CARSHARING AND CARFREE HOUSING:
PREDICTED TRAVEL, EMISSION, AND ECONOMIC BENEFITS

A Case Study of the Sacramento, California Region

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ABSTRACT

In this paper, researchers present simulation findings from three innovative mobility scenarios (forecast to 2025) using an advanced regional travel demand model. This model was employed to approximate the effects of transit-based carsharing (short-term vehicle access linked to transit), real-time transit information services, and carfree housing (residential developments designed with limited parking provisions) in the Sacramento region. The scenarios are evaluated against travel, emission, and economic benefits criteria. The results indicate relatively modest reductions in vehicle travel and emissions, in part, due to limited transit service penetration in the region. Despite the modest travel effects of the scenarios, the economic analysis indicates a net benefit for all of the innovative mobility scenarios. The total per trip benefit ranges from $0.01 to $0.05. The yearly total benefit for all scenarios would be significant.

Key words: Carsharing, advanced transit information, carefree housing, travel demand modeling, economics benefits, emissions, and travel impacts

INTRODUCTION

In the coming decade, the population of California is expected to increase by 18 percent (6 million) with a corresponding 27 percent increase in vehicle miles of travel (VMT) increasing congestion and degrading air quality (*1*). Smart growth policy strategies attempt to tame VMT growth and emissions by redirecting new community development with a high-intensity mix of shopping, jobs, and housing served by high-quality modal alternatives to the single occupant vehicle (SOV). Numerous studies show that the effectiveness of smart growth policy strategies in reducing VMT and emissions hinge on the quality of modal alternatives to the SOV (*2*, *3*, *4*, *5*, *6*). The integration of innovative mobility services (e.g., real-time modal information and carsharing (short-term vehicle rentals)) with traditional modal options in smart growth communities may be key to providing high quality multi-modal alternatives that can effectively compete with the SOV.

In this paper, researchers provide findings from a recent study funded by the California Department of Transportation; California Partners for Advanced Transit and Highways (PATH); and the University of California, Davis (UC Davis), called the *Davis Smart Mobility Model Project*. This project evaluated a range of innovative mobility services that could be integrated into smart growth strategies of the UC Davis Campus, the City of Davis, and the Sacramento region. Institutional evaluations, a campus-wide survey, focus groups, and travel demand analyses were conducted in 2002-2003 to identify current or future locations with smart growth characteristics, document current travel patterns, and evaluate innovative mobility options.

The innovative mobility scenarios, forecast to 2025, are simulated with an advanced regional travel demand model to approximate the effects of carsharing, real-time transit information services, and a carfree housing policy in the Sacramento region. These scenarios are evaluated against travel, emission, and economic benefits criteria. This paper includes four sections. First, researchers provide background on each of the innovative strategies examined: carsharing, advanced transit information, and carefree housing. Second, the simulation methods used in this analysis are documented. Third, the scenarios are described. Fourth, findings are discussed. Finally, conclusions and recommendations are made based on the study results.

CARSHARING, CARFREE HOUSING & ADVANCED TRANSIT INFORMATION: A BRIEF OVERVIEW

This section provides an overview of each of the innovative strategies examined in this paper. The first discussion focuses on shared-use vehicle services, as the application of carsharing examined in this study is primarily a hybrid carsharing model (i.e., a blending of carsharing and station car concepts). In applying the carsharing concept in the Sacramento region, the authors specified a carsharing model, with close transit linkages. Limitations in the model (i.e., detail of spatial representation and modal options) required that we examine transit-based carsharing rather than traditional neighborhood carsharing. Next, the authors provide a brief discussion on advanced transit information, which can enhance carsharing and a carfree lifestyle. Finally, the authors present a brief overview of carfree housing. This concept focuses on residential development designs with limited parking; not surprisingly, these developments promote alternative transportation modes and limited car use.

U.S. Shared-Use Vehicles: Carsharing & Station Cars

U.S. shared-use vehicle services are described in a number of sources (*7*, *8*, *9*, *10*, *11*). Members of shared-use vehicle organizations pay a fee to gain access to a personal vehicle for a trip or segment of a trip. Typically, this service is viewed as short-term vehicle rental. Two types of shared-use vehicle services have been identified: station cars and carsharing. Station cars—generally linked to transit—can be shared, although not always, while carsharing vehicles are always shared. Today, the majority of carsharing programs place vehicles in neighborhood lots (not typically linked to transit), where members access and return carsharing vehicles to the same lot. In contrast, station cars largely serve transit/rail commuters, assisting in transit access either on the home-, destination-end, or both. Increasingly, the carsharing and station car concepts are merging in the U.S., so that they include both elements: transit linkages and distributed lots (*12*).

Shared-use vehicle services started to become popular in the U.S. in the mid- to late-1990s. In a recent study, Shaheen et al. (*13*) report that there are 15 shared-use vehicle programs in the U.S. consisting of eleven carsharing organizations, two station car programs, and two carsharing research pilot programs as of July 2003. Station car programs claimed 112 members and 91 vehicles, and carsharing accounted for 25,615 members and 692 vehicles. While survey findings demonstrate a decline in the number of organizational starts between June 2002-2003 and in station car programs overall, including members and vehicles, carsharing membership and fleet size continue to increase. This survey also revealed exponential growth in U.S. carsharing membership.

