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# Synergistic Integration of Transportation Demand Management Strategies (Land Use, Transit, and Auto Pricing) with New Technologies and Services (Battery Electric Vehicles and Dynamic Ridesharing) to Enhance Reductions in VMT and GHG



MTI Report 12-50



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REPORT 12-50

**SYNERGISTIC INTEGRATION OF TRANSPORTATION  
DEMAND MANAGEMENT STRATEGIES (LAND USE, TRANSIT,  
AND AUTO PRICING) WITH NEW TECHNOLOGIES AND  
SERVICES (BATTERY ELECTRIC VEHICLES AND DYNAMIC  
RIDESHARING) TO ENHANCE REDUCTIONS IN VMT AND GHG**

Caroline Rodier, Ph.D.  
Farzad Alemi  
Dylan Smith

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Mineta Transportation Institute  
College of Business  
San José State University  
San José, CA 95192-0219

Tel: (408) 924-7560  
Fax: (408) 924-7565  
Email: [mineta-institute@sjsu.edu](mailto:mineta-institute@sjsu.edu)

[transweb.sjsu.edu](http://transweb.sjsu.edu)

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## EXECUTIVE SUMMARY

It is widely recognized that new vehicle and fuel technology is necessary, but not sufficient, to meet deep greenhouse gas (GHG) reductions goals for both the U.S. and the state of California. Demand management strategies (such as land use, transit, and auto pricing) are also needed to reduce passenger vehicle miles traveled (VMT) and related GHG emissions. In this study, the authors explore how demand management strategies may be combined with new vehicle technology (battery electric vehicles or BEVs) and services (dynamic ridesharing) to enhance VMT and GHG reductions. Most BEVs can travel only about 60 to 125 miles (97 to 201 km) before recharging. Dynamic ridesharing services automatically match drivers and riders with similar spatial and temporal constraints (e.g., Zimride, Carma, UberPool, and Lyft Line). Owning a BEV or using a dynamic ridesharing service may be more feasible when distances to destinations are made shorter and alternative modes of travel are provided by demand management strategies.

To examine potential markets for dynamic ridesharing and BEVs, the authors use the San Francisco Bay Area Metropolitan Transportation Commissions' (MTC) activity-based microsimulation travel demand model (ABM) for the year 2010. A business-as-usual (Base Case), transit-oriented development (TOD), and auto pricing (VMT Fee) scenarios are simulated with and without high, medium, and low dynamic ridesharing participation levels and BEV driving ranges.

The results of this study suggest that dynamic ridesharing has the potential to significantly reduce VMT and related GHG emissions, which may be greater than land use and transit policies typically included in Sustainable Community Strategies (under California Senate Bill 375), if travelers are willing to pay with both time and money to use the dynamic ridesharing system. The combination of dynamic ridesharing with the TOD and VMT Fee scenarios suggests some policy combinations that may be more effective than dynamic ridesharing alone but perhaps more politically palatable. For example, a moderately used regional dynamic ridesharing with 10% increase in VMT fees may produce reductions in VMT on the order of 11% compared with a business-as-usual scenario in one horizon year. However, in general, large synergistic effects between ridesharing and transit-oriented development or auto pricing policies were not found in this study.

The results of the BEV simulations suggest that TODs may increase the market for BEVs by less than 1% in the San Francisco Bay Area and that auto pricing policies may increase the market by as much as 7%. However, it is possible that larger changes are possible over time in faster growing regions where development is currently at low density levels (for example, the Central Valley in California). The VMT Fee scenarios show larger increases in the potential market for BEV by as much as 7%.

## I. INTRODUCTION

It is widely recognized that new vehicle and fuel technology is necessary, but not sufficient, to meet deep greenhouse gas (GHG) reductions goals for both the U.S. and the state of California. Demand management strategies—such as land use, transit, and auto pricing—are also needed to reduce passenger vehicle miles traveled (VMT) and related GHG emissions. In this study, the authors explore how demand management strategies may be combined with new vehicle technology (battery electric vehicles or BEVs) and services (dynamic ridesharing) to enhance VMT and GHG reductions. Most BEVs can travel only about 60 to 125 miles (97 to 201 km) before recharging. Dynamic ridesharing services automatically match drivers and riders with similar spatial and temporal constraints (e.g., Zimride, Carma, UberPool, and Lyft Line). Owning a BEV or using a dynamic ridesharing service may be more feasible with demand management strategies that reduce distances to destinations and provide alternative modes of travel.

The current study uses the San Francisco Bay Area Metropolitan Transportation Commission's (MTC's) Activity Based Microsimulation Travel Demand Model (ABM) to examine the potential magnitude of markets for VMT and/or GHG reductions from dynamic ridesharing services (DRSs) and the adoption of BEVs with and without land use, transit, and auto pricing policies. The study begins with a discussion of what is known about potential market size and travel effects of DRSs and BEVs and the effects of their interaction with land use, transit, and auto pricing policies. Next, the MTC ABM is described. This is followed by a detailed discussion of the scenarios simulated in the model and the post-processing models developed to estimate the market for BEVs and DRSs. The results of the model simulation of business-as-usual (Base Case), transit-oriented development (TOD), and auto pricing (VMT Fee) scenarios with and without high, medium, and low BEV range and DRS participation are presented. The study concludes with a summary of key results, policy implications, and future research.

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## II. BACKGROUND

### DYNAMIC RIDESHARING SERVICES

#### Overview

DRSs automatically match drivers and riders with similar spatial and temporal constraints (i.e., trip origin/destination locations and departure/arrival times) and communicate matches upon request, in advance, or on demand in real time in as little as 30 to 90 seconds. Smart phone applications are provided to participants, which allow them to request a ride, evaluate and view ratings of drivers and riders, accept or reject matches, and pay drivers. Social networks and incentive systems may be used to expand service participants and use.

Under the general category of DRSs, there are two common service models, peer-to-peer ridesharing and taxi-sharing. In peer-to-peer ridesharing, drivers are independent service participants and reimbursed for trip-related costs (e.g., fuel, tolls, and service fee). Drivers' ability to provide shared rides may be restricted by the spatial and temporal requirements of their own travel. In the U.S., peer-to-peer ridesharing companies (e.g., Zimride and/or Carma) currently operate in five U.S. cities (Austin, TX; San Francisco, CA; Washington, DC; Los Angeles, CA, and New York City, NY).<sup>1</sup> In taxi-sharing services, drivers may be licensed taxi drivers or independent contractors (in a Transportation Network Company [TNC], such as Uber or Lyft), fees are established by service operators to compensate both the driver and service provider, and drivers are better able to conform to riders' spatial or temporal requirements. Drivers are dispatched to maximize vehicle passengers and minimize passenger costs (e.g., travel time, wait time, and fares). In the future, automated vehicles may eliminate the drivers' role and significantly reduce participant costs. Examples of taxi-sharing services in the U.S. are UberPool and Lyft Line.

