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Publication Date

1996

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Travel, Emissions, and Consumer Benefits of Advanced Transit
Technologies in the Sacramento Region

A Report Prepared for PATH

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Subcontractor: Jakes Associates, Inc.
San Jose, CA

July, 1996

Abstract

The travel and emissions effects of advanced transit technologies, including advanced transit information, demand responsive transit, and personal rapid transit, were simulated in the Sacramento region for a twenty year time horizon with a state-of-the practice regional travel demand model (SACMET 95). Total consumer welfare and consumer welfare by income class with and without capital, operation, and maintenance costs were also obtained for these technology scenarios by applying the Small and Rosen method (1981) to the mode choice models in SACMET 95. We found that the advanced transit technologies, which were simulated in this study to act as feeder service for light rail transit, did not significantly reduce congestion and emissions in the region. This was primarily because the Sacramento region lacks extensive penetration by light rail service. Our consumer welfare evaluation showed that all the advanced transit technology scenarios were beneficial and generally equitable, even when capital, operation, and maintenance costs were included in the analysis. However, the analysis showed that advanced transit information service alone produced the greatest increase in consumer welfare; that is, the addition of demand responsive transit and personal rapid transit service to the advanced transit information scenario tended to reduce consumer welfare benefits. The total yearly difference in benefits between the scenarios would be significant. We conclude that the method of obtaining consumer welfare used in this study is a useful analytical tool for identifying optimal bundles of ITS technologies.

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Foreword

This research project for Caltrans and PATH should be viewed in terms of our on-going research program at UC Davis. This program is funded by FHWA, Caltrans, NOAA, and the CEC and develops improved policy guidance and modeling methods. The substantive policies evaluated over the last few years include advanced highway and transit technologies for Caltrans and FHWA and travel demand management (TDM) measures for the CEC, NOAA, and FHWA. Many journal articles have resulted from this work.

Our method developments include procedures for estimating the financial payback for users of automated urban freeways, a comparison of running travel models with and without feedback from assignment to distribution, and the calculation of full social costs for automation and travel demand management scenarios. Recently, we have adapted the Small-Rosen traveler welfare model so that it can be used with aggregate regional data typical of Metropolitan Planning Organizations (MPOs). In this project, we apply this model to advanced transit technologies scenarios.

Our related work involves applying Tranus, an integrated urban (land use/transportation) model, on datasets for the Sacramento region and linking its outputs into a geographic information system (GIS). The GIS-based model then feeds into a set of environmental impact assessment models. This is the first application of a market-based integrated urban model in the U.S. and one of the first attempts to link such a model to impact models in the world. This work is funded by FHWA and Caltrans.

With Energy Commission funding, we are also performing a comparative analysis of four integrated urban models, all on the same Sacramento datasets. We have teams calibrating the Step model (Greig Harvey and associates), Dram/Empal (Sacramento Area Council of Governments, SACOG, and Steve Putman), Tranus (Modelistica in Caracas), and Meplan (Doug Hunt and researchers at the University of Calgary). This project will compare the model results for 25-year projections and explain the differences in terms of differences in model structures. The scenarios examined include no build, transit expansion, outer beltway freeways, and a network of new freeway high occupancy vehicle (HOV) lanes.

Model developments scheduled for next year include: (1) a comparison of the economic welfare measures embodied in the four urban models; (2) further development of the GIS-based impact assessment models; and (3) a more refined calibration of the four models based on better low-density land use data (1980 base data as well as the 1990 data already used) and better floorspace price and consumption data. We also hope to perform a wider comparison of economic welfare models, including several simple ones already in use by federal agencies. Finally, we propose to operate the SACOG travel models with statistical sampling methods that permit the reduction in aggregation error and the estimation of sampling and estimation error. This project will permit us to determine whether the differences among typical scenarios evaluated by MPOs are statistically significant.

Executive Summary

The purpose of this project was to examine the potential travel effects, emissions, and consumer welfare benefits of advanced transit technologies. These technologies included advanced transit information, demand responsive transit, and personal rapid transit.

In order to accomplish this objective we used the Sacramento Regional Travel Demand model (SACMET 95) to simulate the travel effects of advanced transit technologies in the Sacramento region. This is a state-of the-practice regional travel demand model that incorporates most of the recommendations made by the National Association of Regional Councils' "Manual of Regional Transportation Modeling Practice for Air Quality Analysis" (Harvey and Deakin 1993). Some of the key features of this model include full model feedback from trip assignment to all earlier steps; an auto ownership and trip generation step with accessibility variables; a joint destination and mode choice model; a mode choice model with separate walk and bike modes and land use variables; and a trip assignment step that assigns separate A.M., P.M., and off-peak periods and includes an HOV lane-use model.

The California Department of Transportation's Direct Travel Impact Model 2 (DTIM2) and the California Air Resources Board's model EMFAC7F were used in the emissions analysis in this study. The outputs from the travel demand model used in the emissions analysis included the results of assignment for each trip purpose by each time period (A.M. peak, P.M. peak, and off-peak).

To estimate traveler net benefits, we applied the Kenneth Small and Harvey Rosen (1981) method for obtaining consumer welfare from discrete choice models to the SACMET 95 mode choice models. We conducted an analysis of traveler net benefits that includes the capital, operation, and maintenance costs of the technologies, rather than a full social welfare analysis; that is, accident costs and externalities of new projects are not included in our analysis.

As part of this report, we conducted a literature review on the advanced transit technologies examined in this study. We found that, while much of the literature touts the potential reductions of congestion and emissions resulting from advanced transit technologies, very few quantitative analyses of these benefits have been conducted.

Five advanced transit scenarios for the Sacramento region in the year 2015 were examined in this project. The scenarios included various combinations of advanced transit information, demand responsive transit, and personal rapid transit.

Based on the analyses conducted in this study, we found that:

1. In regions like Sacramento that lack extensive penetration of rail or line-haul transit service, advanced transit technologies that act as feeder service may not significantly reduce congestion and emissions.

2. In general, the advanced traveler information and demand responsive transit technologies modeled seemed to provide greater reductions in congestion and emissions than personal rapid transit technology.

3. Combining the modeled advanced transit technologies did not tend to increase the travel and emission benefits by a significant amount over the individual technologies because of overlapping markets in a region with limited light rail service.

4. When capital, operation, and maintenance costs of the advanced transit technologies were not included in consumer welfare estimates, total welfare increased by approximately 1.4 to 1.7 cents per trip (in 1995 present value) across scenarios for all trips in the region.

5. When capital, operation, and maintenance costs of the advanced transit technologies were included in consumer welfare estimates, the advanced transit information scenario yielded a higher consumer welfare benefit (1.5 cents per trip in 1995 present value) than the scenarios that added demand responsive transit and personal rapid transit (from 0.9 to 1.3 cents per trip in 1995 present value).

6. The lowest income class in the region generally received lower net benefits per trip, absolutely, than did the other two income classes.

The travel and emissions results in this study showed that the advanced transit technology scenarios have little impact. As a result, decision makers would not know whether to adopt them.   The consumer welfare evaluation, however, showed that all the advanced transit technology scenarios were beneficial and generally equitable, even when capital, operation, and maintenance costs were included in the analysis. The analysis also showed that advanced transit information service alone produced the greatest increase in consumer welfare; that is, the addition of demand responsive transit and personal rapid transit service to the advanced transit information scenario tended to reduce consumer welfare benefits. The total yearly difference in benefits between the scenarios would be significant. Thus, we conclude that the method of obtaining consumer welfare used in this study is a useful analytical tool for identifying optimal bundles of ITS technologies.

I. Introduction

This project was undertaken to investigate the potential travel, emissions, and consumer welfare benefits of advanced transit technology.   Using the advanced travel demand models of the Sacramento Area Council of Governments (SACOG), the research team examined advanced transit technology scenarios, including advanced transit information, demand responsive transit, and personal rapid transit.

The SACOG models are well-suited to this work, as they include walk and bike modes, elastic trip distribution, an auto ownership step, and land use variables in auto ownership and mode choice. The model has two carpool modes (auto 2 and auto 3+) and a high occupancy vehicle (HOV) lane use probability model. Transit access modes are explicitly represented in terms of walk and drive. Composite costs are used in mode choice, and thus tolls are represented. All mode choice equations are in the logit form and three include an income divided by cost variable, which allows a theoretically correct measure of consumer welfare to be used.

For this work, we applied our adaptation of the Small-Rosen traveler welfare model that takes aggregate data from typical regional travel demand models. This method, in and of itself, is a significant development because it allows California (and other) Metropolitan Planning Organizations (MPOs) to conduct theoretically correct economic evaluations of polices and plans with the use of their regional travel demand models. Economic evaluation methods are completely incorrect in current practice in California, because they do no use utility measures or even differences in travel costs from properly run travel demand models.

Having run SACOG's models for several years in our labs, we have considerable experience with these SACOG models and with the previous model set. We found our travel projections to be reasonable, based on our past modeling and the modeling done by SACOG in their planning process every three years. We also found our welfare projections to be reasonable, judged against theory, both for the aggregate regional estimates and for the estimates broken out by income class.

I I. Literature Review

A. Introduction

Some predict that the application of information and automation technologies, or Intelligent Transportation Systems (ITS), will revolutionize transportation systems in the United States and the world (OTA 1995). ITS programs under consideration today are primarily intended to reduce traffic congestion through applications that increase roadway capacity (e.g., ramp metering and vehicle automation) and encourage travel by transit and carpool (e.g., improved transit service and electronic payment of roadway tolls). If reductions in traffic congestion and shifts from auto to transit and carpooling modes are achieved, then another potential benefit of these ITS technologies may be the reduction of air polluting emissions from the transportation sector.

In this report, we focus on a subarea of ITS technologies: improved and/or new transit services that make use of information and automation technologies. These transit technologies include advanced transit information, demand responsive transit, and personal rapid transit. We examine the potential travel, emissions, and consumer welfare benefits of these ITS technologies.

B. Advanced Transit Information

Advanced transit information technologies would provide travelers with information about available transit service before and during their trip. Travelers can access this information at home, work, transportation centers, wayside stops, and while onboard vehicles through a variety of media such as telephones, monitors, cable television, variable message signs, kiosks, and personal computers. Some systems with links to automatic vehicle location are beginning to be able to provide real-time information about available transit service, such as arrival times, departure times, and delays. There are three types of transit information systems: (1) pre-trip, (2) in-terminal, and (3) in-vehicle. (DOT 1996) In this report, we focus on pre-trip advanced transit information systems.

Pre-trip information that provides travelers with accurate and timely information about transit travel may increase travelers' awareness of available transit service and reduce some of the

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uncertainty surrounding transit use. For some trips, the combination of these two factors may make travel by transit more appealing than traveling by car. Pre-trip information can include transit routes, schedules, fares, and location of park and ride lots. Table 1 provides more detailed examples of the types of pre-trip transit information that can be provided.

Table 1. Examoles of Pre-Trio Information.

Information thrust on...	Comments and Examples
Route/bus to take	This information can be based on traveler selected criteria, such as shortest time, certain itinerary, lowest fare, least walking distance, maximum use of rapid transit
How to get to the bus/train station	(Hard copies should be available)
Transfer points (if necessary)	The following information can be provided: -connection point location -waiting time at the transfer station
Departure time, delays, total travel time	-Real-time information is required -Providing departure time for the next 2 or 3 buses is preferable.
Fares and tickets	The following information can be provided: -structure of the fare system -locations to buy the tickets from -accepted method(s) of payment (e.g., credit card or cash) -available discounts -the cost of the ticket
Return trip information	Information on how to return
Traffic conditions	Dynamic information on traffic conditions
Parking availability	Congestion levels at parking lots
Ride-share opportunities	Providing (static/real-time) ride-share information opportunities can be part of transit services.
Tourist information	Information on places, events, etc.
Reservation information	Systems may allow advanced reservations for trains, hotels, etc.
Services for disabled people	Information on accessibility of various facilities

Currently, there are a number of advanced transit information projects underway in the U.S. One of these projects is the SMART TRAVELER in Los Angeles, California. SMART TRAVELER provides commuters with the following automation information: (1) **up-to-the-**minute freeway conditions and **traffic** speeds, (2) customized transit route planning, and (3) real-time **carpool** matching. Interactive (touch-screen) kiosks were installed to enable travelers to access the Los Angeles County Metropolitan Transportation Authority (LACMTA) bus, train, and shuttle schedules, routes, and fares. The kiosks allowed the traveler to build transit itineraries, print those itineraries, and obtain a list of area carpoolers. A preliminary evaluation of the use of these kiosks was positive, but because of funding problems, they were removed in June 1995. However, telephone information services still provide travelers access to Automated Telephone Rideshare Matching and LACMTA information. From the Internet, travelers can obtain information on freeway conditions. In the future, SMART TRAVELER services may be available on cable television. (DOT 1996)

Few studies have examined the effect of transit information systems on traveler's choice of mode. One study (Polak and Jones 1992), for example, examined travelers' preferences for different types of travel information and methods of inquiry, as well as the effects of travel information on travel behavior. The study made use of a stated preference survey of individuals who used in-home computers that provided pre-trip information on bus and car travel times from home to the city. The results of the study indicated that there was a significant demand for both auto and transit pre-trip information, even among regular car users.

Another study (Abdel-Aty et al. 1995) used computer aided telephone interviews in the Sacramento and San Jose areas of California to identify the transit service information most desired by non-transit users. In addition, customized stated preference choice sets were used to identify the likelihood of a commuters choice to use transit. The study found that 38 percent of the respondence who did not use transit would likely consider using transit if improved information were provided. Such variables as travel time, carpooling, and age were found to have a significant effect on the propensity to use transit.

Shank and Roberts (1996) in their review of ITS benefits found that traveler information technologies may result in shifts from the auto to transit mode; however, resulting emissions benefits may be small. They cite surveys performed in the Seattle, Washington area and the

Boston, Massachusetts area that found a five to ten percent shift from the auto to transit mode when traveler information was provided. However, they estimated that even with sizable mode shifts from auto to transit, reductions in emissions would be still be comparatively small due to the relatively small number of total trips affected by the shift.

C. Paratransit and Demand Responsive Transit

Cervero (1992) describes paratransit as transportation options that range from the private automobile to fixed-route bus service. "Paratransit fills an important market niche: like autos, they are flexible and fairly ubiquitous, connecting multiple places within a region, but at a price far below a taxi" (Cervero 1992). Paratransit service was originally implemented in the U.S. in the 1970s. Over the years, paratransit has changed a great deal. However, today most paratransit service can be characterized as either low-tech or high-tech service (Shaheen 1996).

We define demand responsive transit in this report as a subset of paratransit that uses automation and information technology to improve traditional paratransit service. Thus, demand responsive transit would be considered high-tech paratransit service.

Low-tech paratransit includes dial-a-ride, shared-ride taxis, and airport van services. The shared ride nature of these services makes scheduling more complex than taxi dispatching. The special needs of elderly and disabled passengers, who frequently use paratransit, can also complicate scheduling further. Today, many paratransit operators have computerized scheduling processes.

In high-tech, or smart paratransit, computers are used to satisfy real-time trip requests by predicting the approximate location of vehicles during a daily schedule that is retained in the computer's memory. If a new trip is requested, the computer will revise the schedule and transmit it to the driver so that she can pick up the new passenger. In practice, real time scheduling of paratransit has only been implemented in demonstration projections in the 1970s; the sole surviving service is in Orange County, California. Today, "Orange County operates the largest publicly owned dial-a-ride van service in the country, serving mainly elderly and poor households with some 125 vans on a contract basis" (Cervero 1992).

