How Can Automated Vehicles Increase Access to Marginalized Populations and Reduce Congestion, Vehicle Miles Traveled, and Greenhouse Gas Emissions? A Case Study in the City of Los Angeles

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Caroline Rodier, University of California, Davis
Ihab Kaddoura, Technical University of Berlin
Huajun Chai, University of California, Davis

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7. Author(s)
Caroline Rodier, Ph.D., https://orcid.org/0000-0002-9107-5547
Ihab Kaddoura, Ph.D., https://orcid.org/0000-0002-0940-2255
Huajun Chai, Ph.D., https://orcid.org/0000-0001-8067-9129

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16. Abstract

The research team used the Los Angeles MATSim model to evaluate the travel, greenhouse gas (GHGs), and equity impacts of single- and multiple-passenger automated taxi scenarios, including free transit fares and a VMT tax. The results indicate that automated taxis increase VMT by about 20 percent across scenarios, and automated taxis mode shares more than offset reductions in personal vehicle travel. The automated taxi-only scenario also reduces transit travel by about 50 percent, but the addition of free transit fares reversed this decline and increased transit use somewhat. New empty passenger automated taxi travel compounds the impact of mode shifts in these scenarios and further increases vehicle travel. There is a slight change in mean vehicles speeds across all scenarios. When automated taxis are not battery electric vehicles (BEVs), GHG emissions increase from 16 to 18 percent across scenarios. However, GHGs decline by 23 to 26 percent when automated taxis are BEVs. The equity analysis shows that the automated taxis scenarios provide more accessibility benefits for travelers in three low-income classes than total benefits and benefits for the middle- and high-income travelers. The addition of free transit to the shared automated taxis-only scenario dramatically increases low-income benefits. The VMT tax eliminates almost all of the benefits from the automated taxi and free transit scenarios and creates losses for all three low-income groups.

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Automated vehicles; ridehailing; pooled ridehailing; free transit; distance-based road charges; travel and equity impacts

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TABLE OF CONTENTS

List of Figures

How Can Automated Vehicles Increase Access to Marginalized Populations and Reduce Congestion, Vehicle Miles Traveled, and Greenhouse Gas Emissions? A Case Study in the City of Los Angeles

EXECUTIVE SUMMARY

This study explores how automated vehicles might increase access to marginalized populations and reduce congestion, vehicle miles traveled (VMT), and greenhouse gas emissions (GHGs). We evaluate this question in the Westside Cities area in Western Los Angeles County with a dynamic agent-based model (MATSim). Small urban areas within major urban regions, like the Westside Cities, may be candidates for early deployment of automated vehicles because of high travel volumes, well-maintained roads, and temperate weather conditions. For example, like many other major urban areas, the City of Los Angeles faces high levels of roadway congestion and poverty (slightly less than 1 in 5 residents live in poverty according to the 2019 US Census).

A review of the literature shows that privately owned automated vehicles and shared automated vehicles (with one or more passengers) are likely to increase vehicle travel. Automated vehicles will be faster because of reduced vehicle headways, parking search time, and more enjoyable for drivers because they can engage in other activities. These new benefits may entice all but the most transit-dependent low-income riders from using transit outside the urban core. In addition, automated vehicles can travel without a passenger, for example, to pick up other passengers or return a vehicle home, increasing vehicle travel.

The study uses the Los Angeles MATSim model to evaluate policies scenarios. The open-source travel model was developed specifically for this study and is available for use at the following website: https://github.com/matsim-scenarios/matsim-los-angeles. We developed and calibrated the LA MATSim model with data from the Los Angeles Metropolitan Planning Organization’s current activity-based travel demand model. This data included person-specific travel plans corresponding to person-specific socio-economic attributes, travel-related cost assumptions (e.g., auto operating and parking costs), and roadway traffic volumes. In addition, we obtained roadway networks from OpenStreetMap and transit networks from GTFS (or the general transit feed specification).

Using the LA MATSim model, we simulated the following policies.

1. Automated taxis: We simulate a single-passenger automated taxi service with a minimum fare of $4 and a distance-based fare of $0.55 per mile. We also simulate a multiple-passenger automated taxi service that allows up to four people to share a ride with a minimum fare of $2 and a distance-based fare of $0.15 per mile. We base fare values on a previous review conducted by the authors. Automated taxis service is a door-to-door service for trips inside the Westside Cities area. It also provides access and

egress travel to public transit inside the Westside Cities. The GHG impacts of automated taxis assume electric and conventional gas vehicles.