As interest in shared-use vehicle services continues to grow, decision makers and transit operators are increasingly interested in understanding program impacts. Potential benefits include: 1) promotion of alternative transportation modes by enhancing and supporting existing transit systems (resulting in increased fare box revenues and decreased subsidies needed); 2) greater mobility at substantial savings for people who do not drive everyday (considering 80 percent of private vehicle costs are fixed and 20 percent of a household's expenditures support transportation); 3) increased incentives for compact growth by reducing parking needs through carsharing in new and existing communities and improving transit services by promoting transit-oriented development; 4) energy and emission benefits due to modal shifts from private vehicle trips to alternative transportation, as well as use of energy-efficient cars including ultra-clean internal combustion vehicles, electric, hybrid, and early fuel cell vehicles; and 4) reduced parking needs by alleviating pressure for public funding of parking structures; and 5) more economically efficient use of limited public highways and reduced need for higher taxes to support capacity expansions (*12*).

To date, evaluations of station-car programs (vehicle rentals directly linked to transit) universally support the notion that increased transit connectivity can dramatically reduce VMT by program participants. This is not surprising as many of these programs specifically recruit individuals who would otherwise drive to work rather than commute via public transit. CarLink I, a carsharing pilot program, with a station-car component yielded a net reduction in VMT of approximately 18.5 miles per day per person. CarLink also resulted in 20 *new* daily BART trips among CarLink commuters (with a limited sample of 20 individuals). Several participants stated that if CarLink became a permanent service, they would sell one of their personal cars, which could greatly reduce their transportation costs (*14*). Findings from the San Francisco Bay Area Station Car Demonstration also revealed substantial reductions in commute-related VMT. These findings indicate that personal vehicle mileage declined from 45 percent of all VMT to 3 percent, with drivers substituting toward a combination of rail and electric vehicles (*8*).

Results are less clear in the case of neighborhood carsharing largely due to limited samples, length of time studied, modest behavioral changes, or combination of factors. A study of CarSharing Portland membership behavior after two years of operation indicates that aggregate VMT decreased among members by 7.6 percent. This reduction was largely driven by members who previously owned/leased a car prior to carsharing. For these individuals, VMT decreased by 25 percent, implying that carsharing may impact vehicle ownership decisions. For members without access to a household vehicle, VMT increased by 19 percent (*15*). A similar outcome was observed in a two-year evaluation of City CarShare in San Francisco, which revealed a two percent VMT reduction among members (*16*). Although modest, it is important to note that this measure may underestimate carsharing’s impact on VMT. Among a comparable group of non-members (control group), VMT increased by 49 percent over the same period, suggesting that carsharing may have reduced total VMT beyond the slight two percent reduction reported. The authors hypothesize that over the period of these studies, the influence of carsharing membership on vehicle ownership is likely reflected in reduced VMT among households that either sold or forfeited a car purchase.

With respect to modal shifts, the early program studies support differing conclusions. CarSharing Portland's two-year study indicated a slight increase in transit use and walking/cycling, while the City CarShare year-two study reported declines in walking/cycling and transit use among members who substituted these modes with carsharing and other motorized vehicles (*16*, *15*, *10*).

Neighborhood carsharing appears to have a more tangible impact on vehicle ownership. Most U.S. carsharing studies demonstrate that shared-use vehicles have a mitigating influence on vehicle ownership behavior, motivating members to either sell or avoid a vehicle purchase. For instance, Katzev et al. (*10*) reported that 26 percent of members sold a personal vehicle, and 53 percent were able to avoid purchasing one.

To summarize, these early studies provide indications of the potential of shared-use vehicle services to increase mobility, reduce auto ownership, and promote transit use and walking by early adopters. Nevertheless, there is significant diversity among methodological approaches and findings, which confound aggregate-level analysis. In addition, it is possible that the behavior of early adopters is not representative of the population in general; early adopters tend to be more highly educated, professionally employed, and in a higher income group. To evaluate program-wide effects, a more systematic method of data collection and analysis is needed in the future. This study attempts to gauge social and environmental benefits of transit-based carsharing, carfree housing, and advanced transit information using a different technique: regional travel demand modeling. This approach can be used to estimate the demand for and effects of innovative mobility options on the larger population. For example, more typical carsharing studies may indicate potential mode shifts from the auto to transit among individuals participating in a carsharing study. A modeling study can predict the demand for a specified service among an area's population and the subsequent travel and environmental impacts. It is important to note, however, that service representation may be limited due to the model's structure and the underlying data used to estimate it. The next section includes a brief review of advanced transit information.

Advanced Transit Information

Advanced transit information systems provide travelers with real-time transit and traffic information. Travelers access pertinent information about the transportation system through the telephone, television, internet, kiosks, variable message signs, handheld electronic devices, pagers, and cell phones. With this information, individuals can make more informed travel decisions.

Transit information systems can be categorized broadly into three groups: pre-trip, in-terminal, and in-vehicle. Pre-trip information provides travelers with accurate and timely information about transit travel before making a trip. In general, most pre-trip information consists of transit routes, fares, schedules, and locations. In-terminal information provides travelers with arrival and departure times, schedule updates, and transfer information while a traveler is waiting in a transit terminal; in contrast, in-vehicle information is provided en route, allowing vehicle drivers and transit users to choose alternative routes or modes for their destination.

Many transportation authorities including those of Los Angeles, California; Williamsport, Pennsylvania; and King County, Washington offer riders advanced transit information. "To expand customer service and ridership, transit properties are investing in high-tech methods of providing passengers with real-time information via displays, annunciator systems, the Internet and e-mail" (*17*). King County, for example, uses the Web and e-mail to provide transit customers with arrival information as well as unforeseen delays.