A number of studies (Benkne and Flannelly 1990; Cervero 1992; Flannelly et al. 1991; Franz 1993; and Kowshik et al. 1995) have examined the question of how to expand the target market for paratransit services beyond the traditional users through services catering to the average commuter, such as demand responsive transit that feeds to light rail systems (Shaheen 1996). However, few studies have examined quantitatively the effect of providing paratransit service on the mode choice behavior of travelers.

One study (Flannery et al. 1991) explored Honolulu commuters' interest in a number of different transportation modes. It found that paratransit with improved service was the most widely accepted of all. transit modes. The major causal factor behind this result was the combination of reduced access by auto and a guaranteed seat. The study also suggested that paratransit is capable of attracting the commuters most resistant to changing travel modes.

Another study (Ben-Akiva et al. 1996) provided a framework for examining the effect of various levels of paratransit service on ridership. Revealed preference and stated preference survey data were combined to avoid biases of stated preference surveys. They found a positive correlation between the levels of paratransit service and ridership levels. They also found that age, difficulties in walking, and employment status were important factors in choosing to ride paratransit.

A number of paratransit projects are currently being conducted and evaluated in California. These include the Santa Clara County Smart Vehicle, the Sacramento Real-Time Ridesharing, and the Anaheim AVL Van Pool Service. Shaheen (1996) has conducted a survey of these projects and her major findings are briefly summarized as follows. The Santa Clara County Smart Vehicle project has been developed as an add-on to existing service for those with disabilities. Smart Vehicle reports that as of December 1995, their business was up 39% from the previous year. A survey of 300 participants registered as drivers in Phase I of the Sacramento Real-Time Ridesharing project indicated a general lack of interest. in using the services provided. The Anaheim AVL Van Pool Service will be used by long-distance commute passengers (who will pay for van pool services by the month) and by short stop passengers (who will be able to reserve rides and pay fares on an as needed basis). The demand for this service is still unknown.

C. Personal Rapid Transit

Personal rapid transit (PRT) is a subset of Automated People Movers (APM). In this report, the we differentiate PRT from APM by the number of passengers that the vehicles carry. APM vehicles generally carry 12 to 100 passengers, whereas PRT vehicles generally carry from 1 to 6 passengers. There are no true PRT systems in operation in the U.S. today (the Morgantown, West Virginia, PRT system accommodates 21 people in a vehicle). However, the Northeastern Illinois Regional Transportation Authority is funding a PRT project in Rosemont, Illinois, that is still in the testing stage.

APMs are a system of steel or concrete exclusive guideways with small, driverless, electric-powered vehicles that are generally operated singly or in multi-car trains. APMs can accommodate from 2,000 to 25,000 passengers per hour per direction. The headways for APMs can be very short (e.g., 60 seconds, or even less for smaller systems). APMs operate at high speeds (e.g., 55 mph) and accelerate and decelerate rapidly and smoothly. The safety and reliability of the SkyTrain APM system in Vancouver, Canada, and the VAL APM system in Lille, France, have been documented as excellent; over 99% of runs are on-time within 4 minutes and zero injuries or fatalities have been reported (EcoPlan 1990 and BC Transit 1994; ctd. in Shen, Huang, Zhao 1996)

Shen et al. (1996) survey APM systems throughout the world. Their findings are described as follows. APM systems are generally located in major activity centers, such as, airports, entertainment or educational complexes, retail and employment areas, and central business districts, where medium ridership is expected and comparatively frequent service is needed during off-peak hours. APM systems have been installed in over 50 airports. In addition, 18 APM systems used for trunk line transit services are in operation or under construction throughout the world. Table 2 lists a number of line haul APM systems in the world. The Vancouver SkyTrain and the Lille VAL systems are two successful applications of PRT. In Vancouver, one sixth of all transit passengers use the SkyTrain for at least a portion of their daily transit trip. Thirty-five million passengers a year ride the SkyTrain and 110,000 trips are made daily (BC Transit 1994). In Lille, 50 million passengers ride the VAL system annually and 230,000 trips are made per day. The farebox recovery for both these systems is excellent. The Vancouver SkyTrain recovers 100 percent of costs; the VAL system, 120 percent.

Table 2. Line Haul APM systems in the World

System	Status	Length (mi.)	No. of Stations	No. of Vehicles	Line Capacity (pphpd)
Ankara Metro, Turkey	UDC[1]	9.4	12	108	--[2]
Docklands, England	Operating	16.7	35	80	15,600
Bordeux, France	UDC	6.2	16	64	--
Lille, France	Operating	15.7	36	83	24,000
Lyon, France	UDC	--	--	--	--
Mexico City Sky Train	UDC	13.1	27	60	--
Rennes, France	UDC	5.6	15	16	--
Toulouse, France	Operating	6.2	15	29	--
Turin, Italy	UDC	5.6	16	34	--
Vancouver Sky Train, CAN	Operating	17.9	20	130	25,000
Taipei, Taiwan	UDC	7.2	12	102	24,000
Yamanote Chiba	Operating	5.0	--	--	1,900
Kokura Kitakyusyu	Operating	5.2	--	--	4,800
Kobe Portliner, Japan	Operating	4.0	9	72	10,800
Kobe Rokkoliner, Japan	Operating	2.8	--	--	10,000
Yokohama, Japan	UDC	6.7	14	95	4,300
Osaka, Japan	UDC	4.1	8	60	5,000
Hiroshima, Japan	UDC	11.4	--	--	4,000

Note: 1. UDC stands for under construction;
        2. -- indicates not available
Reproduced from Shen et. al. 1996

III. Methods

A. Travel Demand Modeling

This study uses the 1995 Sacramento Regional Travel demand model (SACMET 95) to simulate advanced transit technology scenarios. The model was developed with a 1991 travel behavior survey conducted in the Sacramento region. SACMET 95 is a standard UTP (Urban Transportation Planning) five-step travel demand model that includes auto ownership, trip generation, trip distribution, mode choice, and traffic assignment steps. Figure 1 on the following page illustrates the SACMET model's general system flow.

SACMET 95 is considered to be a state-of the-practice regional travel demand model. It incorporates most of the recommendations made by the National Association of Regional Councils' "Manual of Regional Transportation Modeling Practice for Air Quality Analysis" (Harvey and Deakin 1993). Some of the key features of this model include:

1. model feedback of assigned travel impedances to all earlier steps

2. auto ownership and trip generation steps with accessibility variables

3. a joint destination and mode choice model for work trips

4. a mode choice model with separate walk and bike modes, walk and drive access modes, and two carpool modes (two and three or more occupants)

5. land use, travel time and monetary costs, and household attribute variables included in the mode choice models

7. all mode choice equations are in logit form

8. a trip assignment step that assigns separate A.M., P.M., and off-peak periods

9. an HOV lane-use probability model.

The model system is iterated on level of service variables by mode until the criterion for convergence is met (i.e., A.M. peak trip assignment impedance is within 3% of that in the last iteration). This usually required five iterations of the model for the year 2015. All submodels have been calibrated to regional survey data and traffic count data. SACMET 95 meets the Environmental Protection Agency's modeling requirements. See Appendix A for a detailed description of SACMET 95.

Figure 1
SACMET Model System
General System Flow

Highway Network

Transit Line Descriptions

Cross-Classified Variables Table

Feedback

Time, Cost & Distance Path-Skimming

Auto Ownership

Trip Generation

Home-Based Work uses a combined destination/mode choice model.

Trip Distribution

Mode Choice

Conversion to Vehicle Trips by Time of Day

A new model of HOV lane utilization is provided.

Traffic Assignment

Transit Assignment

Zone-to-Zone Times, Costs & Distances by Mode

Households Classified by Auto Ownership

Trip Ends by Trip Purpose

Zone-to-Zone Person Trips by Purpose

Zone-to-Zone Person Trips, Purpose by Mode

Zone-to-Zone Vehicle Trips by Occupancy

Highway Traffic Volumes

Transit Boardings & Volumes

SACOG, 1994

B. Emissions Model

The California Department of Transportation's Direct Travel Impact Model 2 (DTIM2) and the California Air Resources Board's model EMFAC7F were used in the emissions analysis. The outputs from the travel demand model used in the emissions analysis included the results of assignment for each trip purpose by each time period (A.M. peak, P.M. peak, and off-peak). The Sacramento Area Council of Governments provided regional coldstart and hotstart coefficients for each hour in a twenty-four hour summer period.

C. Consumer Welfare Model

1. Introduction

Transportation agencies typically use criteria such as lane-miles of congestion, hours of travel delay, travel distance, and mode share to evaluate proposed transportation policies. Such criteria are limited because they fail to account for the balance of effects on travel accessibility because of changes in transportation policies. For example, HOV lanes may reduce travelers' hours of delay but increase their full unobserved travel costs due to increased vehicle miles traveled; the uncalculated balance between these two effects may be a loss or a gain in overall traveler accessibility. Consumer welfare measures capture the net gain or loss in accessibility from changes in transportation policy and assign a dollar value to the resulting changes in accessibility.

The need for more comprehensive traveler welfare measures is highlighted by the Intermodal Surface Transportation Efficiency Act (ISTEA) (1991) requirement that transportation projects and plans be evaluated for economic efficiency. Presumably, the underlying rationale behind this requirement is that, because commuting costs are a major factor in wage inflation, more efficient use of the transportation system--and thus lower commuting costs and less wage inflation--will help maximize the productivity and competitiveness of the U.S. economy.

A complement to the goal of efficiency in transportation is the goal of equity. A highly efficient transportation system that excludes certain groups of people from access to employment and essential services would not generally be considered socially desirable. Consumer welfare measures can be used to calculate the net benefit or loss to specific groups (usually income

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groups) due to transportation policies, which can then be compared to determine whether one group benefits more than another or whether one group gains at the expense of another. With this knowledge it may be possible to redesign policies to redress losses to certain groups.

Quantification of consumer welfare measures is limited by transportation organizations' time, budgets, and technological constraints (Mannering and Hamad 1990). This may explain the inadequacy of consumer welfare measures implemented by transportation agencies to date and the discrepancy between the requirement in ISTEA and the methods for evaluating transportation policies currently used by regional transportation organizations. What is needed, then, are theoretically valid consumer welfare. measures that are quantifiable within the agencies' technological and budgetary limits.

Kenneth Small and Harvey Rosen (1981) illustrate how a welfare measure known as compensating variation can be obtained from discrete choice models (hereafter, the Small and Rosen Method). Our review of the published literature suggests that this method has not been applied to normal (aggregate) regional travel demand models. We develop a method of application and apply it to the SACMET 95 mode choice models. We then compare this method to two other applied consumer welfare methods and evaluate the strengths and weaknesses of each in theory and in practice.

2. ·Consumer Welfare and Small and the Rosen Method

The basic economic concept behind consumer welfare is utility. Utility is defined as the satisfaction derived from the consumption of a good or service. Consumers are assumed to maximize their utility when purchasing goods and services subject to the constraints of prices and income.

Change in consumer welfare is the difference between individuals' utility in a base case scenario and in a policy scenario. If the price of a good is increased in a policy scenario, then individuals can afford less of the good, and thus their utility is decreased. Conversely, if the price of a good is lowered in a policy scenario, then individuals can afford to buy more of the good, and thus their utility is increased. For example, imagine a policy scenario in which bus fares are cut in half over base case levels. As a result, individuals can afford to travel more

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and farther by bus than they could in the base case scenario. Their utility has therefore increased, which produces a gain in consumer welfare. See Appendix B for a general review of consumer welfare measures.

A common method of measuring individuals' utility in policy scenarios is to employ discrete choice models. The mode choice models in SACMET 95 take the specific discrete choice formulation of the **logit** equation. In this model, households are faced with the choice of mode (e.g., car, transit, bike, or walk) to use for a trip. The utility of each mode choice is based on household attributes and the mode's level of service (i.e., travel time and monetary costs). The probability of choosing a particular mode is based on the utility of all modes. For example, the following equation is a **logit** model:

$$Pn(j) = \frac{exp\ V_j}{\Sigma^n_{i=1} exp\ V_i} \tag{1}$$

where the probability of choice j is made from a total number of n choices and V_i represents the indirect utility of the i'th choice. It has been shown that maximum expected utility is equal to the **logsum** of the denominator of the **logit** equation given different choices (i = 1 . ..**n**), household income, and the goods' prices:

$$V\ (total) = ln[e^{V1} + e^{V2} ...+ e^{Vn}] \tag{2}$$

where ln is the natural log (McFadden 1978; Ben-Akiva and Lerman 1979). Therefore, it is possible to measure the change in consumer utility by subtracting the maximum expected utility (or **logsum** of the denominator of the **logit** equation) in the base case (p^0) scenario from that of the policy scenario (p^f):

$$V\ (change) = ln[e^{V1\ (pf)} + e^{V2(pf)} ...+ e^{Vn(pf)}] - ln[e^{V1(p0)} + e^{V2(p0)} ...+ e^{Vn(p0)}] \tag{3}$$

To obtain change in consumer welfare, we need to assign a dollar value to the utility measured in equation (3). The marginal utility of income (λ) is an estimate of the increase in individual utility given an extra dollar (or any other unit) of income:

$$(\lambda)\ (increased\ income) = increase\ in\ utility. \tag{4}$$

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If we are given the increase in utility, then we can divide the additional utility by the marginal utility of income to obtain the increased income:

$$\frac{\text{increase in utility}}{\lambda \iota} = \text{increased income.} \qquad (5)$$

Thus, the change in consumer welfare is the difference between utility from the base case and policy scenarios divided by the marginal utility of income. See Appendix C for a more detailed mathematical description of consumer welfare and the Small and Rosen Method.

Therefore, from equations (1) and (4), the change in consumer welfare due to a change in price from p^0 (the base case scenario) to p^f (the policy scenario) of any of the n choices is:

$$CV_i = -(1/\lambda \iota)\{\,[\ln \Sigma_i \; exp \; V, \; (p^f)] - [\ln \Sigma_i \; exp \; V_i \, (p^0)]\,\} \qquad (6)$$

Kenneth Small and Harvey Rosen in their 1981 paper, "Applied Welfare Economics with Discrete Choice Models," develop this formula and name its product compensating variation (CV). Small and Rosen (1981) also show that the marginal utility of income can be obtained from the estimated coefficient of the cost divided by income variable in the mode choice equations.

Compensating variation has become a popular method of estimating consumer welfare and is considered by economists to have some theoretical advantages over other methods. See Appendices B and C for a full discussion.

To summarize, compensating variation is the difference between the maximum expected utility (or **logsum** of the denominator of the **logit** equation) in the base case scenario from that of the policy scenario divided by the individual's marginal utility of income. Total compensating variation can be obtained by summing the compensating variation of all individuals affected by the change.

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3. Application to the SACMET 95 Mode Choice Model

As described in their documentation, the **SACMET** 95 mode choice models use a **logit** specification. However, person trips, rather than individuals, are the unit of analysis. Person trips are generated for a number of household groups. Thus, the expression for compensating variation in the context of the **SACMET** 95 mode choice models for household groups (h) within each income class (i) is

$$CV_h = -(1/\lambda_i)\{[\ln \Sigma_j \exp V_j(p^f) \times trips,] - [\ln \Sigma_j \exp V_j(p^0) \times trips,]\} \tag{7}$$

where λ_i is the coefficient of the cost divided by income variable for an income class, V_j is the household's utility across modal alternatives for a zone pair, and trips, is equal the number of person trips made by a household class for a zone pair. Because person trips are the units of analysis in the **SACMET** 95 mode choice model, the **logsum** of the denominator (for a zone pair) for a household group is multiplied by the number of trips (for a zone pair) made by a group. This calculation is done for the base case scenario and a given policy scenario. The figure for the base case is subtracted from the figure for the policy scenario, and the result is divided by the marginal utility of income for the household's income group. As discussed above, the marginal utility of income is the negative of the coefficient of the cost divided by income variables in the model (Small and Rosen 1981). Thus, in the mode choice models, the **logsum** of the denominator of the **logit** equation is calculated for trips made by each household group.