2. Free transit: We simulate free transit by reducing the daily cost of transit from $7 in the base case scenario to $0.
3. VMT Tax: We simulate the VMT tax policy by doubling the distance-based fee for personal vehicle travel ($0.16 per mile) in the base case scenario to $0.32 per mile.

We simulated three scenarios: automated taxis only, automated taxis plus free transit, and automated taxis plus free transit and the VMT tax. The results indicate that automated taxis increase VMT by about 20 percent across scenarios, and the increase in automated taxi mode shares more than offset reductions in personal vehicle travel. In addition, the automated taxi scenario reduced transit travel by about 50 percent. However, the addition of free transit fares reversed this decline and increased transit use by about eight percent, and the VMT tax further increased transit travel by 51 percent. Finally, new empty passenger automated taxi travel compounds the impact of mode shifts in these scenarios and further increases VMT.

Regarding congestion, we see a slight reduction in mean vehicles speeds (2%) in the shared automated vehicle scenario. However, the addition of the free transit and then the VMT tax policies to the automated taxi scenario increases mean vehicle speeds by one percent and three percent, respectively, because of smaller increases in vehicle trips and VMT. Overall congestion impacts are minor.

When automated taxis are not battery electric vehicles (BEVs), GHG emissions increase from 16 to 18 percent across scenarios due to changes in vehicle travel. However, GHGs decline from 23 to 26 percent when automated taxis are BEVs.

The equity analysis shows that the automated taxi scenario provides significantly more accessibility benefits for travelers in three low-income classes than total benefits and benefits for the middle- and high-income travelers. The three low-income categories are below the City of Los Angeles' median income and based on different household sizes and income combinations. The extremely low-income category receives the most significant increase in low-income benefits. The addition of free transit to the automated taxi scenario dramatically increases the benefits for extremely low-income travelers. However, the VMT tax eliminates almost all of the benefits from the automated taxi and free transit scenario and creates losses for all three low-income groups. The middle- to high-income group benefit somewhat from this scenario, and total benefits are unchanged from the base-case scenario.

The results of this study have important implications for current transportation planning. First, transit service is essential to low-income travelers, and free transit fare policies for low-income travelers can significantly improve disparities in access between higher and lower-income travelers. Second, a distance-based VMT tax will negatively impact low-income travelers. Road pricing measures should be waived for low-income travelers or reinvested in easy-to-access programs that provide free or reduced-cost transit, microtransit, or ridehailing. Third, automated taxis (and by extension, low-cost ridehailing, and microtransit services) will tend to increase vehicle travel without a very significant road user charge (i.e., much larger than the doubling of distance-based costs for personal vehicles in this study). The size of such a road pricing policy may face strong opposition from the public. Finally, public policies should require zero-emission technology in automated vehicles in the long term and transit and ridesharing vehicles in the near term.

1. Introduction

This study explores how automated vehicles might increase access to marginalized populations and reduce congestion, vehicle miles traveled (VMT), and greenhouse gas emissions (GHGs). This policy question is evaluated in the Westside Cities area in Western Los Angeles (LA) County (see Figure 1 below) with a dynamic agent-based model (MATSim, Multi-Agent Transport Simulation, see www.matsim.org), which is well-suited to simulating shared automated vehicles. Small urban areas within major urban regions, like the Westside Cities, may be candidates for early deployment of automated vehicles because of their high travel volumes, well-maintained roads, and temperate weather conditions. For example, like other major urban areas, the City of LA faces high levels of roadway congestion and poverty (slightly less than 1 in 5 residents live in poverty according to the 2019 US Census). Recent planning efforts to curb auto travel and GHG emissions in the City include enhanced transit service (possibly funded by freeway tolls in carpool lanes) and shared mobility (e.g., micro-transit, bikesharing, and carsharing). Policies to increase access to low-income residents include free transit fares during the COVID19 pandemic, discounted electric carsharing (i.e., BluLA), and low-cost on-demand ridesharing services (i.e., Metro Micro rides for $1).

