations are more likely to rely on estimates resulting from simulation models. Hence, on the one hand, there is a critical need for data from ITS deployments and for models that can be used to predict accurately the demands for—and the benefits of—ITS applications. On the other hand, ITS project evaluators should be fully aware of these limitations.

Third, the results of the case study for the ETC system at Canquiné Bridge suggest that overall the ETC project would realize most of its objectives. It would provide a higher level of service to toll patrons, enable the toll agency to collect more and higher-quality data, increase traffic flow on the bridge, and reduce vehicle emissions and fuel consumption. However, the savings in toll collection and an increase in operating revenue may not offset the initial capital investment, if the demand for ETC use and the operating cost reduction are smaller than forecast. This implies that the ETC project may not achieve the objective of cost reduction.

Finally, promoting ETC usage while reducing costs is essential for cost recovery by the toll agency. Toll agencies should make every effort to market ETC and reduce costs. As shown in the analysis, aggregate time saving accounts for a large proportion of the total benefits. However, the average time saving per trip is small. Similarly, fuel saving per trip is also insignificant. In addition, individual users' decisions to use ETC depend not only on the benefits of time saving and fuel saving, but also on many other factors, such as frequency of trip making, trip purpose, travel time during the day, and other socioeconomic characteristics of travelers. Hence, time saving and fuel saving alone may not provide enough incentive for travelers to adopt ETC. To encourage ETC usage, toll agencies...
may consider increasing the toll for manual toll lanes. Innovative strategies—such as the involvement of, or partnership with, industrial sectors, financial institutions, and other private-sector entities—could be developed to reduce or eliminate the costs of transponders, now borne by the toll agency.

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