To obtain total compensating variation for each income group, the compensating variation for each household within one of the three income groups is summed:

$$CV_i = \Sigma_h CV_h \tag{8}$$

Total **compensating** variation is obtained for the region by summing the compensating variation obtained from each income group:

$$CV = \Sigma_i CV_i \tag{9}$$

Measures of compensating variation could not be obtained for the non-home-based and the home-based school mode choice models because they lack cost and income variables, the absence of which makes it difficult to obtain the marginal utility of income for these trip types. Thus, 63% of the region's total trips are included in the analysis of compensating variation. However, approximately 80% of trip utility is included in the analysis because work trips are valued more highly than nonwork trips.

Table 3 provides the estimates of the marginal utility of net household income by trip purpose used in the compensating variation calculations:

Table 3. Estimates of the Marginal Utility of Income.

Income Groups	Home-Based Work	Home-Based Shop and Other
Income Group 1 (0 to $10,000)	0.5399	1 . 0 9 0 0
Income Group 2 ($10,001-$35,000)	0.2764	0.5580
Income Group 3 ($35,001 and above)	0.1372	0.2770

The distribution of income used in the SACMET 95 model is empirical. The marginal utility of income is the estimated coefficient for travel cost divided by the average income of the household group. Net income, not gross income, is used in the SACMET 95 mode choice model. Net income is calculated as follows:

"Net" Household Income = [0.6 x (Gross Household Income-$20,000)] + $20,000

Since the mode choice models include perceived operating costs (5 cents per mile), rather than actual operating costs, total VMT is obtained from the model and then multiplied by 35 cents. Based on a review of the literature, we assume total operating costs are 40 cents (Small 1992). The change in total operating costs per mile from the base case and the

alternative modeled is then added to the compensating variation figures.

We assume constant miles per vehicle per year into the future as well as constant real total internal (private) costs per vehicle per year, and thus use the current average of 40 cents per mile for total costs.' We use full private costs because the model is cross-sectional, and thus represents long-term equilibrium, i.e., vehicle ownership changes are included. We assume that all policies were put into place by 2010, at the latest, and so five or more years have elapsed to the model year 2015. Thus, vehicle ownership changes are represented correctly.

4 Consumer Welfare and Full Model Iteration

As discussed in the Travel Demand Modeling methods section of this report, the SACMET 95 regional travel demand model is run in the theoretically correct manner with full model iteration on level of service variables. Thus, in the model, expanded roadway capacity will induce more and longer trips.

Full model iteration has several effects on projections of consumer welfare. The value of the new induced trips provide less benefit than existing travel because the former are trips that are foregone in the presence of congestion and, thus, have less value. The benefits due to new trips are about half of those of existing trips (i.e., benefits of new trips compose the triangle rather than the rectangle underneath the demand curve). New trips and increased trip lengths due to increased roadway capacity will counteract much of the travel time savings benefits of roadway expansion projects.

The recent National Academy of Sciences panel report on "Expanding Metropolitan Highways" reviewed research on the elasticity of demand (VMT) with respect to capacity (lane-miles). Several studies found medium-term elasticities in the range from 0.5 to 1.0. Hansen et al. (1993), for example, studied California urban counties with longitudinal data sets and found elasticities from 0.4 to 0.6 after an average of 16 years. The SACTRA commission in the U.K. (SACTRA 1994) reviewed many studies and concluded that elasticities of 0.5 in the short-term and 1 .O in the long-term are reasonable (NAS 1995, pp. 152-159).

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[1] 1995 Nationwide Personal Transportation Survey (1992) data show approximately constant average annual miles per vehicle per year: 11,600 in 1969, 10,679 in 1977, and 10,315 in 1983, and 12,452 in 1990. Thus, there has been a 7% increase from 1969 to 1990.

5 Uncertainties in the Method of Application

Small and Rosen's method has been applied in academic transportation studies to disaggregate discrete mode choice models. In academic studies, the marginal utility of the income for an individual is divided into the logsum of the denominator of that individual. Then, an average for all individuals in the sample by income group is obtained. However, in the application of the Small and Rosen Method to aggregate travel demand models, the average marginal utility of income for an income class is divided into the logsum for trips made between zone pairs for a household income class. The application of the method to the aggregate model is based on the assumption that the average logsum divided by the average marginal utility of income for that class is approximately equal to the mean of the individual logsum for each traveler divided by the individual marginal utility of income.[2]

One limitation of applying the Small and Rosen Method to regional travel demand models is that the consumer welfare measure can only account for changes in the time and monetary costs of available modes to destination choices. The method would not provide measures of the costs and benefits of location choice resulting from changes in the transportation system. For example, the construction of a new freeway might allow a family to buy a larger home farther out in the suburbs because its location is now within commuting distance. Most travel demand models used in the U.S. today are not integrated with land use models that are sensitive to changes in transportation accessibility, and thus cannot capture the welfare effects of location choices. Therefore, the application of such traveler welfare models to transportation investment that will strongly affect sprawl (new beltways, new radial freeway capacity, and all-day tolls) is problematic. However, some theorists maintain that utility changes from location choice are fully captured by measures of utility change from travel choice.

In addition, truck and freight trips are not included in the analysis of consumer welfare. Such trips generally have a high value. As a result, the welfare gains from scenarios that significantly decrease roadway congestion may be underestimated in this study.

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[2] Professor Debbie Niemeier in the Civil and Environmental Engineering Department at U.C. Davis pointed out this limitation in our method.

Finally, our assumption of constant VMT per vehicle per year may result in an overestimation of private costs for policy scenarios that increase VMT (e.g., scenarios that include expanded roadway capacity). Conversely, for policy scenarios that decrease VMT (e.g., pricing and expanded transit), travel cost reductions may be overprojected because of assumed constant VMT. However, travel reductions are likely underestimated for pricing policies because the auto ownership step is not sensitive to travel costs.

6 A Comparison of Recent Welfare Applications

In addition to the compensating variation method described in this report, within the past few years two other consumer welfare methods have been proposed that could also be applied by regional transportation agencies for evaluation of transportation policies. The Federal Highway Administration metropolitan planning technical report, "Evaluation of Transportation Alternatives" (1995), prepared by ECONorthwest and Parsons Brinkerhoff Quade & Douglas, Inc., proposes a consumer welfare method that could be applied to regional travel demand models by MPOs. Also, the Environmental Defense Fund conducted an efficiency and equity analysis of transportation policies in the Southern California region, "Efficiency and Fairness on the Road" (Cameron 1994), using Greig Harvey's STEP model and a consumer welfare measure.

ECONorthwest and Parsons Brinkerhoff Quade & Douglas, Inc. (1995) (hereafter, the ECONorthwest et al. method) calculates user benefits as follows:

$$\text{User Benefits} = (U_0 - U_1)(V_0 + V_1)/2$$

where,

U_0 = the user cost per trip without the policy

U_1 = the user cost per trip with the policy

V_0 = the volume of trips without the policy

V_1 = the volume of trips with the policy

Costs per trip would include per mile auto operating costs, tolls, parking costs, transit fares, and travel time by each mode. Travel time is given a monetary value based on the value of travel time. These figures could be obtained from most regional travel demand models. For equity analyses, costs, VMT, trips, and value of travel time would have to be obtained by

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income class. This method calculates the change in consumer welfare between the base and policy scenarios, rather than the total area under the demand curve above costs for each scenario.

Greig Harvey used the Short-Range Transportation Evaluation Program (STEP) to conduct a benefit-cost analysis for the Environmental Defense Fund (Cameron 1994) (hereafter, the Harvey and EDF method). The benefits included in the analysis are automobile mobility and public transit mobility and the costs are automobile expenses, transit fares, transportation taxes, transportation-related air pollution, and traffic congestion (household cost). The STEP model is used to construct demand curves by five income classes as (1) a function of cost per mile driven and vehicles miles traveled (VMT) and (2) transit fare per passenger mile and transit person miles. The demand curve was created by increasing the per mile cost incrementally (e.g., by one cent) and obtaining the corresponding reduction in vehicle miles traveled or transit person miles traveled. Theoretically, it should be possible to do this for each combination of price and miles traveled along the demand curve; however, "in practice, with the STEP model, it is only possible to accurately estimate travel demand between the range of $0.00 per mile and $0.30 per mile vehicle operating costs" and for transit "fares ranging from $0.01 to $0.38 per passenger mile" (Cameron 1994). A differential multiplier was used to fill in the gaps in the demand curves. Fixed costs were added to the total area of the demand curve for each scenario. Thus, total expenditures for each scenario, rather than the change in welfare between scenarios, were calculated.

Table 4 evaluates the three consumer welfare methods based on four criteria (1) applicability to a broad range of MPO models, (2) comprehensive inclusion of travel benefits, (3) aggregation error, and (4) the ease of application to MPO regional travel demand models.

Table 4. Evaluation of Consumer Welfare Methods.

Evaluation Criteria	Rodier & Johnston	Harvey & EDF	ECONorthwest et al.
Range of Application to MPO Models	Medium (need logit equations in mode choice and estimates of marginal utility of income)	Medium (need recent household travel survey)	High (only need VMT and person hours traveled)
Includes All Travel Benefits	No	No	No
Aggregation Error	Medium (if 3 or more income classes)	Low (microsimulation)	Medium (if 3 or more income classes)
Ease of Application	High	Low (new model)	Low (lots of calculations)

The ECONorthwest et al. method has the highest range of application to MPOs' regional travel demand models. It can be applied to any regional travel demand model; however, 'more accurate estimates of benefits would require that a mode choice model be included in the regional travel demand model and, for equity analyses, that costs be calculated by income class. The Rodier and Johnston method can only be applied to regional travel demand models that include a mode choice step with a logit or probit specification and a cost divided by income variable in the equation or variables that allow estimates of the marginal utility of income. The Harvey and EDF method requires the calibration of the STEP model for each region.

None of the three methods includes the benefits, that may result from transportation policies, of consumers' ability to buy more land at a lower cost than would be possible closer to the urban center. As mentioned previously, the travel demand model would have to be integrated with a land use model that represents land market clearing to obtain such benefits. None of the methods includes producer surplus (business profits).

If we do not examine large all-day roadway tolls or large regionwide capacity increases (such as an outer beltway), land use differences across alternatives will be of minor importance and

therefore can be ignored. There is no producer surplus for almost all auto travel, as households do not take profits. Roadway and transit services are provided by public agencies, and they do not experience profits. In any event, their costs and revenues are so skewed by subsidies that surplus for them would be difficult to interpret. So, we can also ignore producer surplus in regional modeling. Under these not-too-restrictive conditions, all three methods include all travel benefits.

The Harvey and EDF method, which uses the STEP model, is best able to minimize aggregation error in level of service, value of travel time, and marginal utility of income estimates because this model's mode choice step uses a disaggregate sample enumeration procedure[3]. Most regional travel demand models do not use the sample enumeration technique; rather, they aggregate by some form of household class.

The Rodier and Johnston method is the easiest of the three methods to apply to regional travel demand models because the necessary level of service data are summarized into one output, the logsum of the denominator of the logit model. The ECONorthwest method would require the generation of many cost outputs by, mode and by income class. Most regional travel demand models do not currently produce such output, and new programs would have to be written to obtain them. The Harvey and EDF method is time consuming because the model has to be run for each incremental increase in price level in order to construct demand curves. In addition, separate demand curves are required for different types of costs (e.g., time vs. monetary), mode, and income classes. The Harvey and EDF method also unnecessarily adds error into its analysis with its somewhat arbitrary estimate of the demand that could not be constructed by STEP. Using the change in consumer welfare between policy scenarios rather than the total consumer welfare for each policy scenario, would eliminate this problem. A measure of compensating variation using the Small and Rosen Method could be obtained from the STEP model.

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[3] STEP "reads through the household sample, adding level-of-service and land use data to each household record as necessary, and calculates all of the household's travel probabilities. Full model specifications are used, and the sampling framework preserves the richness of the underlying distribution of population characteristics. Household totals are expanded to represent the population as a whole, and summed in various regional and subregional categories" (Cameron 1994).

D. Uncertainty in the Methods of Analysis

The **SACMET** 95 travel demand model is not integrated with a land use model. As a result of using fixed land use inputs, the model underprojects induced auto travel due to major roadway capacity expansions and reduced auto travel due to transit investments and pricing policies.

System equilibrium is assumed in model operation with full feedback from trip assignment to earlier steps until convergence. This implies an elasticity of demand with respect to capacity of about 1.0. If the actual transportation system does not attain complete equilibrium (as some research suggests), our running of the model would exaggerate the trip length in scenarios with expanded roadway capacity. However, this exaggeration is likely to be at least offset by the failure to represent land use changes resulting from transportation policies.

In addition, full model iteration should, in theory, include the feedback of composite impedances (travel time and cost) for all modes to the auto ownership step. In **SACMET** 95, travel times from assignment are fed back to trip distribution for both work trips and non-work trips, and there is limited feedback to the auto ownership step through retail employment and transit accessibility variables. However, trip assignment is not sensitive to travel costs, only travel times on roadways. Thus, a toll on a specific route would cause mode shifts but-not route shifts, and thus the model may slightly overproject mode shifts and underproject route shifts. Note, however, that this bias would be minimal for the results of peak-period tolls in this report because of the low average toll level, approximately 5 cents per work trip. This is because only a small portion of the commute trip takes place on congested roads.

The propensity for auto drivers to switch to transit and/or HOV modes in the presence of higher auto travel time and cost is likely underrepresented in the **SACMET** 95 model. This is an artifact of the cross-sectional data used to estimate the model. Sacramento currently has minimal transit service, one relatively short HOV facility, and comparatively low land use densities (compared to urban areas with high transit use), and thus cross-sectional data on travel behavior collected in this area would contain little variation in transit and HOV mode choice. In addition, if land use densities increased, transit and HOV use would likely be underprojected.

Attributes of modes such as comfort, convenience, safety, and reliability are generally included as mode specific constants, rather than separate variables, in the mode choice models of most regional travel demand models. This is because such variables are very difficult to forecast into the future. Since advanced transit technologies have not been widely implement in the U.S. (much less Sacramento), potential beneficial attributes of these technologies, over and above those of the transit modes, are not represented in the underlying data used to estimate the **SACMET** 95 mode choice models. As a result, our analysis may underestimate travel and consumer welfare benefits.

The **SACMET** 95 model uses zonally averaged land use and distance variables. Zonally averaged variables have less variation and thus weaker explanatory power than, for example, discrete GIS-based models that do not use zonally averaged variables.

In addition, the trip assignment step of **SACMET** 95 lacks the representation of peak spreading or time-of-day choice. Thus, the volume of travel during peak hours may be overestimated for very congested scenarios because the propensity of travelers to move off of the peak is not represented.

There is also a considerable amount of uncertainty surrounding the lowest travel speed in assignment due to extreme congestion; therefore, fixed "floor" speeds are used in the assignment step. Further, in general, the accuracy of speeds in assignment need to be imposed by calibrating to speeds. The effect of these two limitations are unknown.

The magnitude of each of the foregoing limitations of the travel modeling cannot be identified; however, it appears that many of these limitations may offset one another.

Any limitation in the travel modeling, as described above, that affects the accuracy in estimates of transportation level of service will likewise affect the accuracy of the estimates of emissions and consumer welfare.

Finally, it is widely known that emissions are underprojected by the models used in the analysis in this report. However, this should not affect the rank ordering of the scenarios.