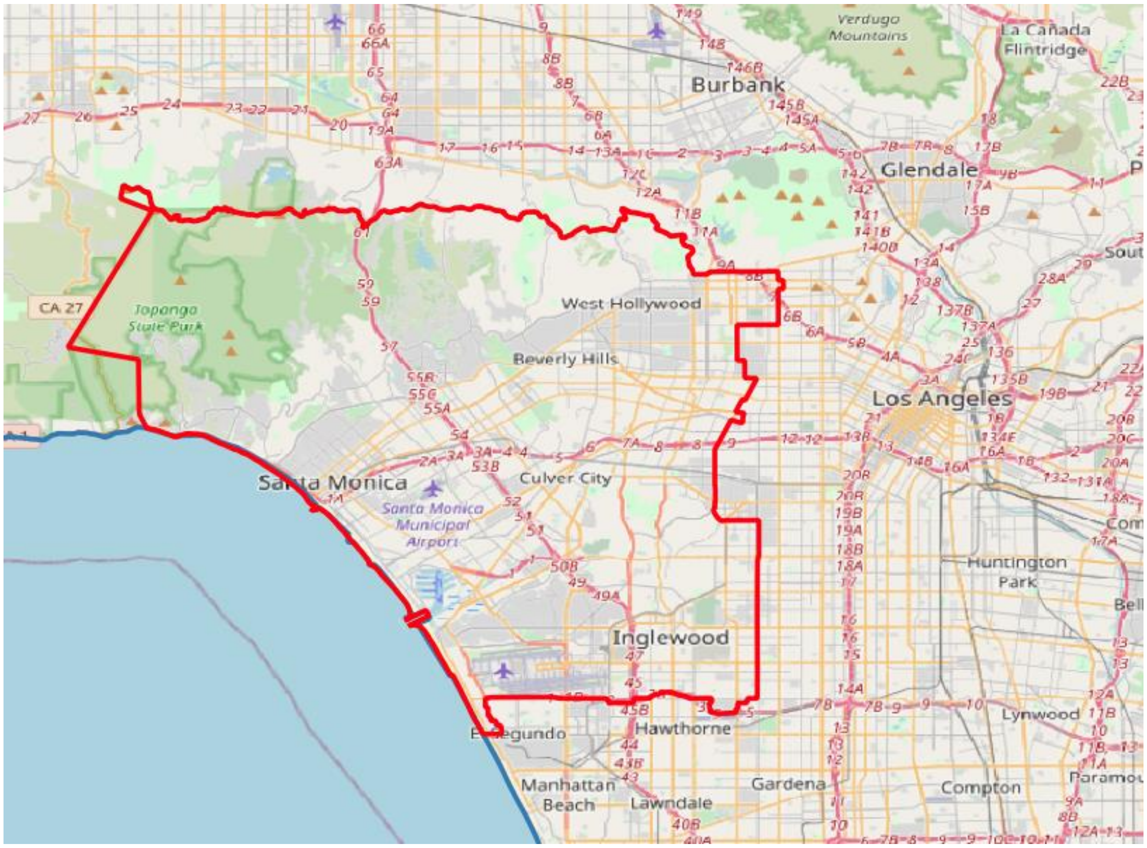

Figure 1. Westside Cities in Los Angeles, California (Background map: © OpenStreetMap contributors).

2. Literature Review

Studies show that privately owned automated vehicles and shared automated vehicles (with one or multiple passenger(s)) are likely to increase vehicle travel. Automated vehicle travel will be faster because of reduced vehicle headways, and parking search time, and more enjoyable for drivers because they can engage in other activities (Rodier et al., 2018; Rodier, 2018; Maciejewski and Bischoff, 2016; Fagnant and Kockelman 2018; Moreno, 2018). These new benefits may entice all but the most transit-dependent low-income riders from using transit outside the urban core (Rodier et al., 2018; Bösch et al., 2018). Without significant subsidies, agencies could reduce or eliminate transit services. In central urban areas, travelers may take an automated vehicle rather than walk or bike. Automated vehicles can travel without a passenger, for example, to pick up other passengers or return a vehicle home, which would also increase VMT. Recent California legislation (Senate Bill 500) addresses the future climate change impact of widespread adoption of automated vehicles by requiring that automated vehicles be emission-free by 2030 (Hawkins, 2021).