In a Northern California study, Abdel-Aty et al. (*18*) employed computer aided telephone interviews in the Sacramento and San Jose areas of California to identify transit service information most desired by non-transit users. Customized stated preference choice sets were used to identify the likelihood of a commuter's choice to use transit. The study found that 38 percent of respondents—who did not use transit—would likely consider using it, if improved information were provided.

To summarize, advanced transit information appears to be a relatively popular innovative mobility strategy. Focus groups conducted by the authors among UC Davis students, staff, and

Davis residents reflected significant participant interest in advanced transit information (*19*). The next section provides an introduction to carfree housing.

Carfree Housing

Carfree housing policies include restrictions on the number of cars owned by residents, limited parking availability, or increased parking costs. The largest existing example of a carfree city is Venice, Italy (*20*). In fact, most European cities include at a small carfree neighborhood typically located near the city center. In the U.S., there are a few carfree areas, for instance, Fire Island and the Ithaca Commons of Ithaca, both in New York State (*20*).

Carfree housing should ideally integrate several factors, including: 1) frequent public transit services (preferably rail); 2) basic shopping and services (or be located in easy walking distance of them); 3) a good cycling network; 4) shelter from traffic noise and pollution; and 5) open space for children to play outdoors without supervision and pleasant enough for adults to spontaneously congregate and use as a natural extension of a private dwelling (*21*).

One study of carfree housing in European cities found that there is a market for carfree housing whether buyers or tenants own vehicles or not (*21*). In German cities, the author found that while the number of carfree households had declined since 1945, this appears to be changing in a few larger cities because of a lifestyle trend towards more single and two-person, young adults, and over-65 households. The author also surveyed carfree households in Dortmund, Germany, and found that 74 percent of respondents were satisfied with not owning a car; 75 percent stated that a car was not necessary for their travel requirements; and 92 percent did not plan to own a vehicle in the near future. In an examination of Amsterdam's carfree housing project, it was also found that a majority of carfree households live a practically carfree lifestyle. One out of 48 carfree households used a car for over 50 percent of all trips, and 57 percent of households only used a car for less than 10 percent of their trips (*21*).

Another study (*22*) examined the travel behavior of residents living in carfree areas and found a correlation between the number of carfree households and the number of private vehicles per resident. The share of carfree households amounted to 92 percent in Vienna, 74 percent in Edinburgh, 62 percent in Amsterdam, and 25 percent in Hamburg. The number of private vehicles was 1 per 27.8 residents in Vienna, 1 per 8.8 in Edinburgh, 1 per 5.8 in Amsterdam, and 1 per 2 in Hamburg. Also, it was reported that Vienna public transport was used three times more, and Edinburgh public transport was used twice as often as public transport in Amsterdam and Hamburg (*22*).

While these study results are quite positive, it is unclear how successful carfree housing might be in the U.S. Anecdotally, the authors have learned that several carfree housing experiments in Germany (where this concept is predominantly used) are less successful than those reported in above. For example, it has been reported that several carfree developments in Germany attract residents due to reduced rental rates; however, many individuals still own vehicles but park them down the street from their residence. If this is indeed true, then, carfree housing would not address the goal of a carfree lifestyle. Given this concern, the authors modeled scenarios that also incorporated carsharing services to offer convenient vehicle access when needed. The next section includes a discussion of the methodology employed by the authors.

METHODOLOGICAL APPROACH

As discussed above, the studies cited in the literature review largely evaluate the social and environmental effects of innovative mobility approaches on participants only. This study, however, uses a relatively advanced travel demand model to gauge the demand for and effects of scenarios on the total population in a region. The drawback of this approach is the level of sophistication with which the model can represent the innovative mobility scenarios (see discussion of scenarios below). Scenario travel results from the simulation are input into an emissions model to estimate emissions effects. An economic model is applied to the mode choice model in the travel demand model to estimate potential scenario benefits. Detailed descriptions of each of these models are provided below.

The Sacramento Regional Travel Demand Model

The Sacramento regional travel demand model (SACMET01) is typical of a traditional four-step travel demand model that has been improved to better meet the current demands of transportation planning. This is accomplished by enhancing the representation of travel time and cost variables throughout the model hierarchy, expanding the range of modal options, including land use variables, and improving the detail of zone and network structures. The model was originally developed with a 1991 regional travel behavior survey and has recently been recalibrated with a 2000 regional travel behavior survey. This discussion highlights key model features. Complete model documentation is provided in the SACMET01 Model Update and Validation Report (*23*).

The SACMET01 model's representation of geographic detail is relatively fine. It includes a detailed transportation network composed of over 10,000 links and 1,142 travel analysis zones. Traffic analysis zones are the geographic units used by travel demand models. Zones contain area-specific information (e.g., number of households and employment) and are the location at which trips begin and end in a model. The network of a travel demand model represents the roadways and transit lines of a region with a series of links connected by nodes. All of the model links are described in terms of key variables (e.g., type of road, speed, and number of lanes).

The SACMET01 model includes an auto ownership step that precedes the trip generation step. The auto ownership step is a logit model that predicts the probability of owning zero, one, two, three, or more autos. The variables in this model include retail employment within one mile; total employment within 30 minutes by transit; a pedestrian environmental factor; and household size, workers, and income.