#### Potential Travel Effects

DRSs provide a new mode of travel at new travel time and cost price points to many destinations in service areas. Ubiquitous DRSs may result in a series of complex and inter-related behavioral and systems-level effects—with both positive and negative impacts—on congestion, VMT, and GHG emissions. In the short term, fewer vehicles may be needed to meet the travel needs of service participants, which would tend to reduce auto travel distance and time. However, in the long term, these benefits may be offset to some degree by induced travel. By improving first- and last-mile access to transit stations, these services (particularly taxi-sharing) could increase transit use and lead to some reduction in congestion and auto travel, depending on induced travel effects. DRS may also provide reduced fares and/or travel times relative to available transit travel and thus may increase auto travel and congestion. Individuals without access to a private vehicle or transit may travel more by auto. This would not increase VMT in the peer-to-peer model, but it could do so in the taxi-sharing model as mediated by taxi-sharing fees. A reliable and affordable alternative to private vehicles may reduce auto ownership among participants, which would tend to reduce auto travel and encourage transit, walking, and bike use. Reduced auto ownership levels may increase demand for more centralized residential locations with high-quality multi-modal access to destinations. In areas with pent-up travel demand,

congestion may not be significantly reduced. On the other hand, overall efficiency (person throughput) and equity (greater access to transportation) could be significantly improved. Table 1 provides a summary of some possible outcomes of DRS and the effects on VMT and GHG emissions.

**Table 1. Dynamic Ridesharing Services: Potential Outcomes and Effects on VMT/GHG**

Category	Possible Outcome	Direction of Change
Auto Ownership	If DRSs replace private auto for all travel needs at a lower cost, then auto ownership declines and use of non-SOV modes increases.	- VMT/GHG*
Trip Generation	If access to a car and transit is limited and DRSs are affordable, then new trips may be induced.	+ VMT/GHG*
Mode Choice	If travel time and costs are lower by DRSs than SOVs, then DRSs increase and SOVs decrease.	- VMT/GHG*
	If time and cost are lower by DRSs than transit, then DRSs increase and transit decreases.	+ VMT/GHG*
	If overall travel time and cost for DRSs (first/last mile) and transit are lower than SOVs, then DRSs and transit increase and SOV decreases.	- VMT/GHG*
Destination Choice	If overall travel time and cost for all modes are reduced to central areas relative to outlying, then travel to central areas is more likely.	- VMT/GHG
	If overall travel time and cost for all modes are reduced to outlying areas relative to central, then travel to outlying areas is more likely.	+ VMT/GHG
Route Choice	DRS travel to pick-up and drop-off passengers and/or relocation miles.	+ VMT/GHG
	If congestion worsens, then longer routes are possible to avoid congestion and minimize travel time.	+ VMT/GHG
	Stop and start travel.	+ GHG
Built Form and Location Choice	If overall travel time and cost for all modes is reduced to central areas relative to outlying, then demand for residential and employment space may be greater in central areas.	- VMT/GHG
	If overall travel time and cost for all modes is reduced to outlying areas relative to central, then demand for residential and employment space may be greater in outlying areas.	+ VMT/GHG

*Note:* \*mediated by induced travel; single occupant vehicle (SOV); - = reduce; + = increase.

Policies, such as transit-oriented development, can reduce the spatial distribution of trip origins and destinations and thus increase the probability of ridesharing. In addition, expanding transit, walking, and bike access increases the probability of ridesharing for one or more segments of a daily tour because it reduces the probability that trip segments within that same tour can be accomplished only by driving alone. Auto pricing policies, such as VMT fees, increase the incentive to actually form rideshares by reducing travel costs for drivers and passengers. Higher costs of auto travel would tend to encourage shorter distances between residential and employment locations and more development around high quality transit, and thus further increase the feasibility of ridesharing.

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## Literature Review

### *Dynamic Ridesharing*

Currently, the authors are aware of no available study that systematically evaluates the travel effects of an operational DRS. However, some recent studies of similar services are of some relevance. Rayle et al.<sup>2</sup> survey taxi and TNC services (e.g., Uber and Lyft) in San Francisco, CA and find that the majority of TNC rides would have taken significantly longer by transit. Overall, passengers take taxis and TNCs to travel to and from transit stations and to access destinations faster than is possible by taking transit.<sup>3</sup> A preliminary evaluation of peer-to-peer carsharing services in Portland, OR indicates that the availability of the service induced new trips and a shift from transit to carsharing travel among participants.<sup>4</sup>

Two studies use survey data to examine the potential demand for DRSs in a university context in Berkeley, CA and Cambridge, MA. They estimate that 20% to 30% of drive-alone commuters to campuses could use a DRS.<sup>5,6</sup> Amey<sup>7</sup> estimates that reductions in VMT could range from 9% to 27% of daily university commute travel, but the analysis does not account for induced travel.

Several simulation-modeling studies evaluate peer-to-peer ridesharing services. Agatz et al.<sup>8</sup> develop an optimization model with fixed morning commute data (i.e., the quantity of travel does not change if travel time and cost change) from the Atlanta regional travel model that matches riders and drivers (with similar temporal and special constraints and fixed travel times) while minimizing system VMT and travel costs and maximizing driver revenues. They find that, even with relative low participation rates (2%) and a time flexibility of 20 minutes, the peer-to-peer ridesharing matching rate is 70%, VMT is reduced by 25%, and travel costs are reduced by 29%. Di Febbraro et al.<sup>9</sup> develop a discrete event model with dynamic pickup and delivery to optimally match drivers, riders, and network paths to minimize access and egress times in a DRS in the morning and afternoon peak period in Genoa, Italy. They find that only 13% and 15% of matches are refused due to excessive delays. Xu et al.<sup>10</sup> developed two equilibrium models, a market pricing, and traditional static assignment to simulate the hypothetical effect of congestion and ridesharing price on the decision of a given number of drivers and passengers to rideshare. Dubernet et al.<sup>11</sup> use the MATsim model to simulate the feasibility of ridesharing in Switzerland and find that between 47% and 87% of all trips made on a daily basis could be matched into two-person carpools.