IV. Advanced Transit Scenarios for the Sacramento Region.

Five advanced transit scenarios in the Sacramento region for the year 2015 were examined in our study. SACOG provided the demographic projections and networks for the 2015 scenarios. The networks include transportation projects listed in SACOG's 1996 Metropolitan Transportation Plan Working Paper #3 (MTP). All changes to the input data and model codes are described for each alternative below.

A.   2015 Base Case Scenario

Description. The future base case scenario includes modest light rail transit extensions east to Mather Field and south to Meadowview road, as well as modest land use projection shifts in some areas of the region. SACOG describes their revised land use projections:

> As for the different land use and growth projections used for this option, the changes are in Sacramento city and county only. Within these jurisdictions, we reallocated post-2005 phasing of growth so that it occurred in a more urbanized fashion with higher densities. All control totals for the 2015 land use and growth projections were maintained. Most of this reallocation occurred within the south Sacramento County area where most of the growth was already projected to occur. Employment centers in downtown Sacramento and the Sunrise/White Rock area of Sacramento County were also increased in terms of the amount of growth forecasted to occur there. (SACOG 1996)

This scenario also includes some ramp meters on freeways and a conservative number of new roadway projects. New HOV lanes are excluded from this scenario and no new mixed flow freeway lanes are built. This base case is used for comparison purposes; that is, all improvements are added to this scenario.

Modeling. All network and land use modeling files were obtained from SACOG's "Transportation Management/Land Use Option" alternative (SACOG 1996). The changes made to these files for our base case scenario were (1) to eliminate all HOV lanes from the roadway network and (2) to eliminate the demand responsive transit from the transit network.

B.   Advance Transit information (ATI) System

Description. Transit users access real time transit scheduling information through 100 kiosks located at transit stations and workplaces, the telephone, the Internet, and cable television. This scenario assumes the broad dissemination of personal digital systems.

Modeling. The maximum initial wait times for all transit service in the model were reduced to three minutes.

C.   Personal Rapid Transit (PRT)

Description. A system of exclusive guideways and small, driverless vehicles is constructed to link regional transit stations to important locations close to these stations. PRT service has one minute **headways** and a fare of fifty cents. The following are the locations for PRT identified by SACOG and RT officials:

1. Power *Inn.* U.S. Army Depot to Power Inn station.

2. *Folsom Blvd & El Caprice Dr.* **Mather** Air Force Base loop and **Rancho Cordova** loop to Folsom Blvd, Paseo Dr., and El Caprice Dr. (a future LRT station).

3. *University/65th St.* California State University Sacramento loop to **University/65th** St. station.

4. 39th St. U.C. Davis Medical Center from Broadway and 50th St. to 39th St. station.

5. *Swansfon.* Arden Fair Mall to **Swanston** station.

6. *Waft//-80.* McClellan Air Force Base to Watt I-80 station.

7. 29th St. Downtown (east) loop from 29th St. station along 29th St. to I St. to 26th St. up Q St. to 29th St. station again.

8. St. *Rosa Lima Park.* St. Rosa Lima Park to H and 8th streets, to the Army Depot to I **&** 7th streets, to 3rd and B streets, and to S. River Road.

9. *8th* and 0 *Station.* Loop to 0 and 3rd streets, to 3rd and R streets, to 7th and R streets, and to 8th and 0 streets.

Modeling: PRT is coded in the transit network file as a new transit only route with direct routes between RT stations and proposed locations with short wait times. **Headways** are

coded as one minute.

D.   Demand Responsive Transit (DRT)

Description. Demand responsive transit service is provided to connect people in the suburbs to light rail transit stations. DRT service areas include the following (see Figure 2):

1. Antelope
2. Citrus Heights/Orangevale
3. Gold River
4. Rancho Cordova/White Rock
5. Elk Grove
6. Laguna
7. Valley High
8. Pocket
9. Natomas

Initial boarding fares are $1.25 and transfers to light rail are $0.75. Headways for demand responsive transit range from fifteen to thirty minutes. This scenario also expanded bus service in El Dorado county.

Modeling: The demand responsive transit files from SACOG's "Transportation Management/Land Use Option" alternative (SACOG 1996) were added to the base case scenario files to create this scenario. SACOG coded the demand responsive transit in the transit network file as new transit only routes with short direct routes between zones and LRT station locations with short wait times.

Yuba/Sutter Inset

LIVE OAK
RTE 99 · RTE 70
RTE 20
MARYSVILLE
RTE 99 · RTE 70
RTE 20
YUBA CITY
RTE 99
RTE 65
RTE 70
WHEATLAND

Downtown Sacramento Inset

I-5
BUS 80
RTE 160
HWY 50

RTE 49
RTE 65
LINCOLN
RTE 193
AUBURN
RTE 193
RTE 99
RTE 70
RTE 99/70
ROCKLIN
I-80
RTE 49
ROSEVILLE
PLACERVILLE
WOODLAND
RTE 16
I-5
FOLSOM
HWY 50
I-505
RTE 113
RTE 49
DAVIS
I-80
WEST SACRAMENTO
DOVER/WHITE ROCK
WINTERS
RTE 16
RTE 84
RTE 99
I-5
RTE 104
GALT

FIGURE 1 - 1996 METROPOLITAN TRANSPORTATION PLAN
2015 TRANSPORTATION MANAGEMENT / LAND USE OPTION
PROJECTS IN ADDITION TO COMMON PROJECTS

Transportation Improvements

Demand Responsive Service Area		Existing Light Rail Lines
Road Widenings		New Rail Lines
Carpool Lanes		Interchange Modifications
New Roads		New Interchanges

Map Feature Legend

— Metropolitan Transportation System
— Regional Water Features
— SACOG Regional Boundary

E. Combination of Scenarios

The advanced transit technologies described above were combined into the following five scenarios.

1. Base Case
2. Advanced Traveler Information
3. Advanced Traveler Information and Personal Rapid Transit
4. Advanced Travel Information and Demand Responsive Transit
5. Advanced Traveler Information, Personal Rapid Transit, and Demand Responsive Transit

V. Findings and Discussion: A Comparison of Scenarios

        A. Travel Results

Daily vehicle travel projections of trips, vehicle miles traveled (VMT), hours of delay, hours of free flow, and total hours of travel for 2015 advanced transit scenarios in the Sacramento region are presented in Table 5.[4]

Table 5. 2015 Advanced Transit Scenarios in the Sacramento Region: Daily Vehicle Travel Projections.

Scenarios	Trips	VMT	Hours of Delay	Hours of Free Flow	Total Hours of Travel
Base Case	6,801,448	61,377,566	247,563	1,433,803	1,681,366
ATI	6,780,253	61,261,723	244,559	1,430,752	1,675,311
ATI & DRT	6,772,184	61,213,765	243,879	1,429,400	1,673,279
ATI & PRT	6,777,053	61,248,163	244,317	1,430,309	1,674,626.
ATI, DRT, & PRT	6,770,166	61,229,989	243,251	1,429,674	1,672,925

These figures are for vehicle travel only; that is, they include only auto and commercial vehicle trips and not transit, walk, and bike trips. The percentage change in daily vehicle travel projections from the base case scenario are presented in Table 6.

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[4] Hours of delay are vehicle hours of travel on congested roads. Hours of free flow are vehicle hours of travel on uncongested roads. Total hours of travel are vehicle hours of travel on congested and uncongested roads.

Table 6. 2015 Advanced Transit Scenarios in the Sacramento Region: Percent Change in Daily Vehicle Travel Projections from the Base Case Scenario.

Scenarios	Trips	VMT	Hours of Delay	Hours of Free Flow	Total Hours of Travel
ATI	-0.31%	-0.19%	-1.21%	-0.21%	-0.36%
ATI & DRT	-0.43%	-0.27%	-1.49%	-0.31%	-0.48%
ATI & PRT	-0.36%	-0.21%	-1.31%	-0.24%	-0.40%
ATI, DRT, & PRT	-0.46%	-0.24%	-1.74%	-0.29%	-0.50%

All of the advanced transit scenarios produce relatively small reductions in trips, VMT, hours of delay, hours of free flow, and total hours of travel over the base case scenario. The reduction in trips ranged from 0.31% to 0.46%; the reduction in VMT ranged from 0.19% to 0.24%; the reduction in hours of delay ranged from 1.21% to 1.74%; the reduction in hours of free flow ranged from 0.21% to 0.29%; and the reduction in total hours of travel ranged from 0.36% to 0.50%. Thus, it appears that the advanced transit scenarios modeled in this study will not provide significant relief from traffic congestion and are unlikely to reduce travel enough to provide significant emissions reductions.

The differences between pairs of the advanced transit scenarios modeled was quite small. The difference among scenarios ranged approximately, from -0.05 to -0.15 percentage points for trips; for VMT, from -0.02 to -0.08 percentage points; for hours of delay, from -0.1 to -0.53 percentage points; and for hours of travel, -0.04 to -0.14 percentage points. The addition of an advanced transit service to a scenario tended to increased its effectiveness. DRT service tended to be more effective than PRT service. The exception was that the ATI and DRT scenario produced a greater decrease in VMT and hours of free flow than the ATI, DRT, and PRT scenario. This is likely due to the fact that the ATI, DRT, and PRT scenario generated more transit drive access trips than the other scenarios (see Table 7). In general, the small differences between scenarios suggests that the model represents limited synergism resulting from the combination of different advanced transit service alternatives due to overlapping markets in a region with poor transit service in general.

Daily mode share projections for 2015 advanced transit scenarios in the Sacramento region are presented in Table 7. The percentage change in mode share projections from the base case scenario are presented in Table 8.

Table 7. 2015 Advanced Transit Scenarios in the Sacramento Region: Daily Mode Share Projections.

Scenario	Drive Alone	Shared Ride 2	Shared Ride 3	Transit Walk	Transit Drive	Walk	Bike
Base Case	49.38%	26.71%	15.57%	0.66%	0.15%	5.89%	1.64%
ATI	49.20%	26.57%	15.53%	1.07%	0.21%	5.80%	1.61%
ATI & DRT	49.14%	26.53%	15.52%	1.20%	0.21%	5.79%	1.80%
ATI & PRT	49.17%	26.55%	15.53%	1.12%	0.21%	5.80%	1.61%
ATI, DRT & PRT	49.12%	26.51%	15.52%	1.26%	0.22%	5.78%	1.60%

Table 8. 2015 Advanced Transit Scenarios for the Sacramento Region: Percentage Change in Daily Mode Share Projections from the Base Case Scenario.

Scenario	Drive Alone	Shared Ride 2	Shared Ride 3	Transit Walk	Transit Drive	Walk	Bike
ATI	-0.37%	-0.52%	-0.27%	63.64%	36.52%	-1.50%	-1.41%
ATI & DRT	-0.48%	-0.69%	-0.33%	83.04%	38.00%	-1.72%	-1.89%
ATI & PRT	-0.42%	-0.59%	-0.29%	71.27%	40.14%	-1.63%	-1.58%
ATI, DRT & PRT	-0.53%	-0.75%	-0.35%	91.57%	41.46%	-1.92%	-2.11%

All the advanced transit scenarios resulted in significant increases in transit with walk access and transit with drive access mode shares over the base case scenario. The transit with walk access mode share increased by approximately 64% to 92%, and the transit with drive access scenarios increased by approximately 37% to 41%. Again, the addition of an advanced transit service in the scenario increased the transit mode share; however, differences among scenarios were generally small with the exception of transit with walk access mode share. DRT service generated a larger transit with walk access mode share than PRT and PRT service generated a larger transit with drive access mode share than DRT. This result is reasonable given the designs of the DRT and PRT scenarios.

Much of the gains in the transit mode shares appears to be derived from losses in the walk, bike, and HOV mode shares, rather than the drive alone mode shares. The smallest reduction in mode share as a percentage comes from the drive alone mode share; however, with respect to the absolute numbers of trips, the reduction in drive alone mode share was the greatest. These results suggest that the time and monetary costs of transit travel in the advanced transit scenarios are not competitive with those of the drive alone mode. Combined transit mode share for the entire region reached its highest level at 1.48% for the ATI, DRT, and PRT scenarios.

Relatively small reductions in auto travel from the base case scenario are likely the result of a number of factors. First, the transit travel time savings were not large enough to compete with the auto mode, despite the innovative transit policies modeled. Second, the scope of the transit network is very limited in the Sacramento region, and thus the effectiveness of any improvement in transit feeder service is limited. Third, as mentioned in the methods section, the propensity for auto drivers to switch to transit modes in the presence of lower transit travel time and costs is likely underrepresented in the SACMET 95 model. This is an artifact of the cross-sectional data used to estimate the model. Sacramento currently has minimal transit service and comparatively low land use densities (compared to urban areas with high transit use), and thus cross sectional data on travel behavior collected in this area would contain little variation in transit mode choice. Finally, variables of comfort, reliability, and security have been shown to be significant variables in the choice to use transit. These variables are not explicitly included in the SACMET 95 model because they are very difficult to project into the future. Generally, such attributes are included in the mode specific constant of the mode choice models in regional travel demand models.

B. Emissions

Emissions for 2015 advanced transit scenarios in the Sacramento region are presented in Table 9. The percentage change in emissions projections from the base case scenario are presented in Table 10.

Table 9. 2015 Advanced Transit Scenarios for the Sacramento Region: Emissions Projections.

Scenarios	TOG (ton)	CO (ton)	NOx (ton)	PM (ton)	Fuel (xl 000 gallons)
Base Case	32.80	219.86	77.75	18.86	2903.50
ATI	32.69	219.25	77.61	18.82	2897.34
ATI & DRT	32.65	218.99	77.53	18.80	2894.57
ATI & PRT	32.68	219.17	77.58	18.82	2896.43
ATI, DRT & PRT	32.65	219.03	77.57	18.81	2896.25

Table 10. 2015 Advanced Transit Scenarios for the Sacramento Region: Percentage Change in Daily Emissions Projections from the Base Case Scenario.

Scenarios	TOG (ton)	CO (ton)	NOx (ton)	PM (ton)	Fuel (xl 000 gallons)
ATI	-0.34%.	-0.28%	-0.18%	-0.21%	-0.21%
ATI & DRT	-0.46%	-0.40%	-0.28%	-0.32%	-0.31%
ATI & PRT	-0.37%	-0.31%	-0.22%	-0.21%	-0.24%
ATI, DRT & PRT	-0.46%	-0.38%	-0.23%	-0.27%	-0.25%

In general, the reduction in emissions are small and consistent with travel reductions in section 1 above. Reductions from the base case scenario for TOGs (total organic gases) range from 0.34% to 0.46%; reductions in carbon monoxide (CO) range from 0.28% to 0.40%; reductions in oxides of nitrogen (NOx) range from 0.18% to 0.28%; reductions in particulate matter (PM) range from 0.21% to 0.32%; and reduction in fuel use range from 0.21% to 0.31%. Again, the differences between scenarios are small, generally less than 0.10 percentage points. The additional advanced transit service tended to increase the reduction of all emission types, with the exception of the ATI, DRT, & PRT scenario (for the same reasons discussed above for similar travel results). DRT tends to be more effective than PRT in reducing emissions. In general, it appears that the advanced transit scenarios modeled in this study will not result in significant reductions in air polluting emissions from transportation in the Sacramento region.

C. Consumer Welfare

1. Total Consumer Welfare

The 1995 present value of total consumer welfare without capital, operation, and maintenance costs obtained from the 2015 advanced transit scenarios in the Sacramento region are presented in Table 11. The benefits from the 2015 scenarios (which are in 1995 dollars) were discounted back 20 years using the present value formula and the real discount rate of 6.26%:

PV 1995 = 2015 Scenario Benefit in $1995/(1.0625)^{20}$

Table 11. 2015 Advanced Transit Scenarios for the Sacramento Region: 1995 Present Value of the Change in Total Consumer Welfare without Capital, Operation, and Maintenance Costs from the Base Case Scenario.