The trip generation step in the SACMET01 model estimates the number of person-trips that begin or end in a zone, based on the number and type of households (number of persons and workers), employment, and school enrollment (college and K through 12th grade). A retail accessibility measure is also included in the trip generation model for some trip purposes.

The SACMET01 model represents six trip purposes: home-work, home-shop, home-school, home-other, work-other, and other-other. The first part of the trip purpose title (i.e., home, work, and other) refers to the activity location at which the trip begins, and the second part refers to the activity location at which the trip ends.

The trip distribution step in the SACMET01 model links the trips from trip generation in an origin-destination pattern using travel times that reflect street traffic as opposed to free-flow travel times. This is accomplished by travel time feedback from the traffic assignment step to the trip distribution step until convergence is achieved. The home-based work trip is a joint destination and mode choice logit model and includes travel time and cost variables (or composite utility). The other trip purposes use the traditional gravity model formulation and include only the travel time variable.

The mode choice step predicts the probability that a traveler will choose a particular mode from a range of available modes. The modes included in the SACMET01 model are drive-alone, shared-ride (2 and 3+), transit (walk and drive access), walk, and bike modes. Modes are chosen as a function of modal attributes (time and cost), household characteristics (auto ownership, income, size, workers), and land use variables (pedestrian amenities and employment distance).

In the traffic assignment step, vehicle trips are assigned to routes with preference given to the fastest routes. The well-known user-equilibrium traffic assignment algorithm is used to assign vehicle trips by separate peak (A.M. and P.M.) and off-peak (midday and evenings) periods. The traffic assignment outputs are link volumes, link speed, vehicle miles traveled (VMT), and vehicle hours of delay. These outputs play an important role in the evaluation of travel effects of transportation alternatives and are key inputs to emission analyses. The next section describes the emission models used.

Emission Models

The California Department of Transportation’s Direct Travel Impact Model 2 (DTIM2) emission model and the California Air Resources Board’s EMFAC7F emission factors were used in this analysis. The outputs from the SACMET01 model used in our emission analysis included the results of assignment for each trip purpose by time period (AM peak, PM peak, midday, and evening). SACOG provided regional cold-start and hot-start coefficients for each hour in a twenty-four hour summer period. EMFAC7G and EMFAC2003 could not be used in the analysis because necessary data are not currently available in this region. Because the emphasis of this study is on the comparison of alternative scenarios (as opposed to a comparison to some fixed criteria), the use of the EMFAC7F emission factors should not affect the authors’ study conclusions (i.e., rank ordering of scenarios). The final section provides a brief overview of the benefit measures employed.

Economic Benefit Measures

Transportation agencies in the U.S. typically use criteria such as lane-miles of congestion, hours of travel delay, VMT, and mode share to evaluate proposed transportation policies. Such criteria are limited because they fail to account for travel time and cost effects resulting from transportation policy changes. Benefit measures that capture travel time and cost changes for all modes, resulting from a policy scenario, can be used to measure gains or losses to specific groups (usually income groups) or the region as a whole.

Kenneth Small and Harvey Rosen (*24*) show how a benefit measure known as compensating variation (CV) can be obtained from discrete choice models:

$$CV = 1/\lambda \left\{ \left[\ln \sum_{m \in M} e^{V_m(p^f)} \right] - \left[\ln \sum_{m \in M} e^{V_m(p^0)} \right] \right\} \qquad (1)$$

where λ is the individual's marginal utility of income, V_m is the individual's indirect utility of all m choices, p^0 indicates the initial point (i.e., before the policy change), and p^f indicates the final point (i.e., after the policy change). The change in indirect utility is converted to dollars by the factor, $1/\lambda$, or the inverse of the individual's marginal utility of income. Small and Rosen show how marginal utility of income can be obtained from the coefficient of the cost variable in discrete choice models.

The compensating variation formula (1) from above was adapted to suit the specifications of the SACMET01 mode choice models. In these models, households are segmented into income/worker categories and person trips are generated for those categories. To obtain compensating variation for each income/worker category h the following formula was applied for all modes m and for all trips Q between all origins i and all destinations j:

$$CV_h = 1/\lambda_h \left\{ \sum_{i \in I} \sum_{j \in J} \left[\left(\ln \sum_{m \in M} e^{V_{ijmh}(p^f)} * Q_{ijh} \right) - \left(\ln \sum_{m \in M} e^{V_{ijmh}(p^0)} * Q_{ijh} \right) \right] \right\} \qquad (2)$$

where λ is provided by the coefficient of the cost variable in the mode choice equations. Total compensating variation was obtained by summing the compensating variation obtained from each income/worker group.

The benefit analysis includes avoided parking costs, carsharing service fees, and operation and maintenance costs of advanced transit information. In the analysis, the cost of the carsharing service to the consumer is assumed to be $1.10 per trip, which approximates a $300 monthly fee. This monthly service fee is consistent with that charged for a carsharing pilot project in the San Francisco Bay Area (Shaheen and Wright, 2001). The yearly operation and maintenance costs for the advanced transit information services are assumed to be $160,000 per year and are based on estimates from the SMART TRAVELER project in Los Angeles (*26*). The next section includes a description of the innovative scenarios modeled.