Two studies use actual taxi record data to simulate the effects of taxi-sharing services. Santi et al.<sup>12</sup> develop a graph-theoretic model that estimates the trade-off between the time and monetary benefits and costs of using a taxi-sharing service with data on 150 million taxi trips in New York City in 2011. They find significant potential for reduced vehicle travel (40%) at relatively low levels of discomfort with reduced service and passenger costs. In this study, activity data is fixed and thus induced travel effects are not represented. Martinez et al.<sup>13</sup> use an agent based model that matches taxis to clients while meeting the spatial and temporal requirements of clients' trips given a maximum wait time in Lisbon, Portugal. A micro-simulation traffic model simulates taxi trips using fixed activity data from taxi records that include origin and destination and start time information for each trip.

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They find a possible average reduction in passenger fares of 9% in the taxi-sharing service compared with a traditional taxi service.

Fagnant and Kockelman<sup>14</sup> use travel activity data from an Austin, TX regional travel demand model (trip-based model) with MATsim to simulate an automated ridesharing system. In this study, shared autonomous vehicles (SAVs) service the travel needs of the entire population in the region (one SAV for ten private autos). Travelers participate in DRS when doing so will add no more than 10% of their trip travel time. Relocation methods are also tested and compared. Relative to a comparable non-SAV system, SAVs generated 10% more VMT without DRS and 10% less with DRS. This study uses fixed activity data from regional travel model.

In another study, Fagnant and Kockelman<sup>15</sup> conduct sensitivity analyses of SAVs without dynamic ridesharing, which provide some insights into how congestion and VMT effects may be mediated in a simulation in which travel activity or demand is not fixed. These sensitivity analyses allow trip generation, destination choice, and land use patterns to vary. The results indicate that low congestion levels in centralized urban areas are keys to reduced induced travel from SAVs.

In sum, a limited number of studies quantify the effects of dynamic ridesharing systems in a real or theoretical urban environment. Most of these studies use one or more types of models: static or dynamic traffic/route assignment with and without optimization techniques. Traveler or vehicle demand characteristics are almost always fixed (or not sensitive to changes in travel time and cost introduced by the DRS), including origin and destination locations, as well as departure and arrival times. Many studies test the effectiveness of different optimization techniques to match potential drivers and passengers. Other studies attempt to simulate the decision to share based on DRS fees and travel time delays.

### *Battery Electric Vehicles*

Driving-range anxiety is known to be a major barrier to the adoption of BEVs. Most BEVs can travel only about 60 to 125 miles (97 to 201 km) before recharging, while gasoline vehicles can travel more than 300 miles (483 km) before refueling. People whose daily travel patterns are within the range of BEVs are frequently dissuaded from purchasing a BEV because of the occasional need to make long-distance trips. Fiat has addressed this problem for its BEV (with a range of 87 miles or 140 km) by providing 12 days of rentals from Enterprise each year with the purchase of its BEV.

Compact development, transit access, and auto pricing will tend to reduce the daily distances traveled by drivers. There is evidence that residential density is positively associated with the purchase of smaller, more fuel efficient vehicles.<sup>16</sup> Brownstone and Golob<sup>17</sup> find that higher densities were associated with a 6% reduction in fuel use, of which 70% was attributed to reduced VMT and 30% to more fuel-efficient cars. Compact development and transit access, by reducing distances traveled, may also increase the cost-effectiveness and adoption of BEVs because the car could accomplish more driving on a battery charge.

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### III. METHODS

Travel demand models use the location and characteristics of population and employment and the activities they generate, along with a physical representation of the transportation system (roadways, rail and bus lines, sidewalks, and bike lanes), to forecast the total quantity and quality of travel (time and cost) by different modes (automobile, transit, walk, and bicycle) to and from different destinations using certain routes.

Climate change legislation in California has spurred the development of new activity-based microsimulation travel demand models (ABMs) that can simulate land use, transit, and pricing policies. The attributes of the output data from ABM simulations allow analyses of the market for new technologies and services as well as the potential impacts on VMT and/or GHGs. Unlike traditional trip-based four-step travel models, ABMs track individual and household activities and travel throughout a typical day. This makes it possible to identify trip start and end times by location, purpose, and mode. This data can be used to identify the number of individuals, their characteristics, and trips that could feasibly use new technology and services as well as the potential magnitude of avoided vehicle trips, VMT, and/or GHGs from their implementation.

Activity-based microsimulation travel demand models (ABMs) simulate individual travel as derived from the need to participate in activities in specific space and time contexts. The sequence by which individuals participate in activities and travel is based on time-use decisions over time (24 hours or longer). Individuals' socio-economic attributes and travel environment (i.e., quality by mode of travel to different destinations) are typically represented at a high level of resolution. The probability of an individual traveler selecting a given alternative is a function of his or her socioeconomic characteristics and the relative attractiveness of the alternative. As a result, these models are better able to simulate the effect of changes in travel time and cost from the introduction of demand management strategies.

The San Francisco Bay Area MTC's ABM belongs to the CT-RAMP (Coordinated Travel-Regional Activity Modeling Platform) family of ABMs developed by Parsons Brinkerhoff. Activities or day patterns driving individuals' need to make travel-related choices are based on MTC's 2000 Bay Area Travel Behavior Survey. The data from this survey include two-day travel diaries from 15,000 households. In the model, tours are the unit of analysis in a day pattern. A tour represents a closed or half-closed chain of trips starting and ending (in hourly increments) at home or at the workplace and includes at least one destination and at least two successive trips. The MTC ABM includes four mandatory tours (work, university, high school, and grade school) and six non-mandatory tours (escort, shop, other maintenance, social/recreational, eat out, and other discretionary). A more advanced feature of the CT-RAMP models is the representation on intra-household travel.

All individuals and their socioeconomic characteristics in the MTC study area are generated through a process known as a population synthesis, which expands survey samples (i.e., 2000 Public Use Microdata Sample and 2010 Census data) of households using statistical methods that represent the entire population. Demographic and employment categories include households by four income quartiles, population by five age categories, population by four income categories, high school and grade school enrollment, and employment by six North American Industry Classification System categories.

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Transportation supply is represented by transportation analysis zone system (geographic units of analysis) and roadway and transit networks. The following modes are represented in the MTC ABM: drive alone free and pay, shared ride free and paid, walk, bike, and transit (with walk, bike, and drive access/egress modes). The 2010 zone system includes 1,454 zones. Networks are developed for the following time periods: early off-peak (3 a.m. to 6 a.m.), morning peak (6 a.m. to 10 a.m.), midday (10 a.m. to 3 p.m.), afternoon peak (3 p.m. to 7 p.m.), and off-peak late (7 p.m. to 3 a.m.). Traffic is assigned to the network using static assignment processes.