Scenarios	Total per Day	Total per Trip
ATI	$99,722.19	$0.015
ATI & DRT	$105,580.17	$0.016
ATI & PRT	$90,490.59	$0.014
ATI, DRT, & PRT	$114,459.85	$0.017

All of the scenarios produced an increase in total consumer welfare because of the faster transit travel times. However, the differences between the scenarios are small for the same reasons discussed above. Again, the addition of DRT service to ATI service tended to provided greater consumer welfare than the addition of PRT service. The total consumer welfare is less for the ATI & PRT scenario than ATI scenario because there are fewer trips in the ATI & PRT scenario. The per trips difference, however, is not significantly different.

Capital, operation, and maintenance cost figures for advanced transit information technology are based on estimates from the SMART TRAVELER project in Los Angeles. Cost figures for DRT are based on interviews with managers at the Santa Clara Valley Transportation Agency and Sacramento Paratransit and on the Lea & Elliott Transit Compendium (1975). Cost

figures for PRT are based on information from system developers whose systems can be considered to be in an advanced state of development, including Raytheon 2000, Taxi 2000, and Yeoida systems. Table 12 presents our estimates of the 1995 present value of capital, operation, and maintenance costs that would be incurred in the year 2015. See Appendix D for a detailed discussion of the methods used to obtain these figures.

Table 12. 1995 Present Value of Capital, Operation, and Maintenance Costs.

Scenarios	Total Capital Costs	Annual Capital Costs (incurred in 2015)	Daily Total Including Operation and Maintenance Costs (incurred in 2015)
ATI	$563,889.43	$22,926.09	$1,392.09
ATI & DRT	$4,215,637.39	$171,395.48	$23572.47
ATI & PRT	$112,447,930.37	$4.571.803.90	$18.286.56
ATI, DRT. & PRT	$116,663,567.76	$4,743,199.39	$54,140.20

The 1995 present value of the total consumer welfare including capital, operation, and maintenance costs for the 2015 advanced transit scenarios are presented in Table 13. These figures were obtained by subtracting the 1995 present value of the daily cost of the capital, operation, and maintenance costs from the 1995 present value of the daily welfare benefits.

Table 13. 2015 Advanced Transit Scenarios for the Sacramento Region: 1995 Present Value of the Change in Total Consumer Welfare with Capital, Operation, and Maintenance Costs from the Base Case Scenario.

Scenarios	Total per Day	Total per Trip
ATI	$98,330.10	$0.015
ATI & DRT	$82,007.70	$0.013
ATI & PRT	$72,204.03	$0.011
ATI, DRT, & PRT	$60,319.65	$0.009

With the inclusion of capital, operation, and maintenance costs, there is still a consumer welfare gain for all the advanced transit scenarios; however, the rank ordering of the scenarios is altered. ATI service alone produces the greatest increase in consumer welfare ($0.015 per trip); that is, the addition of DRT and PRT service to the ATI scenario tends to reduce consumer welfare benefits. On average the addition of DRT service to the ATI scenario decreased per trip benefits by $0.002, the addition of PRT service decreased per trip benefits by $0.004, and the addition of both DRT and PRT service decrease per trip benefits by $0.006. These results are due to the low costs and high travel time savings of ATI service in comparison to DRT and PRT service; the time savings estimated in the model from DRT and PRT service do not appear to be great enough to offset their capital costs. DRT and PRT service, however, could possibly be adjusted to obtain a better balance between time savings to travelers and the cost of service provided. Although per trip differences between scenarios are small, total yearly differences in benefits would be significant. Thus, it appears that the analysis of consumer welfare may be useful in identifying optimal bundles of ITS technologies.

2. Consumer Welfare by Income Class

The 1995 present value of consumer welfare by income class without capital, operation, and maintenance costs for the 2015 advanced transit scenarios are described in Table 14.

Table 14. 2015 Advanced Transit Scenarios for the Sacramento Region: 1995 Present Value of the Change in Consumer Welfare by Income Class without Capital, Operation, and Maintenance Costs from the Base Case Scenario.

	Income Class One (low)		Income Class Two (middle)		Income Class Three (high)	
Scenarios	Total per Day	Per Trip	Total per Day	Per Trip	Total per Day	Per Trip
ATI	$455.53	$0.008	$23,008.45	$0.016	$76,258.21	$0.015
ATI & DRT	$486.29	$0.008	$24,063.67	$0.017	$81,030.22	$0.016
ATI & PRT	$459.64	$0.008	$22,876.64	$0.016	$67,154.32	$0.013
ATI, DRT & PRT	$503.10	$0.009	$26,317.36	$0.018	$87,639.40	$0.017

All of the scenarios result in an increase in consumer welfare to each income class; however, the lowest income class benefits least, absolutely. Lower income classes have a lower value of time, and thus the savings in transit travel time are valued less for this class than for the other classes. The highest income class tends to benefited less on average per trip than the middle income class. Income class three has a higher value of travel time than income class two; however, their lower average or equal consumer welfare for the scenario may be due to the fact that this class received less advanced transit service near their work or home locations. In general, the differences among the benefits of the three income classes are relatively small.

The results of the analysis of consumer welfare by income class that included capital, operation, and maintenance costs for the 2015 advanced transit scenarios (1995 present value) in the Sacramento region are presented in Table 15. These figures were obtained by subtracting the 1995 present value of the daily cost of the capital, operation, and maintenance costs incurred by each income class from the 1995 present value of the daily welfare benefits

received by each income class. Capital, operation, and maintenance costs of the technologies are assumed to be borne by individuals in proportion to their amount of travel. See Appendix D for a full discussion.

Table '15. 2015 Advanced Transit Scenarios for the Sacramento Region: 1995 Present Value of the Change in Consumer Welfare by Income Class with Capital and Operation and Maintenance Costs from the Base Case Scenario.

	Income Class 3ne (low)		Income Class Two (middle)		Income Class Three (high)	
Scenarios	Total per Day	Per Trip	Total per Day	Per Trip	Total per Day	Per Trip
ATI	$443.06	$0.008	$22,703.03	$0.016	$75,184.00	$0.015
ATI & DRT	$275.29	$0.005	$18,891.96	$0.013	$62,480.46	$0.012
ATI & PRT	$295.94	$0.005	$18,864.61	$0.013	$53,043.48	$0.010
ATI, DRT & PRT	$18.52	$0.000	$14,439.14	$0.010	$45,862.00	$0.009

With the inclusion of capital, operation, and maintenance costs, the distribution of benefits across the three income classes did not significantly change. This result is to be expected, given our assumption regarding the distribution of costs.

VI. Conclusions

In this study, we used a state-of-the-practice regional travel demand model (SACMET 95) to simulate the effects of advanced transit information, demand responsive transit, and personal rapid transit in the Sacramento region. We used DTIM2 and EMFAC7F to estimate the emissions effects of these scenarios. We also obtained consumer welfare measures from this model by applying the Small and Rosen method (1981) of estimating compensating variation from discrete choice models.

Table 16 summarizes the findings for the 2015 Scenarios for the Sacramento region.

Table 16. Summary of Findings for 2015 Scenarios for the Sacramento Region.

Scenarios	Vehicle Hours of Delay	Emissions	Total Welfare (with Capital and O&M Costs)	Equity
ATI	+	+	++	+
ATI & DRT	+	+	+	+
ATI & PRT	+	+	+	+
ATI, DRT, & PRT	+	+	+	+

KEY: - = loss, + = improvement, ++ = comparatively large improvement

The analyses provided in the previous section allow for a number of general conclusions to be drawn in this study.

1. In regions like Sacramento that lack extensive penetration of rail or line-haul transit service, advanced transit technologies that act as feeder service may not significantly reduce congestion and emissions.

2. In general, the advanced traveler information and demand responsive transit technologies modeled seemed to provide greater reductions in congestion and emissions than personal rapid transit technology.

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3.	Combining the modeled advanced transit technologies did not tend to increase the travel and emission benefits by a significant amount over the individual technologies because of overlapping markets in a region with limited light rail service.

4.	When capital, operation, and maintenance costs of the advanced transit technologies were not included in consumer welfare estimates,, total welfare increased by approximately 1.4 to 1.7 cents per trip (in 1995 present value) across scenarios for all trips in the region.

5.	When capital, operation, and maintenance costs of the advanced transit technologies were included in consumer welfare estimates, the advanced transit information scenario yielded a higher consumer welfare benefit (1.5 cents per trip in 1995 present value) than the scenarios that added demand responsive transit and personal rapid transit (from 0.9 to 1.3 cents per trip in 1995 present value).

6.	The lowest income class in the region generally received lower net benefits per trip, absolutely, than did the other two income classes.

The travel and emissions results in this study showed that the advanced transit technology scenarios have little impact. As a result, decision makers would not know whether to adopt them. The consumer welfare evaluation, however, showed that all the advanced transit technology scenarios were beneficial and generally equitable, even when 'capital, operation, and maintenance costs were included in the analysis. The analysis also showed that advanced transit information service alone produced the greatest increase in consumer welfare; that is, the addition of demand responsive transit and personal rapid transit service to the advanced transit information scenario tended to reduce consumer welfare benefits. The total yearly difference in benefits between the scenarios would be significant. Thus, we conclude that the method of obtaining consumer welfare used in this study is a useful analytical tool for identifying optimal bundles of ITS technologies.

VI I. Future Research

The results of this study suggest that advanced technologies acting as feeder service to rail or line-haul transit service may not result in a significant reduction in congestion or emissions in the Sacramento region. We hypothesized that this result was due primarily to limited market penetration of light rail service in the Sacramento region.   This hypothesis could be tested by re-modeling the scenarios analyzed in this study with a greatly expanded transit network in **SACMET** 95. We have already created such a network for a previous PATH study.

However, because **SACMET** 95 is not integrated with a land use model, it cannot capture the effect of major changes in the transportation network and, thus, **accessibility** on regional land use patterns. This may be a potentially serious limitation with aggressive expansion of light rail. Therefore, we also propose modeling the same advanced transit scenarios with a greatly expanded transit network in Tranus, an integrated land use and transportation model. Recent reviews suggest that this model is one of the most theoretically robust and policy-relevant among the new generation of general-equilibrium integrated urban models. By the end of July, we will be running Tranus in our lab. A greatly expanded light rail transit network equivalent to the one prepared for **SACMET** 95 has already been created for Tranus for another project. Tranus also provides a measure of consumer surplus which captures the costs and benefits of location choice resulting from changes in the transportation system (see discussion above in Part II, Section C [5]).

A comparison of the results of the advanced transit technologies scenarios from **SACMET** 95 and Tranus would **not only** allow us to better gauge the accuracy of the travel projections, but would also test two interesting hypotheses regarding the differences between travel demand models and integrated urban models. First, travel results could be compared to determine whether the changes in accessibility and land uses captured in Tranus produce travel projections significantly different from those of **SACMET** 95. Second, the consumer welfare measure from **SACMET** 95, which captures changes in travel accessibility, could be also be compared to the consumer surplus measure in Tranus, which captures the costs and benefits of location choice, to determine if the two are significantly different. Some theorists maintain that utility changes from location choice are fully captured by measures of accessibility change from travel choice.

We would also like to explore methods of incorporating the mode-specific attributes of advanced technologies, such as comfort, reliability, safety, and convenience, into the travel and consumer welfare results of **SACMET** 95. This could be achieved by obtaining data from studies of advanced technologies in other regions of the country and comparing them to **SACMET** 95 data.

Finally, this summer we plan to develop a method for incorporating the consumer welfare benefits resulting from the effect of reduced congestion and, thus, faster travel times for truck and freight trips in the **SACMET** model. As discussed above, our analysis currently does not include these benefits. However, because truck and freight trips are highly valued, their inclusion in the welfare analysis could significantly increase the benefit of any advanced transit technology scenario that reduces regional congestion.

Appendix A: Travel Demand Modeling

This section describes the 1994 Sacramento Regional Travel demand model (SACMET 95) and is drawn primarily from the documentation of the model by DKS & Associates (1994) (hereafter, DKS).

1. Overview

The study used SACMET 95 to simulate the effects of the transportation alternatives. The development of the model was completed in 1994. The model update utilized a 1991 travel survey. SACMET 95 is a five-step model that includes auto ownership, trip generation, trip distribution, mode choice, and traffic assignment steps. Figure 1 illustrates the SACMET model system and its general system flow. The model system is iterated on zone-to-zone times, costs, and distances by mode until the criterion for convergence is met (i.e., A.M. peak trip assignment is within 3% of those in the last iteration). This usually required five iterations of the model for the year 2015.   See Figure 1.

2. Travel Survey

A region-wide survey of people's weekday travel behavior was conducted by SACOG in the Spring and Fall of 1991. The surveyed region included Sacramento, Sutter, Yolo, and Yuba Counties, and the western portions of El Dorado and Placer Counties. SACOG timed their survey to coincide with Caltrans' state-wide travel survey and used the same survey forms and survey firm as Caltrans did. As a result, SACOG was able to add 1,000 households surveyed by Caltrans in the region to the 3,400 households obtained from SACOG's survey.

A number of alterations were made to the travel survey data in order to use them in the travel model update. First, rigorous logic or consistency checks were performed on the data to detect and correct errors.   If a logic or consistency problem were found in data from a household, then all of the trips from that household were excluded. Second, the representation of different classifications of households in the survey data was compared to that in the 1990 census. From this comparison, weighting factors were developed and applied

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in order to minimize sampling error. Third, change mode trips, serve passenger trips, and incidental work trips were "linked" for analytical purposes. The "clean" **dataset** used for model estimation, retained 1,962 households from the original 4,003 households in the survey.

3. Zonal Structure and Networks

In the **SACMET** 95 model, the number of Travel Analysis Zones **(TAZ's)** increased from 860 to 1077 zones. The increase in zones was the result of splitting old zones in urban areas and the expanded network coverage of the region.

The increase in the number of zones required a corresponding increase in network detail and an extension of the existing network into new zones. Where zones were split, arterials, collectors, and centroid connectors were added to the network. Many centroid connectors were added to these zones to improve zone to zone access for walk trips. A new class of links, exclusive walk access, was also added to allow walk trips among these very small zones. In the expanded areas, freeways, arterials, and collectors were added to the network. The total number of links increased from 11,722 to 15,494.

4. Auto Ownership

The auto ownership model included in the **SACMET** 95 model takes a **logit** formulation. The model uses the variables of household size, number of workers in a household, household income, retail employment within 1 mile, total employment within 30 minutes by transit, and a pedestrian environment factor index to estimate the probability of owning zero, one, two, or three or more vehicles. Vehicles are defined as autos, pickup trucks, vans, recreational vehicles, and motorcycles. This **submodel** is based on the auto ownership model developed by Portland's Metropolitan Service District (Metro) for their regional travel demand model.

The 1991 travel survey **dataset** was used to estimate the parameters of the auto ownership model. However, the auto ownership **submodel** included in **SACMET** 95 takes a **"semi-disaggregate"** form: "a cross-classified **dataset** gives numbers of households under each unique combination of household size, workers in households, and household incomes in each zone" (DKS). Thus, in the applied auto ownership model, households rather than individuals are the unit of analysis.

The results of the t-tests on the coefficients of the logit model have the correct sign and indicate that all the variables are significant at the 0.05 level for at least one alternative. In addition, "the coefficients developed from the 1991 Sacramento travel survey compare well with those developed from the 1985 Portland travel survey" (DKS).

5. Trip Generation

The trip generation submodel estimates the number of person trips that will be produced or attracted in any zone based on a set of land use variables. Walk and bicycle person-trips are included in this model, as are auto and transit person trips. Commercial trips are included in this model by extrapolating from studies in other regions. Local data is not yet available for truck trips.