INNOVATIVE MOBILITY SCENARIOS

The authors developed three innovative scenarios to model. To begin, a base case scenario was specified, reflecting the Sacramento region's 2025 Metropolitan Transportation Plan (MTP). Next, the authors specified three innovative scenarios based on the following innovations: 1) carsharing (a transit-based carsharing model), 2) carfree housing, and 3) advanced transit information. A brief description of each follows. Scenario One consists of *Carsharing Only*. Scenario Two includes *ATI and Carsharing*, and Scenario Three is a combination of *Carfree Housing, ATI, and Carsharing*.

Base Case Scenario

The Base Case scenario represents the region's 2025 MTP, which includes a significant expansion of light rail, addition of bus rapid transit, and new or widened freeways. The 2025 MTP map is illustrated in Figure 1 (below).

Carsharing

Carsharing was provided in key areas throughout the region to allow people to more quickly access light rail and bus rapid transit and/or a key employment center (UC Davis). Again, the limitations of the travel demand model used in this study required that we specify a transit-based carsharing service rather than a neighborhood service. These areas included downtown Sacramento, North Natomas, South Sacramento, Elk Grove, Folsom, Roseville, Carmichael, Rancho Cordova, Citrus Heights, and Woodland (to UC Davis). The areas served by carsharing are highlighted in Figure 1. The carsharing service was coded as a transit access link with very short direct routes and frequent service between zones and transit station locations or the UC Davis employment center. More specifically, the representation of carsharing in this scenario provides access to a carsharing vehicle to transit stations or the UC Davis employment center to all residents within the highlighted zones in Figure 1 when they need it. This scenario represents a carsharing service with a high level of vehicle availability (to the population served), but a low level of flexibility with respect to the service (i.e., connects to transit and the employment center only). The traveler choice to use a carsharing vehicle in the model is based on the relatively travel time and cost of all the modes available to the traveler for a trip origin and destination location. Thus, this scenario approximates a carsharing services and the simulation results indicate both the demand for and effect of the specified service.

Carfree Housing

This scenario represents a hypothetical future policy to create carfree housing in the region. This policy would require that 10 percent of all households with two or more cars in all zones outside of the downtown area (with carsharing services) become one-car households. In the downtown zones, 5 percent of all households with two or more cars would become zero-car households and 5 percent of the households would become one-car households. This “what if” scenario uses the available model to examine the effects of a specific level of auto ownership reduction in specific geographic areas well served by transit.

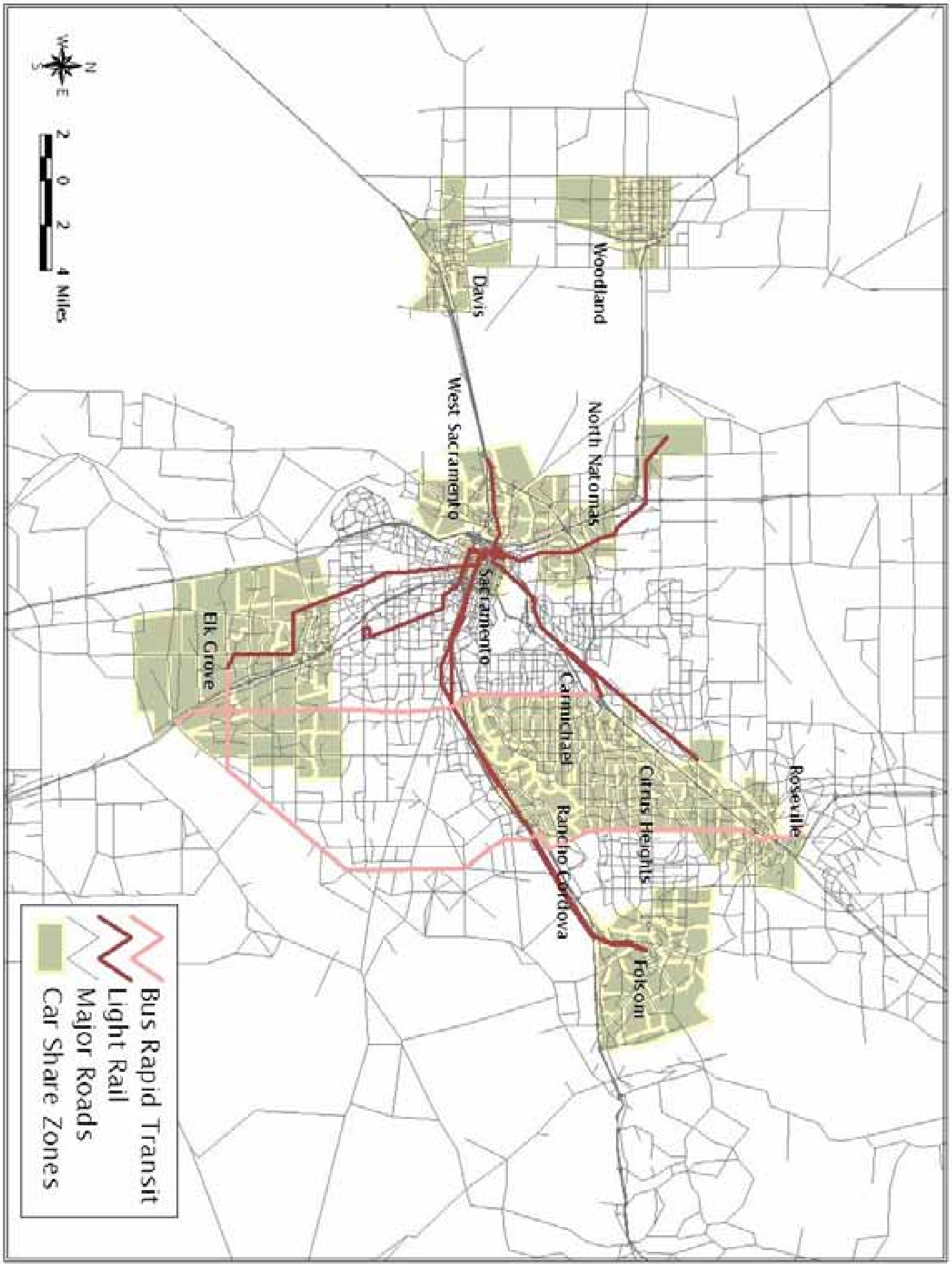
Advanced Transit Information (ATI)