In this study, induced travel is represented through the application of empirical elasticities from the literature as opposed to the complete travel time convergence process in the MTC ABM. Post-processing coding for DRS using the convergence process would have been much more complex, and computer run times would have been significantly longer. (A fully iterated run requires at least three days, and post-processing for DRS scenarios can require from six to 24 hours). As a result, the authors used the fully converged 2010 Base Case scenario and simulated the policy scenarios (TOD and VMT Fee) with one additional model run. This approach allowed them to run multiple scenarios for each policy type and conduct numerous sensitivity analyses that address the considerable uncertainty in the effects of DRSs.

The DRS scenarios required post processing of the Base Case, VMT Fee, and TOD model files, as described below. For the scenarios that would result in a change in average vehicle miles per hour (MPH) traveled (i.e., VMT fee, TOD, and DRS), long-run elasticity of VMT with respect to average vehicle MPH (0.64, or 1 kmh) was used to represent induced travel (from Cervero<sup>18</sup>). The elasticity was applied to the change in average MPH in each of the five time periods in the model, and the resulting change in VMT for each time period was summed for each scenario. In other words, a factor developed from the empirical literature on induced travel was applied to average vehicle speed to represent the additional travel that would result from any increase in vehicle speed resulting from the scenarios. Change is always relative to the 2010 Base Case.

## IV. SCENARIOS

In the Transit-Oriented Development scenarios (TOD), residential densities are increased by 10%, 20%, and 50% around transit stations by randomly selecting households from the least to most dense zones around transit stations. Density was calculated with a quarter-mile buffer at the TAZ level. Table 2 lists the percent of total population moved in each land use scenario.

**Table 2. Percent of Total Household and Population Moved in TOD Scenarios**

TOD Scenarios	Households	Population
10%	0.44%	4.28%
20%	0.76%	8.07%
50%	1.53%	14.93%

In the VMT scenario, the per-mile auto operating cost of passenger vehicle travel in the MTC ABM (17.9 cents) was increased by 10%, 30%, and 50%. See Table 3.

**Table 3. Per Mile Auto Operating Costs for Base and VMT Fee Scenarios**

VMT Fee Scenarios	Per Mile Operating Cost
Base	17.9 cents
10%	25.4 cents
30%	40.4 cents
50%	55.4 cents

A post-processing program was developed in C to estimate the potential market and travel effects of DRS, as illustrated in Figure 1. In stage I, the relevant MTC ABM files are read into the program. These include the following files

- Household and individual characteristics from the population synthesis,
- Tour and trip level daily travel data by individual and household, and
- Zonal network distance estimates.

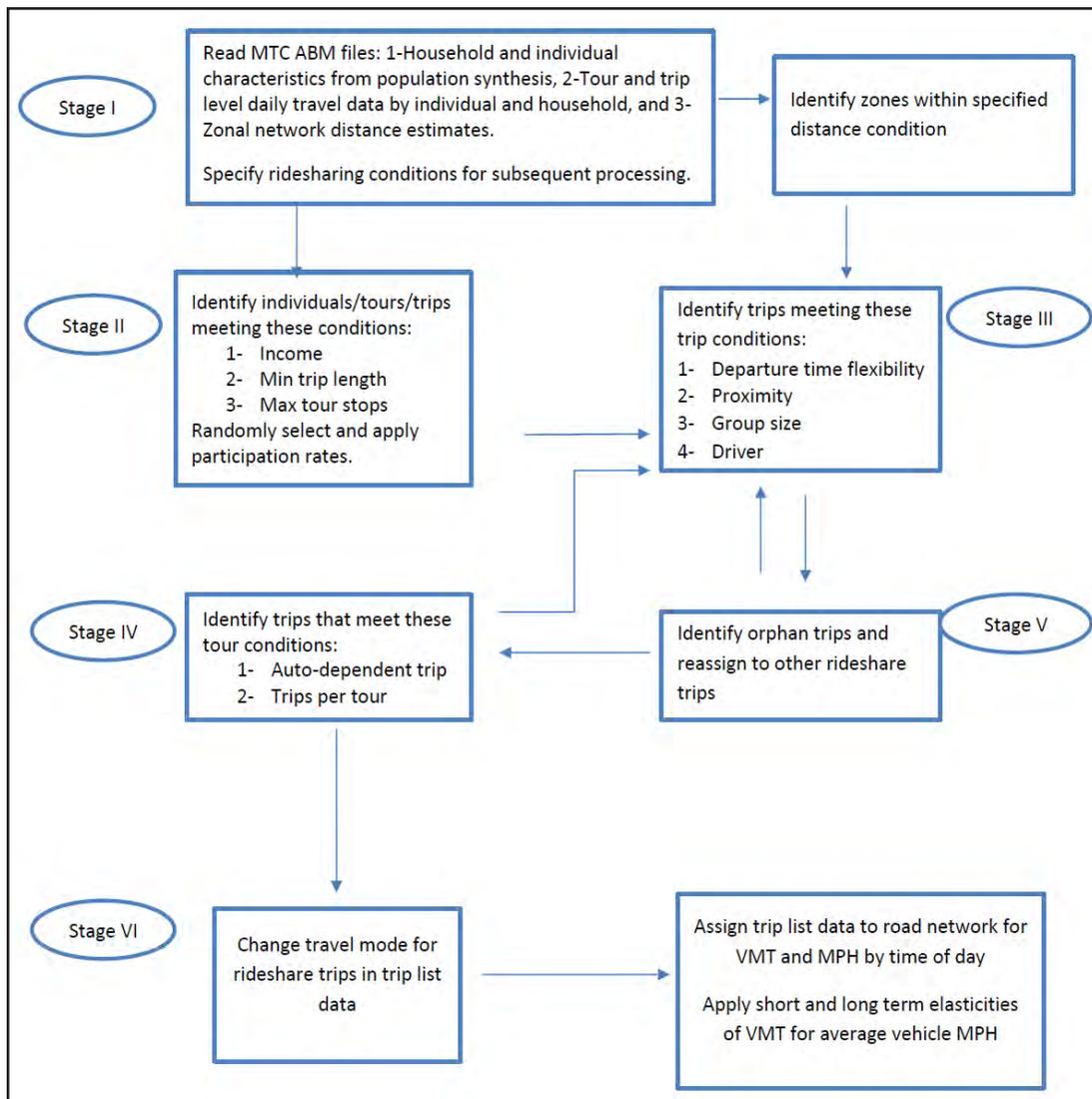
The program at this stage specifies the following global conditions for ridesharing:

1. Minimum and maximum number of travelers allowed in a ridesharing trip (*group size*),
2. The presence of one *driver* for each rideshare trip,

3. Maximum number of minutes a traveler is willing to wait to rideshare (*max departure time flexibility*),
4. The minimum trip distance required for a traveler to participate in a rideshare (*minimum trip length*)
5. The maximum percentage of ride-sharable trips (or trips that could be shared) within a tour required for a traveler to rideshare (*maximum ride-shareable trips per tour*),
6. Maximum number of stops allowed in a tour for a traveler to participate in a ride-share trip (*maximum tour stops*),
7. Maximum individual *income* required for a traveler to participate in ridesharing,
8. Rate at which travelers will rideshare given the ability to rideshare (*participation rate*), and
9. Maximum miles between trip origin zones of potential rideshares (*proximity*).

In the current study, the following conditions are fixed across all scenarios: maximum individual income (\$500,000), group size (2 to 5), driver (1), ride-sharable trips per tour (50%), and maximum tour stops (6). Sensitivity analyses of income, participation rate, trip length, origin proximity, and travel time flexibility are conducted as part of this study. Variable conditions in the dynamic ridesharing scenarios (maximum, moderate, and minimum use) include departure time, participation rate, and proximity.

Stage II identifies individuals with tours and trips that meet maximum income, minimum trip length, and maximum tour stops conditions. Then these individuals are randomly selected to rideshare based on specified participation rates. In stage III, the trips identified in stage II are evaluated to identify those who meet departure time flexibility, proximity, group size, and driver conditions. The MTC ABM currently uses one-hour departure time windows. As a result, the 2000 BATS survey is used to estimate the distribution of trip departures by 15-minute intervals by hour within each time period and by county. Trips within each hour from the model are then randomly selected and then assigned departure times within the hour based on weighting factors developed from this distribution. The resulting trips are then evaluated in stage IV against tour level conditions, including auto-dependent trip and trips per tour, to further refine ride-sharable trips. In stage V, the program identifies rideshare trips that lost a rideshare group (orphan trips) between stage III and stage IV. The program reassigns these trips to new ridesharing groups, as feasible, based on an iterative process among stage III, stage IV, and stage V. In stage VI, travel modes for ride-sharing trips are changed in the original input trip list. Finally, the revised trip list is assigned to the roadway network to estimate VMT and MPH by time of day that are adjusted, as described above, to represent long term elasticities.



**Figure 1. Diagram of ABM Post-Processing for DRS Scenarios**

As the previously mentioned literature review points out, there is currently very little evidence about the effect of the global conditions, used in the post-processing program, on the willingness to participate in DRS. The focus of this study is on the potential market and VMT reduction for DRS. The current study does not include the cost of participating in DRS; however, this is planned for future research. The sensitivity results for income, participation, trip length, proximity, and flexibility on key travel outputs (ride-sharable trips, weighted average speed, and long run VMT) are presented in Table 2. Ride-sharable trips are elastic with respect to participation rates and length of trips. However, all other travel results are inelastic with respect to variation of the other condition variables. As maximum individual income, participation, and flexibility increase, ride-sharable trips and average weighted speeds increase while VMT decreases. As the maximum miles between trip origin zones and the minimum trip distance increases, ride-sharable trips and average weighted speeds decrease while VMT increase.

**Table 4. Sensitivity Analyses and Elasticities of Travel for Condition Values**

Variable	Value	Ride-Sharable Trips	Weighted Average Speed	VMT (LR)
Income	\$50K, \$100K, \$150K, & \$500K	0.0342	0.0014	-0.0040
Participation	20%, 40%, 60%, & 100%	1.7011	0.0135	-0.0322
Trip Length	30, 20, 10, & 5 miles	-60.0523	-0.0360	0.0924
Proximity	5 & 10 miles	-0.0211	-0.0011	-0.0013
Flexibility	15 & 30 minutes	0.1069	0.0046	-0.0152

Note: Long Run (LR) Elasticity of VMT with respect to average vehicle MPH.

Three DRS scenarios were created in which DRS parameters were varied to represent minimum use, moderate use, and maximum use of the service. The parameters selected for these scenarios are described in Table 5. The authors did not vary income because the results of the sensitivity test indicated that participation and VMT were relatively less sensitive to this variable compared with other variables (with the exception of flexibility). Because the TOD scenario would affect proximity, the authors decided to include this in the scenario despite the relatively low elasticity values. The high and low scenarios are designed to be extreme use scenarios, and the moderate scenario is likely a conservative estimate of use of a dynamic ridesharing service with high quality region-wide service and affordable use costs.

**Table 5. Minimum, Moderate, and Maximum DRS Use Values**

Variable	Minimum	Moderate	Maximum
Participation	20%	50%	100%
Trip Length	30 miles	10 miles	5 miles
Proximity	1 mile	5 miles	15 miles
Flexibility	15 minutes	30 minutes	60 minutes

A post-processing program was developed in C to estimate the number of vehicles that could be replaced given BEV ranges of 50, 75, and 100 miles (80, 120, and 160 km) with and without the TOD and VMT fee policies. The individual and joint tour and trip list data from the MTC ABM are read into the program for processing. The program first identifies individuals whose daily vehicle travel is less than the specified BEV range from individual tour and trip list data. Next, the program uses the joint household tour and trip list data to determine whether the total daily vehicle miles for their households (which include individuals from the previous step) is less than the number of household autos multiplied by the specified BEV range. This is a conservative assumption that allows the possibility that an individual family member's daily vehicle travel may vary by day of the week.