Home-based trip productions rates are estimated for cross-classifications of the number of workers by the number of persons in the household and with the use of accessibility variables (e.g. location in a district or number of retail employees within five miles). Trip attractions are estimated with the use of two employment categories (inside and outside the central business district) and detailed household categories. The submodel includes a separate school trip purpose.

For each trip purpose, alternative classifications (persons in household, workers in household, household income, auto owned) and estimation techniques (regression and aggregate maximum likelihood techniques) were tested and compared. Models were selected based on the results of analysis of variance and F-tests.

6. Trip Distribution

The submodels for trip distribution or destination choice of trips were developed with the 1991 travel survey data; include walk, bike, transit, and auto trips; and "use travel times that reflect the presence of traffic on the streets, instead of 'free flow' time" (DKS).

The trip distribution model for the non-work trip purposes uses the traditional gravity model based on auto travel time. The general form of the gravity model is as follows:

$$T_{ij} = \frac{P_i * A_j * F(t_{ij})}{\Sigma_{j'=1..n}A_{j'} * F(t_{ij'})}$$

"where T_{ij} are the trips produced in zone i and attracted to zone j, P_i are the trip ends produced in zone i, A_j is the attraction of zone j, $F(t_{ij})$ is the distribution-propensity factor between zones i and j, a function of the travel time t_{ij} between those zones" (DKS). This is a doubly constrained gravity model that "uses the conventional iterative method to estimate each zone's attraction so as to best achieve the relation: $\Sigma_{i'=1..n}T_{i'j}$ = Attraction trip ends in zone j (from trip generation), subject to the overriding constraint that $\Sigma_{j'=1..n}T_{ij'} = P_i$ "(DKS). The non-work trip purpose gravity models use off-peak travel times from the trip assignment step.

The trip distribution model for work trip purposes takes the form of a nested destination/mode choice model. The advantage of this model is that it uses composite impedance for the separation function [F(t) function in the gravity model] that accounts for the travel time and cost of all available modes, not just auto travel time.

The general form of the "common" nested destination/mode choice model used in the **SACMET** 95 model is as follows:

$$Pr(m\backslash d) = \frac{exp \ (Util_{m,d})}{\Sigma_{m' \in \ \{modes\}} \ exp(Util_{m'\backslash d})} \qquad \begin{matrix} n \\ \\ d \end{matrix}$$

$$Pr(d) = \frac{exp(\ominus * ln[\Sigma_{m' \in \ \{modes\}} \ exp(Util_{m'\backslash d})])}{\Sigma_{m' \in \{zones\}}exp(\ominus*ln[\Sigma_{m' \in \ \{modes\}} \ exp(Util_{m'\backslash d'})])}$$

"where Pr(m\d) is the probability of choosing mode m given the choice to go to destination d (the mode choice model), $Util_{m,d}$ is the utility of taking mode m to destination d (i.e., the weighted sum of time, cost, and traveler variables), Pr(d) is the probability that the traveler will choose destination d, by any mode, $\ominus$ is the estimated coefficient of the **logsum**, and $ln[\Sigma_{m' \in \ \{modes\}} \ exp(Util_{m'\backslash d'})$ is the **logsum** for the mode choice set of the given destination d' (DKS).

In the estimation of the destination choice model, "it is impractical to enumerate every zone (especially by mode) as the choice set" (DKS). Thus, a technique of "stratified importance sampling reduced the choice set to 10 destination zones for each recorded trip (9 sampled plus the zone actually chosen)" (DKS; see Ben Akiva and Lerman 1985).

7. Mode Choice

The mode choice submodels in **SACMET** use a **logit** specification to predict the choice of mode for trips. Unlike typical **logit** models, person trips by household class, rather than individuals, are the unit of analysis. The home-based shop, home-based other, home-based school, and non-home based mode choice models take following general multinomial **logit** form:

$$Pn(i) = e^{V(in)}/\Sigma_j \in C_n e^{V(jn)}$$

"where $Pn(i)$ is the probability that trip n uses alternative i, e is the base of natural logarithms, $V(in)$ is the (deterministic) utility of alternative i for trip n, and $\Sigma_j \in C_n e^{V(jn)}$ is the sum of the exponential term over all alternatives within trip n's choice set" (DKS).

The utility terms are defined as a linear combination of variables and respective coefficients. The following is the generalized form of the expression used in the models:

$$V(in) = \beta + \beta_1 D_{1(in)} + \beta_2 D_{2(in)} + \beta_3 D_{3(in)} + \ldots$$

"where $D_{1(in)}, D_{2(in)},$ and so on are the variables applicable to alternative i for trip n, each multiplied by corresponding coefficients $\beta_1, \beta_2,$ and so on" (DKS).

The home-based work destination-mode choice model takes the nested **logit** form:

$$V_{\{nest\}} = \ominus \log \Sigma_{i \in \{nest\}} e^{V(i)}$$

"where {nest} is a subset of alternatives, $\log \Sigma_{i \in \{nest\}} e^{V(i)}$ is the so-called **logsum** of the nest of alternatives, and $\ominus$ is the coefficient of the **logsum** in the multinomial **logit** model between this subset of alternatives and others" (DKS).

Modal alternatives include drive alone, shared ride (2), shared ride (3 or more), transit with walk access, transit with drive access, walk, and bicycle. SACMET 95 is one of the few regional models that treat walk and bicycle travel as distinct modes. The explanatory variables in the mode choice model can be grouped into three categories, household attributes, level of service, and land use variables.

Household characteristics and their interactions are represented in the mode choice model by classifications of households by number of persons, number of workers, income, and by number of autos available. This is considered to be a semi-disaggregate representation of household attributes. Mode choice for person trips are predicted for each household class.

Level of service variables, travel time, cost, and distance, were obtained for each mode between zone pairs from "skims" of the shortest paths from the current computerized representation of the loaded highway and transit networks for the base year, 1990. Morning peak skims were used for home-based work mode choice models and off-peak skims were used for the other mode choice models. Perceived auto operating cost was estimated in calibration by SACOG to be $0.05 per mile, and auto parking costs were obtained from the 1989 Regional Transit System Planning Study.

A statistically significant relationship between mode choice and in-vehicle travel time was difficult to find for the home-base work model. As a result, the coefficient was fixed and all other coefficients were reestimated. The value of the fixed constant was based on a review of the literature.

The land use variables included in the model are the pedestrian environmental product, carpool partner density, transformed employment density, and a Davis dummy variable. The pedestrian environmental factor of each zone is a rating from 1 (bad) to 3 (good) of the continuity of streets and walkways, ease of crossing streets, provision of sidewalks, and topographic barriers. The pedestrian environmental product is the product of the pedestrian environmental factor at each trip end. The carpool partner density variable combines household density, employment density, and an inverse function of travel time and "is roughly proportional to the number of workers who live within 1 mile of the traveler's residence and work within 1 mile of the traveler's work place" (DKS). The transformed employment density variable includes employment and college enrollment in a zone to indirectly represent the

factors that encourage transit use and walk and bike trips in downtown areas. The Davis dummy variable attempts to capture the strong propensity of residents in the city of Davis to ride bicycles.

8. Traffic Assignment

The **SACMET** 95 traffic assignment model uses the user-equilibrium traffic algorithm, which was adapted to prohibit single-occupant vehicles from using HOV facilities.

Traffic is assigned for five periods of the day, 3 hour A.M. peak, 3 hour P.M. peak, off-peak, 1 hour A.M. peak, and 1 hour P.M. peak. Time of day factors are based on the recorded start and end time of each trip in the 1991 travel survey **dataset**. Total daily traffic on the links is obtained from the sum of the A.M. peak, P.M. peak, and the off-peak traffic assignment.

Single-occupant vehicles (**SOVs**) and high-occupant vehicles (**HOVs**) are separately assigned and distinguished as either users of HOV lanes or non-users of those facilities.

Metered on-ramps are explicitly coded in the highway network in either the A.M. or P.M. peak period. Bypass lanes for **HOVs** are also coded distinctly. Delays on metered on-ramps are due to the ramps' traffic volume, not a fixed time penalty.

Travel cost is not considered in the assignment of traffic on routes, and thus shift in traffic on tolled routes will be reflected in mode choice, rather than a shift in route,

A model of the choice of **HOVs** to use or refuse HOV lanes on any freeways along the trip was developed as a post-assignment model. It is a disaggregate **logit** model that predicts the probability that a HOV driver will use the HOV lane based on measures of travel time savings, **difficulty** in weaving, distance of travel on the freeway, and trip purpose. The model was estimated on data obtained from a survey conducted on two 8 to 10 mile sections of a 30-mile long HOV facility of U.S. 101 in Santa Clara and San Mateo Counties. These surveys included mail-back surveys and traffic counts by vehicle occupancy for each lane of the freeway and each interchange ramp.

Appendix B: Review of Consumer Welfare Measures

The basic concepts behind consumer welfare measures are that of utility and law of demand. The law of demand states that, for a normal good, if price rises, demand for that good will fall. Thus, the demand curve will be downward sloping. Utility is defined as the satisfaction derived from the consumption of a good or service.   Consumers are assumed to maximize their utility when purchasing goods and services given current prices subject to the constraint of income. Thus, the demand curve is derived from utility maximization.

Figure 3 illustrates a demand curve for some quantity Q.   If the price of a normal good fell from P, to P,, consumers would be better off because they could pay less for the same amount purchased before the price change (see rectangle P_1ACP_2) or they could buy more for the same amount of money (triangle ABC). The total, or the trapezoid P_1ABCP_2, represents a difference in consumer welfare.

Economic theory provides three measures of consumer welfare: consumer surplus, compensating variation, and equivalent variation,   Consumer surplus generally refers to the total consumer welfare (e.g., in Figure 3, the trapezoid P_1ABCP_2 as well as the triangle above it); whereas, compensating variation and equivalent variation refer to change in welfare (e.g., in Figure 3 trapezoid P_1ABCP_2). However, sometimes, the term consumer surplus is used interchangeably with consumer welfare. We use the term consumer surplus in a narrow sense as described below.

Figure 3. Consumer Welfare
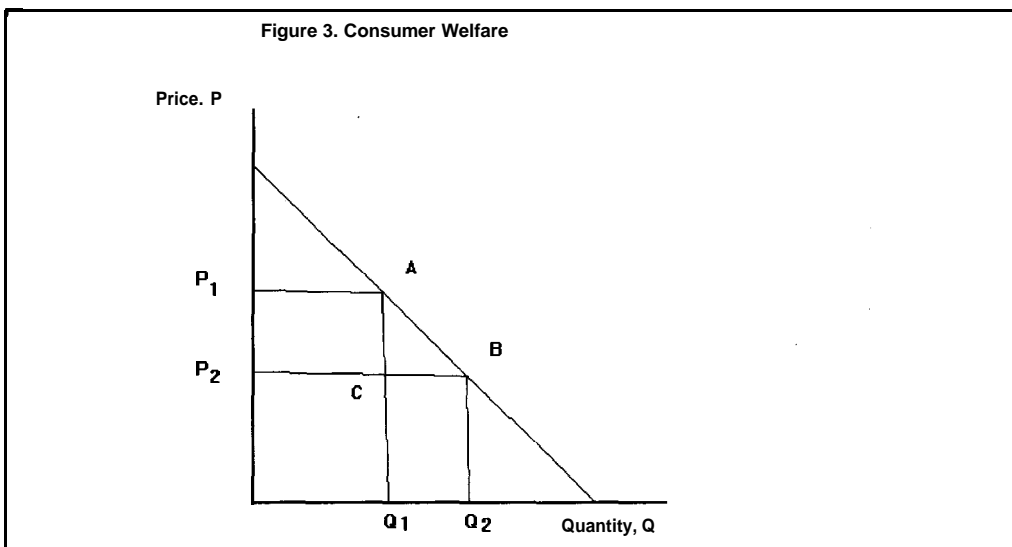
The consumer surplus measure of welfare is derived from the Marshallian, or ordinary, demand curve, which is a function of prices and income. It is assumed that because individuals maximize their utility, given a budget constraint, their optimal level of utility is indirectly obtained from the price of goods and individuals' income. The Marshallian demand curve is represented in Figure 4 by the curve $x(Px/Py, M)$, where Px is equal to the price of the normal good in question, Py is equal to the price of all other goods, and M is equal to income.

Compensating variation and equivalent variation measures of welfare are derived from the Hicksian demand curve, which is a function of prices and utility. This measure can be calculated from the expenditure function which assumes that individuals will minimize their expenditures (expenditure is equal to the sum of the price of goods purchased multiplied by quantity of goods purchased) in order to achieve a given utility. A Hicksian demand curve is represented in Figure 4 by the curve $h(Px/Py, U)$, where U is equal to utility.