This advanced transit information scenario is another example of a “what if” scenario. It imagines regional access to real-time transit scheduling information through signs located at transit stations and phones, the Internet, and cable television. Because this information technology is not represented directly in the model, this future scenario assumes that the technology is effective enough to reduce the maximum initial passenger wait times for all transit services in the model by one-half. Thus, this scenario examines the effects of a future advanced transit information system that significantly reduces passenger wait times region-wide in combination with the carfree housing policy and carsharing services.

Summary of Scenario Analysis Approach

This study uses a relatively advanced regional travel demand model to simulate the effects of carsharing, carfree housing, and advanced traveler information systems. Carsharing and advanced information systems are not directly represented in the model. Since these advanced services have not been widely implement in the U.S. (much less Sacramento), demand for these services, over and above those of traditional transit modes, are not represented in the underlying data used to estimate the model. The model did allow for an approximation of a transit-based carsharing service and thus an analysis of potential demand as well as travel effects. However, with respect to advanced transit information, a “what if” scenario analysis approach was taken; that is, what would be the effects of a future advanced transit information technology service that reduced passenger wait times by half. A similar approach was taken to evaluate the effects of a hypothetical future carfree housing policy that that reduced auto ownership by a specified level in zones well serviced by transit.

FIGURE 1. 2025 MTP map with carsharing zones.



MODELING RESULTS

Modeling results for each of the innovative mobility scenarios developed are discussed below. Findings are discussed according to: 1) regional travel effects, 2) economic benefits, and 3) vehicle emissions.

Regional Travel Results

At the regional level, each scenario provides relatively modest increases in transit mode share and fairly small reductions in auto mode share. It is important to note the distinction between this study and innovation analyses described in the literature review to understand the difference in the magnitude of findings. The current study specifies model scenarios, and then, estimates the region-wide demand for these services and their effects on total travel. Again, as described above, there are some limitations to the representation of our innovative scenarios in the model. The studies cited in the literature review, particularly with respect to carsharing, evaluate programs that may be different than the scenarios in this study and, typically, evaluate effects on particular program users not the total regional market.

The daily mode choice results are presented in Table 1 (below). Carsharing and ATI improve access to and egress from regional light rail and bus rapid transit and thus improve transit travel time relative to the auto for some trips. The addition of advanced transit services tends to boost the increase in transit mode share and the reduction in auto mode share. In the *Carsharing Only* scenario, the daily transit mode share is increased by 2.78 percent, and the drive alone and shared ride mode shares are decreased by 0.15 and 0.31 percent, respectively. (Note that all reported percentages are percentage change from the Base Case to the innovative mobility scenarios.) Carsharing is applied to selected areas in the region, but the ATI service reduces transit wait times across the region, and thus ATI produces a greater magnitude of shifts relative to the *Carsharing Only* scenario. In the *ATI and Carsharing* scenario, the daily transit mode share is increased by 19.06 percent, and the drive-alone and shared-ride mode shares are decreased by 0.39 and 0.55 percent, respectively. After adding the carfree housing policy to the ATI and Carsharing scenario (*Carfree Housing, ATI, and Carsharing* scenario), the daily transit mode share is increased by 17.96 percent, and the drive-alone and shared-ride mode shares are decreased by 0.48 and 0.44 percent, respectively. It appears that the restrictive auto access of the carfree housing policy in the SACMET01 model tends to promote ridesharing rather than transit use. This increase in ridesharing, however, could be accommodated by a carsharing service that was more flexible than the light rail based-service represented in this study. If such a service was integrated into carfree development with reduced parking, then more dramatic reductions in the auto mode share could be possible. These types of developments are now occurring in the U.S.

TABLE 1. Daily Mode Share for 2025 Sacramento Innovative Mobility Scenarios

	Drive-Alone	Shared-Ride	Transit	Walk	Bicycle
Base Case	49.51%	42.89%	1.50%	5.23%	0.87%
Carsharing	49.43% (-0.15%)[1]	42.75% (-0.31%)	1.54% (2.78%)	5.25% (0.27%)	0.87% (0.27%)
ATI & Carsharing	49.32% (-0.39%)	42.65% (-0.55%)	1.79% (19.06%)	5.23% (-0.07%)	0.87% (-0.63%)
Carfree Housing, ATI & Carsharing	49.27% (-0.48%)	42.70% (-0.44%)	1.77% (17.96%)	5.24% (0.05%)	0.87% (0.17%)

[1] Figures in parentheses are percentage change from the base case scenario.