## V. RESULTS

### DYNAMIC RIDESHARING SERVICES

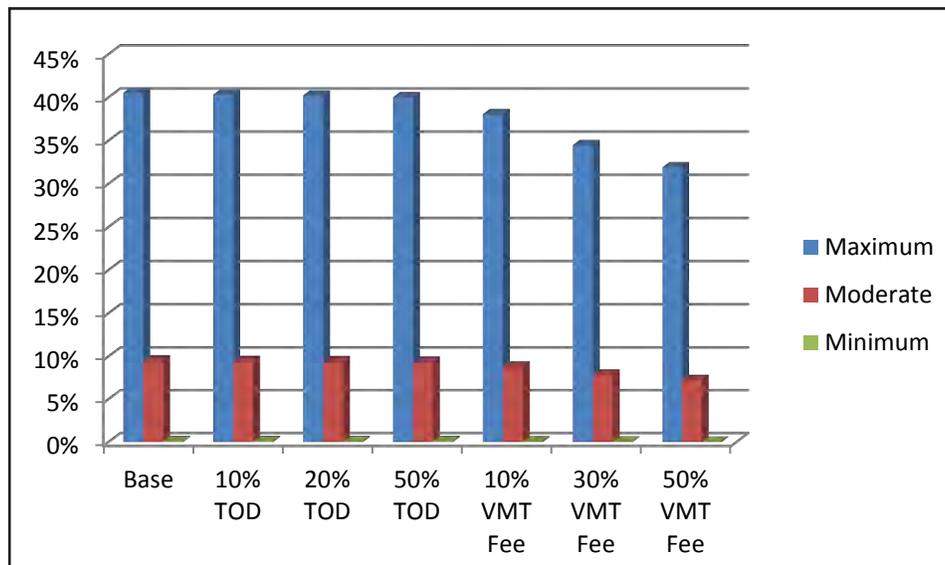
The share of ride-sharable trips relative to total trips in each scenario is presented in Table 6 and Figure 3. At maximum levels of ridesharing use, 32% to 41% of all trips are ride-sharable (or trips that can be shared given the specified conditions if a traveler decides to share it) across the policy scenarios. At minimum levels, less than 1% of all trips are ride-sharable. At moderate levels, 7% to 10% are ride-sharable. As discussed previously, the high and low scenarios are designed to be extreme scenarios that bookend the more moderate ridesharing use scenario.

Compared with the Base Case scenario, ride-sharable trips decline somewhat at higher levels of the TOD and VMT Fee policy scenarios across all levels of ridesharing use. In the TOD scenario, as land uses intensify around transit stations, transit, walking, and bike modes are better able to compete with the auto and rideshare travel. In the VMT Fee scenario, there is less auto travel and thus less potential for form rideshares.

It is important to note that the share of ride-sharable trips does not include induced travel effects, and thus this share may be under-estimated. Reduced auto travel times, due to increased ridesharing (as described below), would tend to induce more auto trips, which in turn could increase the potential for more rideshare trips.

**Table 6. Share of Ride-Sharable Trips Relative to Total Trips by Scenario**

Scenarios	Ridesharing		
	Maximum	Moderate	Minimum
Base	40.54%	9.56%	0.11%
10% TOD	40.33%	9.48%	0.11%
20% TOD	40.24%	9.46%	0.10%
50% TOD	40.03%	9.40%	0.10%
10% VMT Fee	38.07%	8.85%	0.09%
30% VMT Fee	34.49%	7.90%	0.07%
50% VMT Fee	31.92%	7.26%	0.06%

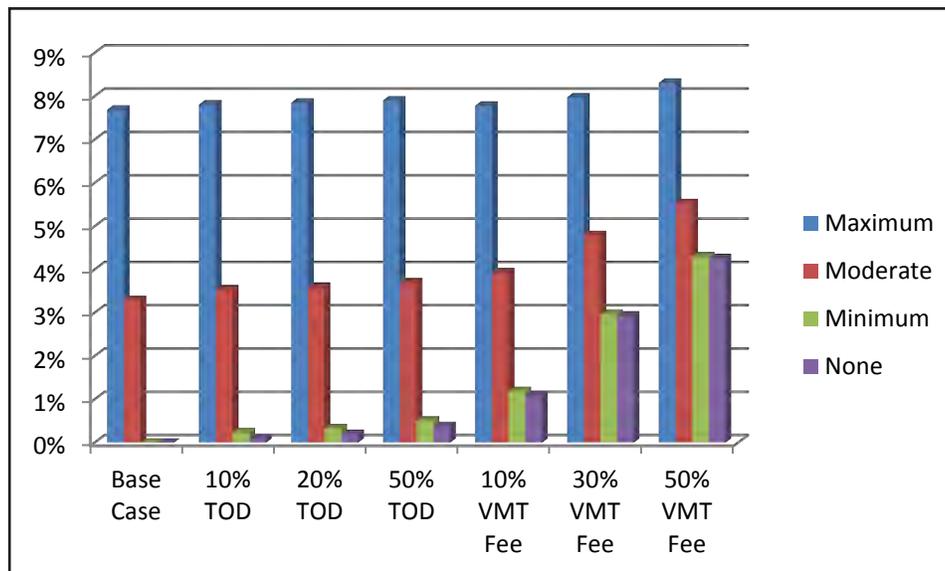


**Figure 2. Share of Ride-Sharable Trips Relative to Total Trips by Scenario**

In the ridesharing scenarios, daily average weighted speed (MPH), relative to the Base Case without ridesharing, increases by about 8% for maximum use levels, 3% to 6% at moderate use levels, and 0% to 4% for minimum use scenarios (Table 7 and Figure 3). There is greater variation in results across the VMT Fee scenarios relative to the TOD scenarios. Again, induced travel is not represented in these figures, and thus increased speeds are likely over-estimated.

**Table 7. Percentage Change in Daily Average Weighted Speed (MPH) Relative to the Base Case without Ridesharing for Policy Scenarios with and without Ridesharing**

Scenarios	Ridesharing			No Ridesharing
	Maximum	Moderate	Minimum	
Base Case	7.7%	3.3%	0.0%	0.0%
10% TOD	7.8%	3.5%	0.2%	0.1%
20% TOD	7.8%	3.6%	0.3%	0.2%
50% TOD	7.9%	3.7%	0.5%	0.4%
10% VMT Fee	7.8%	3.9%	1.2%	1.1%
30% VMT Fee	8.0%	4.8%	3.0%	2.9%
50% VMT Fee	8.3%	5.5%	4.3%	4.3%