As Figure 4 illustrates, the slope of the Hicksian demand curve is steeper than that of the Marshallian demand curve. This is because the Hicksian demand curve represents only the substitution effect of a change in price, whereas the Marshallian demand curve represents both the substitution and income effects of a change in price.
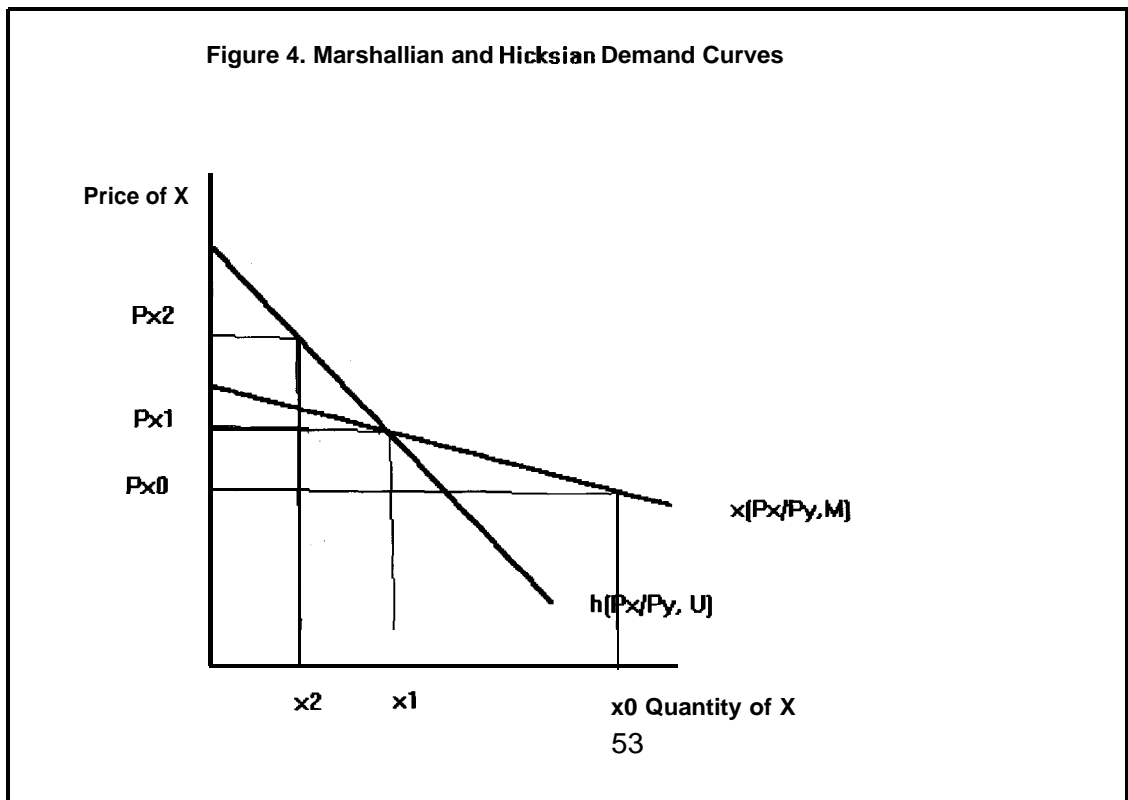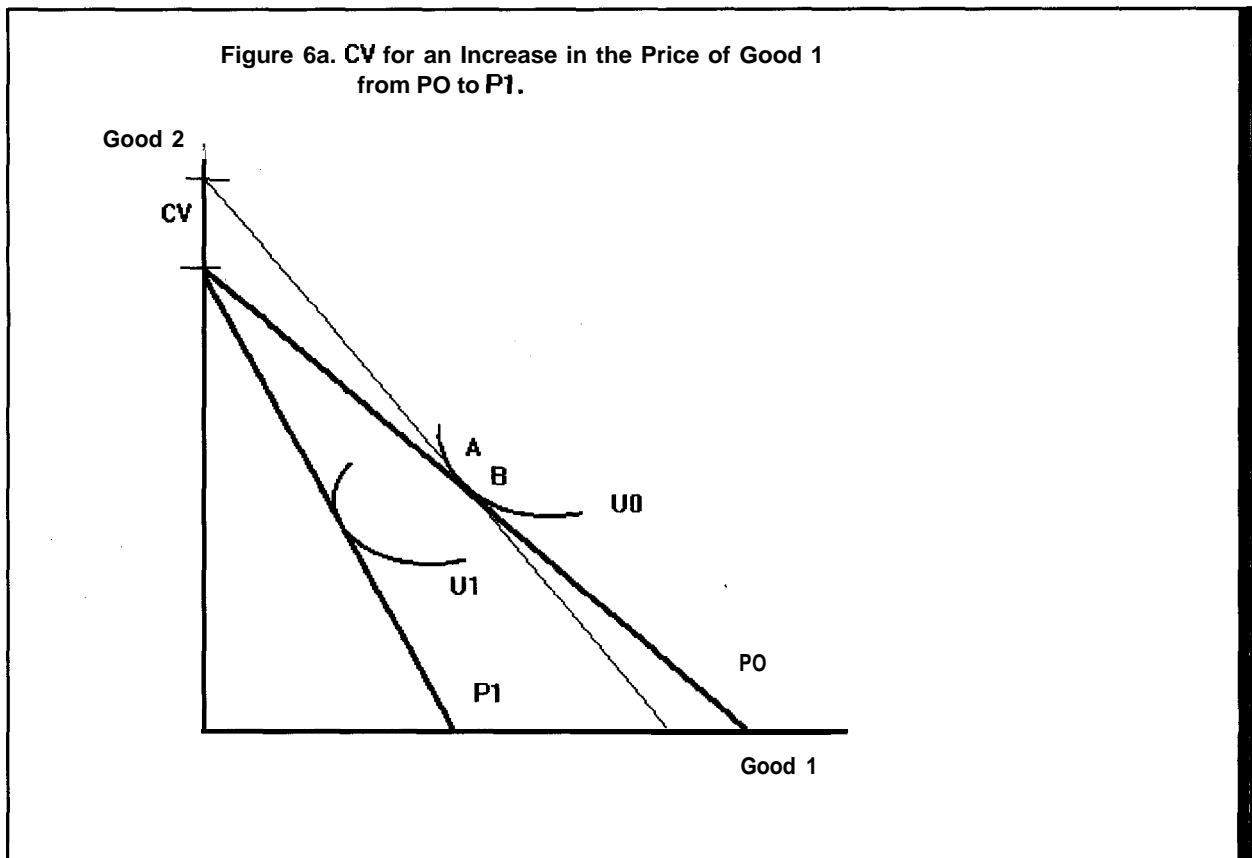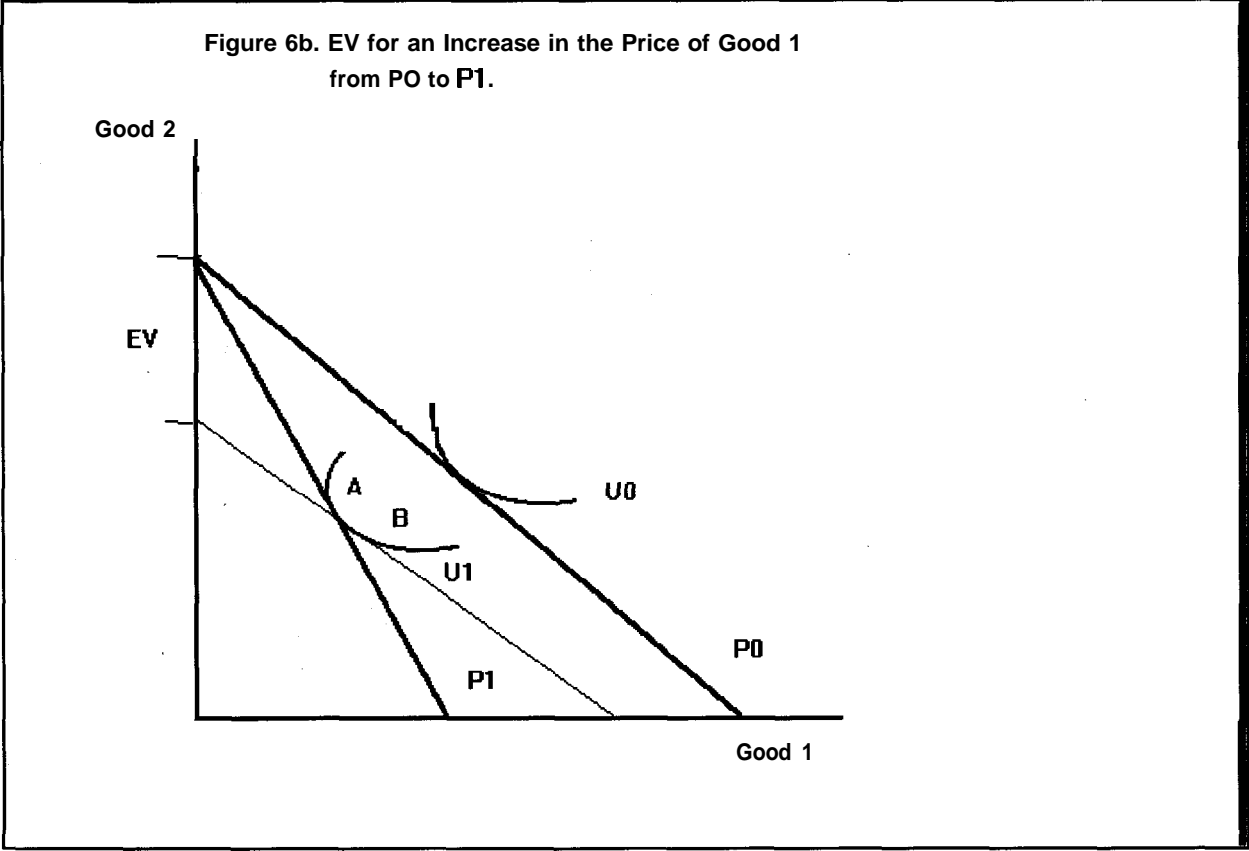

Figure 4. Marshallian and Hicksian Demand Curves

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Figure 5 illustrates the income and substitution effects of a fall in the price of normal good X, where I is equal to the consumers budgetary constraint, U is equal to the consumer's indifference curve, and 0 and 1 indicate the initial and final points. When the price of X falls from P^1x to P^2x, the quantity of goods purchased will shift from X*, Y* to X**, Y**. The substitution effect involves the movement on the initial indifference curve (U,) to point B. At this point, the marginal rate of substitution is equal to the new price ratio. In other words, because the price of X has decreased, this good competes more favorably with other goods, and more of X will be purchased even if its initial utility does not rise. The income effect is the movement to a higher level of utility due to the increase in real income resulting from the price decrease. The reduction in the price of good X gives consumers more to spend on other goods as well as on good X. Consumers gain real income, and thus utility.

Figure 5. Income and Substitution Effects of a Fall in the Price of X.
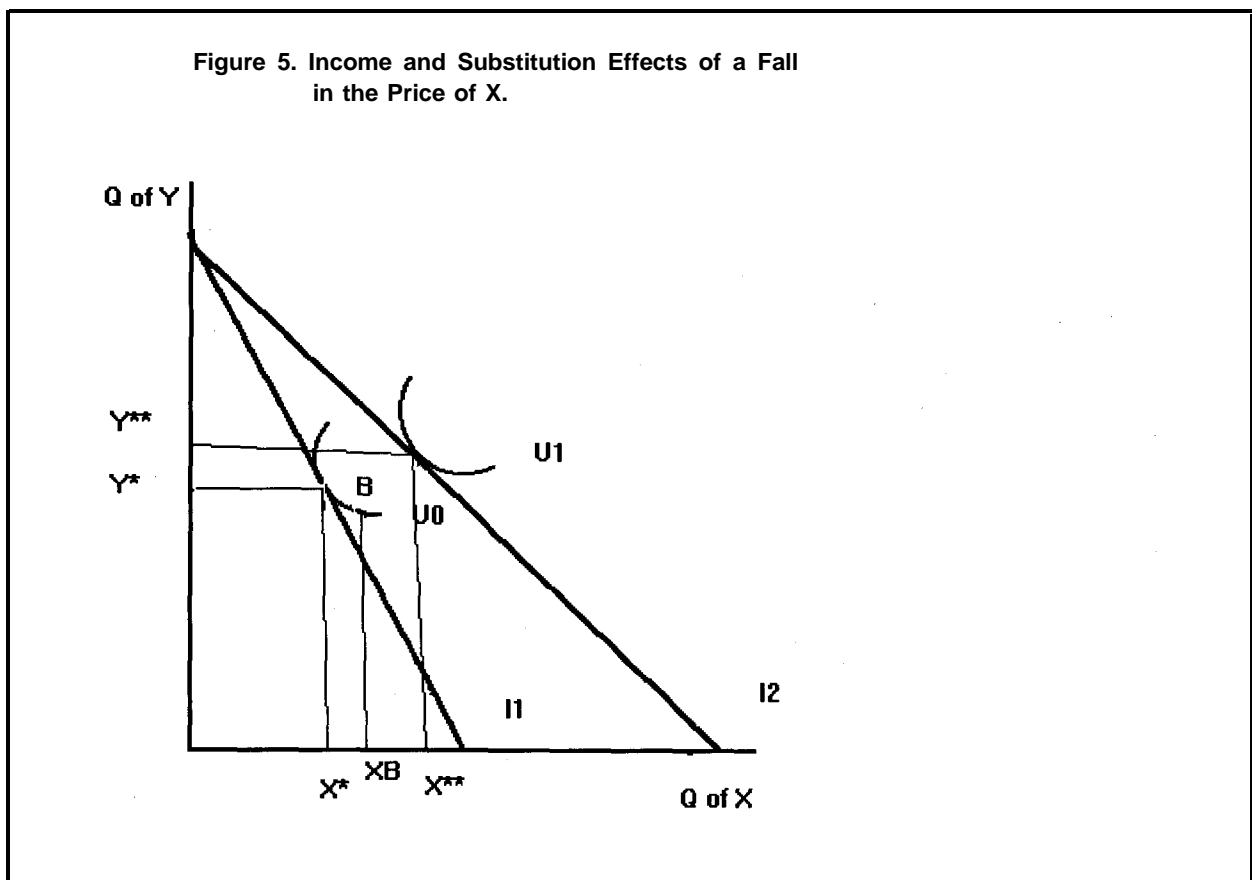
Figures 6a and 6b illustrate the difference between the compensating and equivalent variation measures of consumer welfare. Compensating variation (in figure 6a) is the increased consumption of good 2 resulting from the price increase of good 1 or the substitution effect due the reduction in the price of X measured in reference to the new price and the initial utility $(U,)$. Conversely, equivalent variation (in figure 6b) is the substitution effect due the reduction in the price of X measured in reference to the initial price and new utility $(U,)$.

Figure 6a. CV for an Increase in the Price of Good 1 from PO to P1.

Figure 6b. EV for an Increase in the Price of Good 1 from PO to P1.

Good 2

EV

A

B

U0

U1

P0

P1

Good 1

Conversely, the area under the Marshallian demand curve is less than the area under the Hicksian demand curve for a increase in the price of X because the decrease in income is captured in the Marshallian, but not the Hicksian, demand curve.

Figures 7a and 7b illustrate the welfare effects of a price increase and price decrease as represented by the measures of consumer surplus, compensating variation, and equivalent variation. In figure 7b, The total consumer surplus gain for a price decrease from Px^1 to Px^0 is the area defined by the trapezoid Px^1CAPx^0, which is bordered by the Marshallian demand curve. In figure 7a, the total consumer surplus loss due to the price increase from Px^0 to Px^1 is the area defined by the trapezoid Px^0ACPx^1. Consumer surplus tells us how much consumers would be willing to pay for the right to consume more of a good at a lower price, rather than being forced to do without the good.

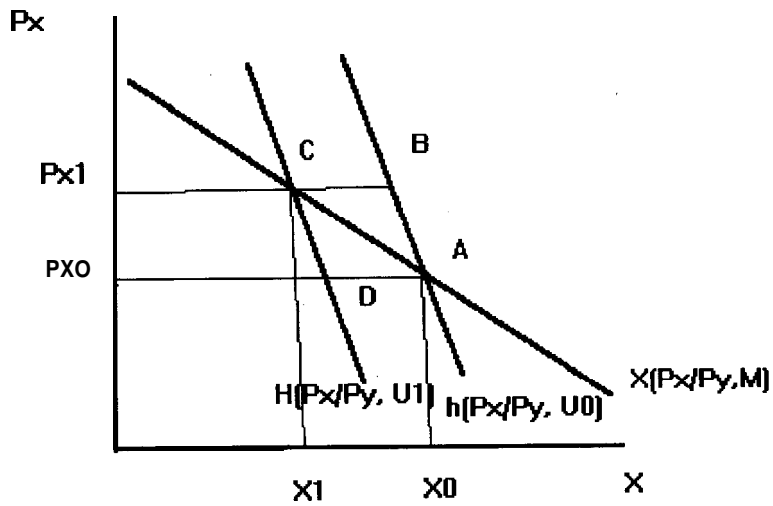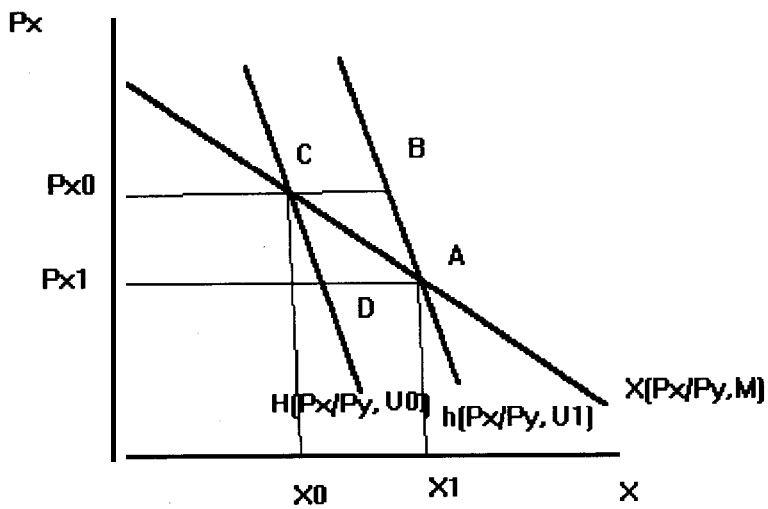**Figure 7a. Welfare Effect for a Price Increase [normal good].**

Figure 7b. Welfare Effect for a Price Decrease [normal good).