The daily travel results (see Table 2 below) are consistent with the daily mode share results, presented in Table 1 (above). The modest increases in transit mode share and reduction in auto use tend to produce modest reductions in vehicle trips, VMT, and vehicle hours traveled. Again, the layering of innovative strategies in each of the three scenarios increases overall effectiveness. The *Carsharing Only* scenario reduces vehicle trips by 0.01 percent, VMT by 0.02 percent, and vehicle hours of travel by 0.04 percent. The *ATI and Carsharing* scenario reduces vehicle trips by 0.16 percent, VMT by 0.15 percent, and vehicle hours of travel by 0.23 percent. The *Carfree Housing, ATI, and Carsharing* scenario reduces vehicle trips by 0.23 percent, VMT by 0.17 percent, and vehicle hours of travel by 0.26 percent.

TABLE 2. Daily Travel Results for the 2025 Sacramento Innovative Mobility Scenarios

	Vehicle Trips	VMT	Vehicle Hours Traveled
Base Case	7,898,314	65,387,054	1,774,724
Carsharing	7,897,227 (-0.01%)[1]	65,376,657 (-0.02%)	1,774,058 (-0.04%)
ATI & Carsharing	7,885,380 (-0.16%)	65,289,479 (-0.15%)	1,770,600 (-0.23%)
Carfree Housing, ATI & Carsharing	7,880,165 (-0.23%)	65,278,085 (-0.17%)	1,770,065 (-0.26%)

[1] Figures in parentheses are percentage change from the MTP Base.

The City of Davis

The City of Davis is unique in the Sacramento region because it contains a strong transit and bicycle network that supports bus and bike travel throughout the city and, in particular, to the University of California. Table 3 (below) provides daily mode choice results, both for trips produced in and attracted to the City of Davis. As discussed above, carsharing is simulated between Woodland (north of Davis) and UC Davis. The modest increase in transit and decrease in auto mode share reflects the limited carsharing market between Woodland and the City of Davis. In this context, it is important to note that light rail does not extend from Sacramento to Davis in the 2025 Base Case scenario, thus transit modal shifts between these two cities is somewhat limited (i.e., to bus service only). However, because the City of Davis has a strong transit network, the effect of the ATI service is significantly greater in the City of Davis compared to the Sacramento regional analysis above. The increase in transit mode share is approximately 35 percent, and the reduction in the drive alone and shared ride modes is approximately two percent. As in the Sacramento regional analysis, the addition of carfree housing to the *ATI and Carsharing Scenario* tends to reduce drive alone and shared ride mode shares and dampen the increase in the transit mode share. Again, it appears that the restricted auto access of carfree housing in the SACMET01 model tends to promote ridesharing rather than transit use.

TABLE 3. Daily Mode Share for the 2025 Sacramento Innovative Mobility Scenarios in the City of Davis

	Drive Alone		Shared Ride		Transit		Walk		Bicycle	
	P	A	P	A	P	A	P	A	P	A
Base Case	39.04%	40.43%	40.55%	40.43%	5.89%	5.41%	11.20%	10.33%	3.32%	2.28%
Carsharing	39.03% (-0.01)[1]	40.42% (-0.02)	40.55% (0.01)	40.42% (-0.02)	5.89% (0.01)	5.41% (0.02)	11.20% (0.00)	10.33% (0.05)	3.32% (0.00)	2.28% (0.08)
ATI & Carsharing	38.16% (-2.25)	39.62% (-2.02)	39.72% (-2.04)	39.62% (-2.02)	7.90% (34.15)	7.35% (35.80)	10.98% (-2.02)	10.12% (-2.03)	3.24% (-2.30)	2.23% (-2.12)
Carfree Housing, ATI & Carsharing	37.84% (-3.06)	39.95% (-1.18)	40.10% (-1.10)	39.95% (-1.18)	7.67% (30.28)	7.16% (32.41)	11.04% (-1.48)	10.18% (-1.47)	3.34% (0.67)	2.28% (0.14)

[1] Figures in parentheses are percentage change from the MTP Base.

Percentage change in transit travel time (relative to the Base Case) in the City of Davis was calculated. No significant change was estimated for the *Carsharing Only* scenario; however, the reduction in travel time for the *ATI and Carsharing* and *Carfree Housing, ATI, and Carsharing* scenarios ranged from 0.64 to –0.06 percent. The standard deviation was 0.35 percent for the *ATI and Carsharing* scenario, and the standard deviation was 0.36 percent for the *Carfree Housing, ATI, and Carsharing* scenario.

Economic Benefits

The daily regional traveler benefit results for home-based work trips for the innovative mobility scenarios are presented in Table 4 (below). As described in the methods section, these figures include avoided parking costs, carsharing service fees, and operation and maintenance costs for the ATI services. All the scenarios yield a positive net total benefit and a net benefit for all income groups. Value of travel time increases with income, and thus benefits increase from the lowest income class (one) to the highest income class (three). As the transit services and carfree housing policy are layered onto carsharing, total benefits increase. The total per trip benefit for the *Carsharing Only* scenario is $0.01, *ATI and Carsharing* scenario is $0.03, and *Carfree Housing, ATI, and Carsharing* scenario is $0.05. Again, the ATI service has a greater scope than the carsharing service and thus provides a greater benefit. The *Carfree Housing* strategy appears to improve benefits because of avoided auto operating costs. The yearly total, however, for all scenarios would be significant.