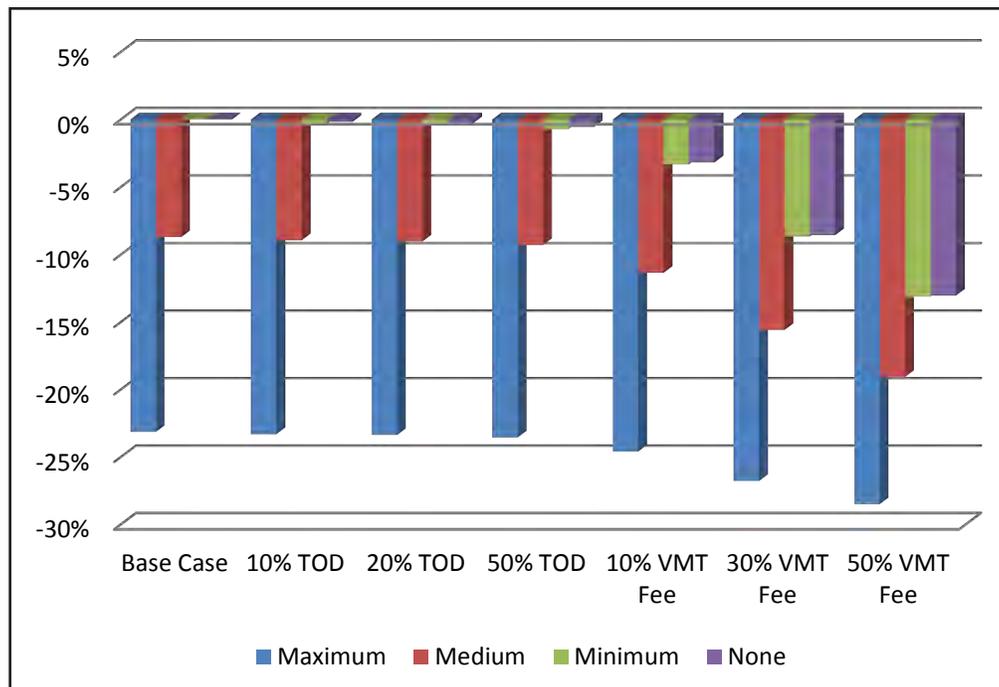


**Figure 3. Percentage Change in Daily Average Weighted Speed Relative to the Base Case without Ridesharing for Policy Scenarios with and without Ridesharing**

The VMT results, which include long-run induced travel effects, are shown in Table 8 and Figure 4. Reductions in VMT in the TOD scenarios relative to the Base Case are relatively small. This is not surprising in the San Francisco Bay Area, which already has relatively high levels of residential density and transit use compared with other regions in California and the U.S. On the other hand, VMT reduction for the VMT fee scenarios is comparatively large, ranging from 3% to 13% with long-run induced travel. Dynamic ridesharing added to the Base Case, TOD, and VMT Fee scenarios show reductions in VMT on the order of 9% to 30%. Modest synergistic effects are found for the low ridesharing scenario with the VMT pricing policies and for the high ridesharing scenario with lowest increase in the VMT Fee. The rest of the results are not synergistic (equals the sum of ridesharing with base and no ridesharing with TOD and VMT Fee scenarios) or less than synergistic (or less than that sum). Thus, in some scenario combinations, ridesharing competes for less travel and/or less effectively with transit, walking, and bike modes.

**Table 8. Percentage Change in Long Run VMT Relative to the Base Case without Ridesharing for Policy Scenarios with and without Ridesharing**

Scenarios	Ridesharing			No Ridesharing
	Maximum	Moderate	Minimum	
Base Case	-23.1%	-8.7%	0.0%	0.0%
10% TOD	-23.3%	-8.9%	-0.3%	-0.2%
20% TOD	-23.4%	-9.0%	-0.4%	-0.3%
50% TOD	-23.5%	-9.3%	-0.7%	-0.6%
10% VMT Fee	-24.6%	-11.3%	-3.3%	-3.2%
30% VMT Fee	-26.8%	-15.6%	-8.7%	-8.5%
50% VMT Fee	-28.5%	-19.1%	-13.1%	-13.0%



**Figure 4. Percentage Change in Long-Run VMT Relative to the Base Case without Ridesharing for Policy Scenarios with and without Ridesharing**

## BATTERY ELECTRIC VEHICLE SCENARIOS

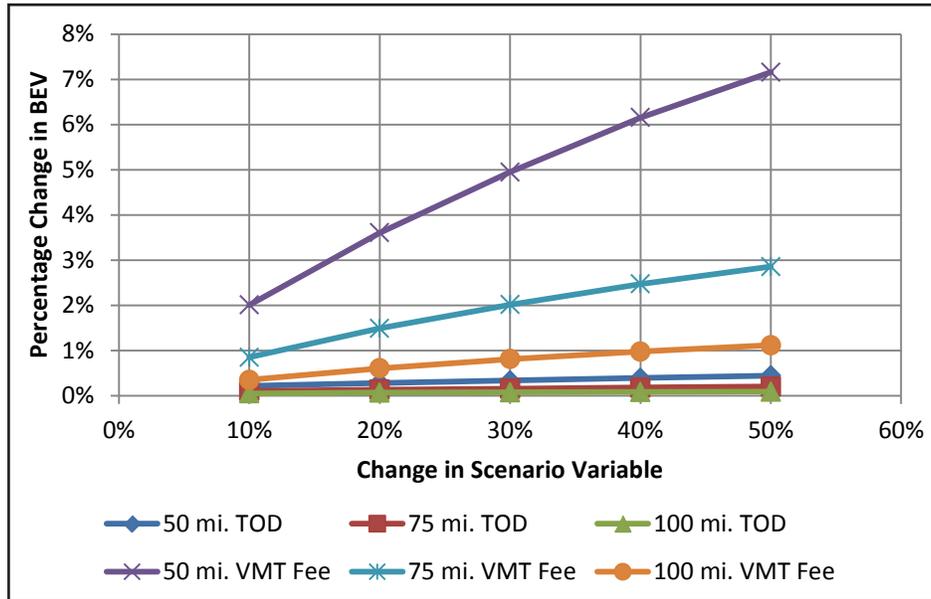
To gain insight into the potential effect of TOD and VMT Fees on the possible market for BEVs, the results of the Base, TOD, and VMT Fee scenarios were compared to understand the number of vehicles that travel within three daily range (50, 75, and 100 miles, or 80, 120, and 160 km) of currently available and reasonably affordable BEVs (Table 9 and Figure 5). Not surprisingly, the scenarios with the largest reduction in VMT produce the greatest increase in the potential market for BEVs. The increase in the market for BEV was less than 1% in the TOD scenarios. However, in the VMT scenarios, the increase in market share was as high as 7%. Again, larger changes in the BEV market may be realized in faster growing regions that shift from low-density sprawling development to focused development around transit stations (e.g., in California, the Central Valley).