Compensating variation tells us how much a consumer would be willing to sacrifice to keep utility at its initial level (U,) and evaluated at its new price level (Px'). In other words, how much compensation the consumer needs to be as well off after the price change as before it. In Figure **7b**, for a price decrease, compensating variation is represented by the area Px^0DCPx^1. This area is bordered by the **Hicksian** demand curve. In Figure **7a**, for a price increase, compensating variation is represented by the area Px^0ABPx^1. The general formula for compensating variation is the difference between the areas underneath **Hicksian** demand curve for the initial utility, or expenditures, for the initial and final price of the good:

$$CV = E(Px^1, Py, U,) - E(Px^0, Py, U_o)$$

Equivalent variation tells use how much the consumer would be willing to sacrifice in order to keep utility at its final level (U,) and evaluated at the initial price level (Px^0). In other words, how much the consumer would sacrifice to answers the question of how much the consumer is willing to pay for the price decrease to occur. In Figure **7b**, for a price decrease, equivalent variation is represented by the area Px^0ABPx^1. In Figure **7a**, for a price increase, equivalent variation is represented by the area Px^0DCPx^1. The general formula for compensating variation is the difference between the areas underneath the **Hicksian** demand curve for the new utility, or expenditures, for the initial and final prices of the good:

$$EV = E(Px^1, Py, U,) - E(Px^0, Py, U,)$$

Thus, when the price decreases, compensating variation will be less than consumer surplus, and equivalent variation will be greater than consumer surplus. When a price increases, compensating variation will be greater than consumer surplus, and equivalent variation will always be less than consumer surplus. The difference between equivalent variation and compensating variation is due the referenced level of utility and price. When consumer welfare is measured at a higher utility level, the value of the price reduction will then be greater than when it is measured at the lower utility level. Thus, when the price falls, the equivalent variation at the higher utility level will be greater than the compensating variation at the lower utility level. The opposite will be true when the price rises.

From a theoretical perspective, benefit-cost analysis seeks to measure the loss or gain in utility resulting from a change in price, and thus, the income effect must be excluded from the

calculation. Gramlich (1981) states that "to measure the true utility gain from the price fall, we need to hold utility constant and measure consumer surplus by comparison with that baseline." Further, "as prices fall and real income rises, the income effect gives the change in consumption and consumer surplus from the derived change in income, indicating a form of double counting" (Gramlich 1981). As a result compensating variation and equivalent variation are the theoretically correct measures to use in welfare analysis; however, as Gramlich (1981) notes, "if alterations in the price of some goods do not change consumers incomes much, or if income changes do not affect consumption, consumer surplus could be measured exactly from the ordinary demand curve."

Small points out another advantage of compensating and equivalent variation over consumer surplus: compensating and equivalent variation measures "do not suffer from dependence on an arbitrary chosen path of integration" (1992). In the equation for consumer surplus the marginal utility of income changes as price changes. Silberberg (1990) states that "although the integral [in the above equation] takes on some value, it is not identifiable with any operational experiment concerning consumer behavior." Further, when there are multiple price changes, he states, that

> The value of the integral depends on the order in which prices are. changed. That is, even for specified initial and final price and income vectors, the value of the integral is not unique, but dependent on the path of prices between the initial and final values. Therefore, without further assumptions on the shape of the indifference curves, there is no obvious way to evaluate, in some useful sense, the gains or losses derived from one or more price changes, using the Marshallian demand functions alone.

Thus, to avoid these problems, the marginal utility is frequently assumed to be constant, which renders consumer surplus equivalent to compensating and equivalent variation.

Finally, the choice of the welfare measure used should ideally be based on theoretical considerations; however, Willig (1976) has found that in practice the use of consumer surplus is not a fatal flaw. This is because errors in estimates used to calculate the measures tend to be greater than the differences between the measures.

Appendix C: Mathematical Description of Compensating Variation
and Small and Rosen's Method

Kenneth Small and Harvey Rosen in their 1981 paper, "Applied Welfare Economics with Discrete Choice Models," develop a method for obtaining a measure of compensating variation from disaggregate **logit** models.

Compensating variation is derived from the **Hicksian** or utility-held constant demand curve. Given an expenditure function, minimized (E*) to achieve a given utility V for a particular set of prices (p_i), by the envelope theorem:

$$x_i^u = \frac{\partial E^*}{\partial p_i} \tag{1}$$

where x_i^u the **Hicksian** demand for good i and ∂ is a partial derivative. Therefore, compensating variation is the area to the left of the **Hicksian** demand curve or the change in the value of the expenditure function:

$$-\int_{p0}^{pf} x_i^u \, dp_i = - \int_{p0}^{pf} \frac{\partial E^*}{\partial p_i} \, dp_i = E^*(p^f, V^0) - E^*(p^0, V^0) \tag{2}$$

where p^0 and p^f are the initial and final price, The units of equation (2) are dollars because expenditure is equal to price time quantity $(E = \sum p_i x_i)$.

Consumer surplus is derived from the Marshallian (income-held constant) demand **curve**.[5] Given a utility function V, maximized with respect to a budget constraint to obtain optimal utility V*, from Roy's Identity:

$$\frac{\partial V^*}{\partial p_i} = -\lambda_i \bullet x_i \,, \tag{3}$$

where λ_i is the marginal utility of income and x, is the Marshallian demand for good i. From (3), we can obtain:

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5. Note that the following derivation is informed and adapted from the California Energy Commission's 1994 "California Transportation Energy Analysis Report".

$$x_i = \frac{\partial V^*}{\partial p_i} \cdot \frac{1}{\lambda\imath} .$$ (4)

As a result, change in consumer surplus due to a change in the price of good i from the initial price to the final price can be written as:

$$-\int_{p0}^{pf} x_i \, dp_i = \int_{p0}^{pf} \frac{\partial V^*}{\partial p_i} \cdot \frac{1}{\lambda\imath} \, dp_i .$$ (5)

Therefore, change in consumer surplus is the area to the left of the Marshallian demand curves. The change in utility is converted to dollars by the factor, $1/\lambda\imath$, or the inverse of the marginal utility of income.

However, if the marginal utility of income is assumed constant for small price changes (as is the case of this study), then it can be moved to the front of the integral sign:

$$-\int_{p0}^{pf} x_i \, dp_i = \frac{1}{\lambda\imath} \int_{p0}^{pf} \frac{\partial V^*}{\partial p_i} = \frac{1}{\lambda\imath} [V^*(p^f) - V^*(p^0)] .$$ (6)

Thus, in **(6)**, the area to the left of the demand curve between the two prices is the change in utility divided by the marginal utility of income. Because this equation has constant marginal utility of income, its area corresponds to that of compensating variation in (2). The difference between consumer surplus and compensating variation measures of consumer welfare is accounted for by the point in time in which utility is converted to dollars, i.e., continuously as the price changes (consumer surplus) or after the price change (compensating variation). Thus, if constant marginal utility of income is assumed, the solution to consumer surplus or compensating variation will be the same regardless of the time (or price level) at which utilities are converted to **dollars.**[6]

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6. The same is true for equivalent variation. In the absence of the assumption of constant marginal utility of income, equivalent variation would differ from compensating variation because of the conversion **of utility** to dollars before the price change.

Small and Rosen (1981) develop the expression for compensating, variation in the context of the **logit** formulation. Given the **logit** equation:

$$Pn(j) = \frac{exp\ V_j}{\Sigma^n_{i=1}\ exp\ V_i} \tag{7}$$

where the probability of choice j is made from a total number of n choices and V_i represents the indirect utility of the i'th choice. It has been shown that maximum expected utility is equal to the **logsum** of the denominator of the **logit** equation given different choices (i = 1...n), household income, and the goods' prices:

$$V\ (total) = ln[e^{V1} + e^{V2}...+ e^{Vn}] \tag{8}$$

where ln is the natural log (McFadden 1978; Ben-Akiva and Lerman 1979). Therefore, it is possible to measure the change in consumer utility by subtracting the maximum expected utility (or **logsum** of the denominator of the **logit** equation) in the base case (p^f) scenario from that of the policy scenario (p^0):

$$V\ (change) = ln[e^{V1\ (pf)} + e^{V2(pf)}...+ e^{Vn(pf)}] - ln[e^{V1(p0)} + e^{V2(p0)}...+ e^{Vn(p0)}] \tag{9}$$

From **(6)**, the change in compensating variation due to a change in price (or other attribute) of any of the n choices is:

$$CV_i = -(1/\lambda)\{\ [ln\ \Sigma_i\ exp\ V_i\ (p^f)] - [ln\ \Sigma_i\ exp\ V_i\ (p^0)]\ \} \tag{10}$$

Small and Rosen (1981) also show that the marginal utility of income is provided by the negative of the coefficient of the variable cost divided by income in the **logit** equation. Small (1992) states that "because portions of the utility V_j that are common to all alternatives cannot be estimated from the choice model, $\lambda = \partial Vj/\partial y$ [where y is income] cannot be estimated directly; but if a price or cost variable p is included, as for example... [cost/income], λ can be determined from Roy's Identity" (Small and Rosen 1981):

$$\lambda = \frac{-1}{x_j} \cdot \frac{\partial V_j}{\partial p_j} \cdot \tag{11}$$

To summarize, compensating variation is the difference between the maximum expected utility (or **logsum** of the denominator of the **logit** equation) in the base case scenario from that of the policy scenario divided by the individual's marginal utility of income. Total compensating variation can be obtained by summing the compensating variation of all individuals affected by the change.

Appendix D: Estimates of Capital, Operation, and Maintenance Costs of Scenarios

The advanced transit information technology assumes that information will be disseminated through kiosks, the telephone, the Internet, and cable television. Based on estimates from the SMART TRAVELER project in Los Angeles, we assume that the capital cost of each kiosk is $14,000, for a total of $140,000, and that the operation and maintenance costs for all the information services are $160,000 a year (Ratcliff 1996).

The capital, operation, and maintenance costs for the DRT services were based on interviews with Martin DeNero, Paratransit Services Coordinator for the Santa Clara Valley Transportation Agency; William Durant, Director of Sacramento Paratransit; and on the Lea & Elliott Transit Compendium (1975). The following factors were considered in the calculation of cost estimates for DRT service:

1. Modified van vehicles generally cost approximately from $35,000 to $60,000 each.

2. Sedan or taxicab type vehicles cost approximately from $500 to $5,000 each. Vehicles are retrofitted with two-way radio communications.

3. Based upon survey information, automotive type vehicles are generally procured used and at auction. While used vehicles may be more maintenance intensive to operate, this additional cost is assumed to be negligible.

4. Generally, central dispatch facilities use one dispatcher working on an eight-hour shift.

5. It is assumed that one DRT vehicle will service a one square mile service area.

The scenarios that include DRT also include limited light rail feeder service by El Dorado transit. We assume that the capital, operation, and maintenance cost of this service is $1.00 per passenger mile.

Capital, operation, and maintenance costs for the PRT technology were based on information from system developers whose systems can be considered to be in an advanced state of development, including Raytheon 2000, Taxi 2090, and Yeoida systems (Anderson 1988 & 1985; Mizera 1994; Woobo Architects & Engineers, Inc. 1994; Schupp 1996). The following factors were considered in the calculation of cost estimates for PRT service:

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1. PRT vehicle capital costs were based on relatively low annual production quantity. Significant price reductions could be achieved through high volume (i.e., greater than 100,000 vehicles) annual production quantities. For the system modeled in this study, vehicle cost was estimated to be $75,000.

2. Two stations would be provided per mile of guideway. Stations can be integrated into buildings, stand alone structures, or designed for all-weather applications. Each station was estimated to cost $1.08 million.

3. The maintenance facilities were sized for a fleet of less than 40 vehicles. The total maintenance facility capital cost was estimated to be $2.0 million.

4. **Guideway** capital costs did not include street reconstruction (if necessary), utility relocation, landscaping, right-of-way acquisition, legal fees, advertising, additions and modifications to signing, or modifications to buildings.

5. One minute vehicle **headways** with 2.4 vehicles operating in any one-mile segment of the system at any time were assumed.

6. PRT vehicles have a capacity of 4 seated adults.

Table 17 provides a breakdown of the capital cost estimates for the DRT and PRT advanced transit technologies.

Table 17. Breakdown of the Capital Cost Estimates for the DRT and PRT Advanced Transit Technologies per Mile in Millions of 1995 Dollars.

Cost Estimates	DRT	PRT
Guideway	$0.00	$4.68
Stations	$0.00	$2.16
Vehicles	$0.03	$0.18
Systemwide (power and control systems)	$0.01	$2.70
Maintenance Facility and Equipment	$0.01	$0.12
Design/Engineering	$0.00	$1 .oo
Pre Start-Up (3%)	$0.01	$0.32
Contingency (15%)	$0.01	$1.67
TOTAL	$0.07	$12.83

Table 18 provides the operation and maintenance costs per revenue vehicle mile and per passenger mile of the DRT and PRT advanced transit technologies.

Table 18. Operation and Maintenance Costs per Revenue Vehicle Mile and per Passenger Mile in 1995 Dollars.

O&M Costs	DRT	PRT
Cost per Revenue Vehicle Mile	$2.99	$0.84
Cost per Passenger Mile	$0.75	$0.21

Total capital costs of the DRT and PRT technologies were calculated by multiplying the total distance of service by the cost per service mile as described above. Capital costs for the ATI technology were calculated by multiplying the capital costs of the kiosks by the number of kiosks included in the scenario (100).

It is assumed that all projects are constructed in 2010. Thus, the present value of the total capital costs (which are in 1995 dollars) are discounted back 15 years to 1995 with a 6.25% discount rate as follows:

$$\text{PV 1995 Capital Costs} = \text{Total Capital Costs in } \$1995/(1.0625)^{15}$$

We assume that the technologies would be funded with a 25 year bond, which would be beneficial to the technologies. To obtain the annual payments over 25 years, the 1995 present value of the capital costs were amortized with the nominal interest rate (which includes the real rate of 6.25% and the inflation rate of 3.75%) as follows:

$$\text{Annual Payment} = \text{PV 1995 Capital Costs } [0.1(1.1)^{25}/[(1.1)^{25} - I]$$

Next, the annual payments calculated above that would be made in 2015 for the scenarios are discounted back 20 years using the nominal interest rate:

$$\text{PV 1995 Annual Payment} = \text{Annual Payment in } 2015/(1.1)^{20}$$

Because consumer welfare estimates are for daily weekday travel, the annual capital costs were adjusted to obtain daily weekday payments (260 days a year).

Daily operation and maintenance costs in 1995 dollars were obtained for the PRT and DRT modes by multiplying the cost per passenger mile by the daily passenger miles and by subtracting fare revenue. Daily passenger miles and fare revenue were obtained from model output. Operation and maintenance costs (in 1995 dollars) would be incurred in 2015 for the scenarios modeled, and thus they were discounted back 20 years to 1995 with a 6.25 discount rate as follows:

$$PV\ 1995\ O\&M\ Costs = O\&M\ Costs\ in\ \$1995/(1.0625)^{20}$$

Table 19 presents the 1995 present value of the estimated of capital, operation, and maintenance costs.

Table 19. 1995 Present Value Capital, Operation, and Maintenance Costs.

Scenarios	Total Capital Costs	Annual Capital Costs (incurred in 2015)	Daily Total Including Operation and Maintenance Costs (incurred in 2015)
ATI	$563,889.43	$22,926.09	$1,392.09
ATI & DRT	$4,215,637.39	$171,395.48	$23,572.47
ATI & PRT	$112,447,930.37	$4,571,803.90	$18,286.56
ATI, DRT, & PRT	$116,663,567.76	$4,743,199.39	$54,140.20

We assume that individuals pay for these technologies in proportion to the amount they travel; that is, total daily costs are divided by the total number of trips (by all modes) for a scenario, which is then multiplied by the number of trips made by an income class.

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