TABLE 4. Daily Benefit Results (in 2000 dollars) for Home-Based Work Trips for the 2025 Sacramento Innovative Mobility Scenarios

	Income Class One (Lowest)		Income Class Two		Income Class Three (Highest)		Sum Total	
	Total	Per trip	Total	Per trip	Total	Per trip	Total	Per trip
Carsharing	73.61	0.00	1,581.10	0.00	8,877.72	0.01	10,532.43	0.01
ATI & Carsharing	267.78	0.02	10,028.21	0.02	37,935.81	0.04	48,231.80	0.03
Carfree, ATI & Carsharing	439.60	0.02	9,568.41	0.03	78,246.65	0.06	88,254.65	0.05

Vehicle Emission Benefits

The vehicle emission results (see Table 5 below) are consistent with the daily travel results (presented in Table 2 above). All scenarios produce modest vehicle emission reductions because of the decrease in vehicle travel described above. The layering of innovative strategies in each of the scenarios increases the overall effectiveness with respect to emission reductions.

TABLE 5. Daily Vehicle Emissions Results (tons) for the 2025 Sacramento Innovative Mobility Scenarios

	TOG	CO	Nox	PM
Base Case	25.06	228.20	80.93	88.98
Carsharing	25.00 (-0.24%)[1]	227.97 (-0.10%)	80.90 (-0.04%)	88.80 (-0.20%)
ATI & Carsharing	24.98 (-0.32%)	227.64 (-0.25%)	80.78 (-0.19%)	88.61 (-0.42%)
Carfree, ATI & Carsharing	24.96 (-0.40%)	227.53 (-0.29%)	80.76 (-0.21%)	88.55 (-0.48%)

[1] Figures in parentheses are percentage change from the Base.

SUMMARY AND CONCLUSIONS

In this paper, the authors presented results from future innovative mobility scenarios (2025) simulated with an advanced regional travel demand model for the Sacramento region. The SACMET01 travel demand model was used to approximate the effects of carsharing, ATI services, and carfree housing in the Sacramento region. Overall, results indicate relatively modest reductions in vehicle travel and emissions. The *Carsharing Only* scenario increases transit mode share by 2.78 percent and reduces VMT by 0.02 percent and NOx by 0.04 percent, compared to a *Base Case* scenario that represents the future transportation plan for the region. The *ATI and Carsharing* scenario increases transit mode share by 19.06 percent and reduces VMT by 0.15 percent and NOx by 0.19 percent. The difference between the carsharing and ATI effects in these two scenarios can be explained by their scope of application. *Carsharing Only* is applied to selected areas in the region, while the ATI service is applied regionwide. The *Carfree Housing, ATI, and Carsharing* scenario increases transit mode share by 17.96 percent and reduces VMT by 0.17 percent and NOx by 0.21 percent. Restricted auto access in carfree housing tends to promote ridesharing rather than transit use in the simulation method. This ridesharing increase, however, could be accommodated by a carsharing service that was more flexible than the light rail based-service represented in this study. If such a service was integrated into carfree development with reduced parking, then more dramatic reductions in the auto mode share could be possible. These types of developments are now occurring in the U.S.

In general, the relatively limited penetration of traditional transit in the region restricts the effectiveness of carsharing, ATI services, and a carfree housing policy. Results for the City of Davis, which contains a much more dense transit network than Sacramento, illustrates this point. Indeed, the mode choice effects for transit in the City of Davis are approximately double those found regionally in the *ATI and Carsharing* scenario and the *Carfree Housing, ATI, and Carsharing* scenario.

Despite the modest travel effects of the scenarios, the economic analysis indicates a net benefit for each of the innovative mobility scenarios for home-based work trips. The total per trip benefit for the *Carsharing Only* scenario is $0.01, $0.03 for the *ATI and Carsharing*, and $0.05

for the *Carfree Housing, ATI, and Carsharing* scenario. Again, the ATI service has a greater scope than the carsharing service and thus provides a greater benefit. The carfree housing policy increases benefits due to avoided auto operating costs. The yearly total, however, for all scenarios would be significant. Thus, the study results suggest that a combination of services and policies increase benefits. It is possible that carsharing organizations may reap greater benefits by linking their services with other innovations, such as advanced transit information or partnerships to develop carfree housing or both.

This study used a relatively advanced travel demand model to assess the potential demand for carsharing, advanced transit information, and carfree housing scenarios and their travel, emission, and economic effects in the Sacramento region. Past studies of these services and policies have typically evaluated the effects of individual programs on participants only. This is particularly true with respect to carsharing. The primary limitation of the modeling approach taken in this study is the complexity of scenario representation allowed by the model. For example, the model's structure allowed for the representation of a largely transit-based approach to carsharing. The simulation analysis results indicated relatively small travel and emission effects. A more sophisticated representation of carsharing would have allowed for more flexible carsharing services with different payment methods (e.g., per mile charges that reflect variable transportation costs versus more traditional fixed costs) and a more detailed representation of the land use characteristics of carfree housing developments (e.g., fewer parking spaces). A more complex representation of policies and services in the model could provide for a greater magnitude of effects in our results.

Travel demand models are estimated on current data and largely replicate the current transportation system. Thus, it is difficult for these models to predict a future that is different from the past. The lack of tools to evaluate innovative mobility service/policy effects could be a barrier to their implementation on a regional level. Models are needed that offer a more detailed representation of land use and demographic characteristics as well as modal options. One step toward achieving these objectives may be to coordinate model development efforts with data collection (stated preference and revealed preference) of innovative mobility pilot projects.

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