**Table 9. Percentage Change in 2010 Market for BEV (Vehicles with Daily Travel of 50, 75, and 100 miles, or 80, 120, and 160 km) for TOD and VMT Fee Scenarios from Base Case**

Scenario	Daily Vehicle Range	50 miles	75 miles	100 miles
TOD	10%	0.22%	0.11%	0.05%
	20%	0.28%	0.14%	0.07%
	50%	0.44%	0.20%	0.09%

VMT Fee	10%	20%	30%	40%	50%
	10%	2.01%	0.85%	0.35%	
	20%	3.60%	1.49%	0.61%	
	30%	4.95%	2.01%	0.81%	
	40%	6.15%	2.47%	0.98%	
	50%	7.16%	2.86%	1.12%	

Note: Values for 30% and 40% were interpolated for the TOD scenario and 20% and 40% for the VMT scenarios.



**Figure 5. Percentage Change in 2010 Market for BEV  
(Vehicles with Daily Travel of 50, 75, and 100 miles, or 80, 120, and 160 km)  
for TOD and VMT Fee Scenarios from Base Case**

Note: Values for 30% and 40% were interpolated for the TOD scenario and 20% and 40% for the VMT Fee scenarios.

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## VI. CONCLUSIONS

This study uses the San Francisco Bay Area's Metropolitan Transportation Commission (MTC) ABM to explore the potential reduction in VMT and related GHG emissions from a regional dynamic ridesharing system at different levels of use. The results of this study suggest that dynamic ridesharing has the potential to significantly reduce VMT and related GHG emissions, which may be greater than land use and transit measures typically included in Sustainable Community Strategies (under California Senate Bill 375), if travelers are willing to pay with both time and money to use the dynamic ridesharing system. The combination of dynamic ridesharing with the TOD and VMT Fee scenarios suggest some policy combinations that may be more effective than dynamic ridesharing alone but perhaps more politically palatable. For example, a moderately used regional dynamic ridesharing with 10% increase in VMT fees may produce reductions in VMT on the order 11% compared with a business-as-usual scenario in one horizon year. However, in general, large synergistic effects between ridesharing and transit-oriented development or auto pricing policies were not found in this study.

To gain insight into the potential effect of TOD and VMT Fees on the potential market for BEVs, the results of the Base, TOD, and VMT Fee scenarios were compared to understand the number of vehicles that travel within three BEV ranges (50, 75, and 100 miles, or 80, 120, and 160 km). The VMT fee scenarios showed the greatest potential for market growth, while the TOD scenario showed a small potential. Again, larger changes in the BEV market may be realized in faster growing regions that shift from low-density sprawling development to focused development around transit stations.

Future research should explore the factors associated with higher dynamic ridesharing and BEV use including individual attributes, characteristics of tours and trips, and time and cost benefits. In addition, the travel effects of dynamic ridesharing systems should be simulated explicitly, including auto ownership, mode choice, destination, and extra VMT for passenger pick-up.

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## ABBREVIATIONS AND ACRONYMS

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ABM	Activity-Based Microsimulation Travel Demand Model
Base Case	Business-as-Usual Scenario
BEV	Battery Electric Vehicles
CT-RAMP	Coordinated Travel-Regional Activity Modeling Platform
DRSs	Dynamic Ridesharing Services
GHG	Greenhouse Gas
LR	Long Run
MPH	Vehicle Miles per Hour
MTC	San Francisco Bay Area Metropolitan Transportation Commission
SCS	Sustainable Community Strategies
TOD	Transit-Oriented Development Scenario
VMT	Vehicle Miles Traveled
VMT Fee	Auto Pricing Scenario

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## ENDNOTES

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## ABOUT THE AUTHORS

### **CAROLINE RODIER, PH.D.**

Dr. Caroline Rodier is a research associate at the Mineta Transportation Institute and the associate director of the Urban Land Use and Transportation Center and a research scientist at the Institute of Transportation Studies, University of California, Davis. Her major areas of research include transport, land use, and environmental planning and policy analysis. Dr. Rodier has extensive experience applying land use and transport models to inform public investment, planning, and policy decisions. She has managed the development activity-based microsimulation travel models for the State of California and the San Joaquin Valley as well as the California's PECAS land use model. Dr. Rodier has expertise in the design and implementation of research projects that routinely make use of expert and stakeholder interviews, focus groups, and travel behavior surveys. This research has been conducted in a variety of contexts including parking information and pricing technologies pilot projects (most recently SFpark); shared-use modes to facilitate first- and last-mile access to transit; travel needs and mobility solutions for diverse populations in California (e.g., elderly and immigrants); traffic safety impacts of Variable Message Signs; and the scoping plan for California's landmark climate change legislation, Assembly Bill 32. Dr. Rodier has also conducted reviews of legal and institutional challenges in the areas of automated speed enforcement, low-speed modes (e.g., Segways and neighborhood electric vehicles), and the provision of public parking for carsharing services. Most recently, Dr. Rodier led the development of the content for scenario activities used in the workshop on Automated Vehicles within the Built Environment: 2020, 2035, and 2050 at the Automated Vehicle Symposium 2014 and 2015. She currently serves at the chair of the Transportation Research Board's Emerging and Innovative Public Transport and Technologies Committee. She holds a B.A. in US History from Barnard College at Columbia University and an M.S. in Community Development, and a Ph.D. in Ecology from the University of California, Davis.

### **FARZAD ALEMI**

Farzad Alemi is a third-year Ph.D. student at the University of California, Davis, Institute of Transportation Studies (ITS). He is interested in various transportation and land-use related topics, particularly travel demand modeling, land-use modeling, travel behavior, traffic engineering, and sustainable transportation. Prior to coming to UC Davis, he completed his MSc in Urban and Regional Planning (University of Greenwich, 2009-2010). Before that, he received his BSc in Civil and Environmental Engineering from Iran University of Science and Technology (2009). He is currently working on research projects to quantify/explore the effects of new technology-enabled transportation alternatives on future mobility.

### **DYLAN SMITH**

Dylan Smith is a software developer based in the San Francisco Bay Area. He is a recent graduate from the University of California, Davis. Holding a bachelor's degree in computer science, he is primarily interested in computer science and its applications in transportation engineering. During his undergraduate career, he worked at the Institute of Transportation

Studies (2014-2015) and in an on-campus civil engineering research position (2013-2015), where he developed software to help explore the feasibility of ride-sharing in the Bay Area and the interactions between dynamically-routed vehicles and traffic lights. He is currently helping to found a transportation-focused startup in the Bay Area.

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