Some solutions to the potential downsides of vehicle automation may be pricing policies that increase the cost of driving (e.g., VMT tax or congestion pricing) and that reduce the cost of transit use or other shared mobility modes (e.g., free or reduced fares) (Rodier et al., 2018; Gurumurthy et al., 2019; Simoni et al., 2019). Depending on the traveler and the trip, one or both these policies may discourage automated vehicle travel. In addition, shared automated vehicles with one or more passengers could provide first-and last-mile service to high-quality transit rail in urban areas to reduce the overall time and monetary costs of traveling by transit relative to automated vehicles (Rodier et al., 2020, Huang et al., 2021). Finally, shared automated vehicles with multiple passengers could provide services similar to microtransit but at lower costs due to avoided driver labor costs (Bösch et al., 2018).

3. Methods

3.1 The MATSim Framework

We use the agent-based and dynamic transport simulation framework MATSim (Multi-Agent Transport Simulation). See Horni, Nagel, and Axhausen (2016) for detailed model documentation. MATSim is an open-source model programmed in Java and available from GitHub. The model simulates travel for cities and regions using local transportation networks and travel demand. Its framework facilitates large-scale simulations by implementing queue-based network loading rather than car-following behavior in the dynamic routing model. The model uses a co-evolutionary algorithm that allows individuals (or agents) to try new travel choices, which, in addition to route, include departure time and mode choice. Through an iterative process, agents interact while driving on the roadway network across space and time to optimize their daily travel plan. A “score” measures the degree to which a travel plan optimizes activity or trip characteristics, which can be interpreted as economic utility.

Figure 2 illustrates the generalized modeling process of the MATSim model framework. Initial demand includes all trips made by a person over a typical 24 hour period. Trip information includes departure and arrival times, travel mode, purpose, origin, and destination location. Person-specific socio-demographic attributes can also be linked to travel plans. During the execution step, all individuals and vehicles are loaded onto the transportation system network in second-by-second time increments to accomplish their travel plans. The score of an executed plan will decrease when individuals spend more time and money traveling to activities rather than engaging in them. The replanning step allows individuals to modify their plans and improve their scores by changing travel time of day, mode, and route. The iterative process ends when the average population score stabilizes.

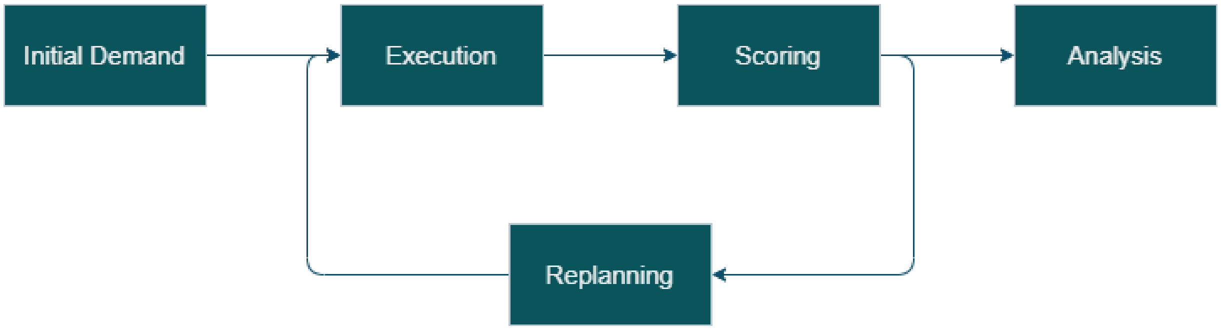

Figure 2. The MATSim Framework (reproduced from Horni, Nagel, and Axhausen 2016).

3.2 The LA County MATSim Model

The LA County MATSim model developed for this study is open-source and available at the following website for anyone to use: https://github.com/matsimscenarios/matsim-los-angeles. As described in Figure 3 below, we used multiple data sources to develop the LA County MATSim model. The Southern California Association of Governments' (SCAG) current activity-based travel demand model was the source of person-specific travel plans corresponding to person-specific socio-economic attributes, including household income, household size, ethnicity, gender, employment, educational attainment, and access to personal vehicles. We obtained roadway networks from OpenStreetMap and transit networks from GTFS (or the general transit feed specification) provided by the local public transit services. Finally, we obtained other travel-related cost assumptions from the SCAG model (e.g., auto operating and parking costs).

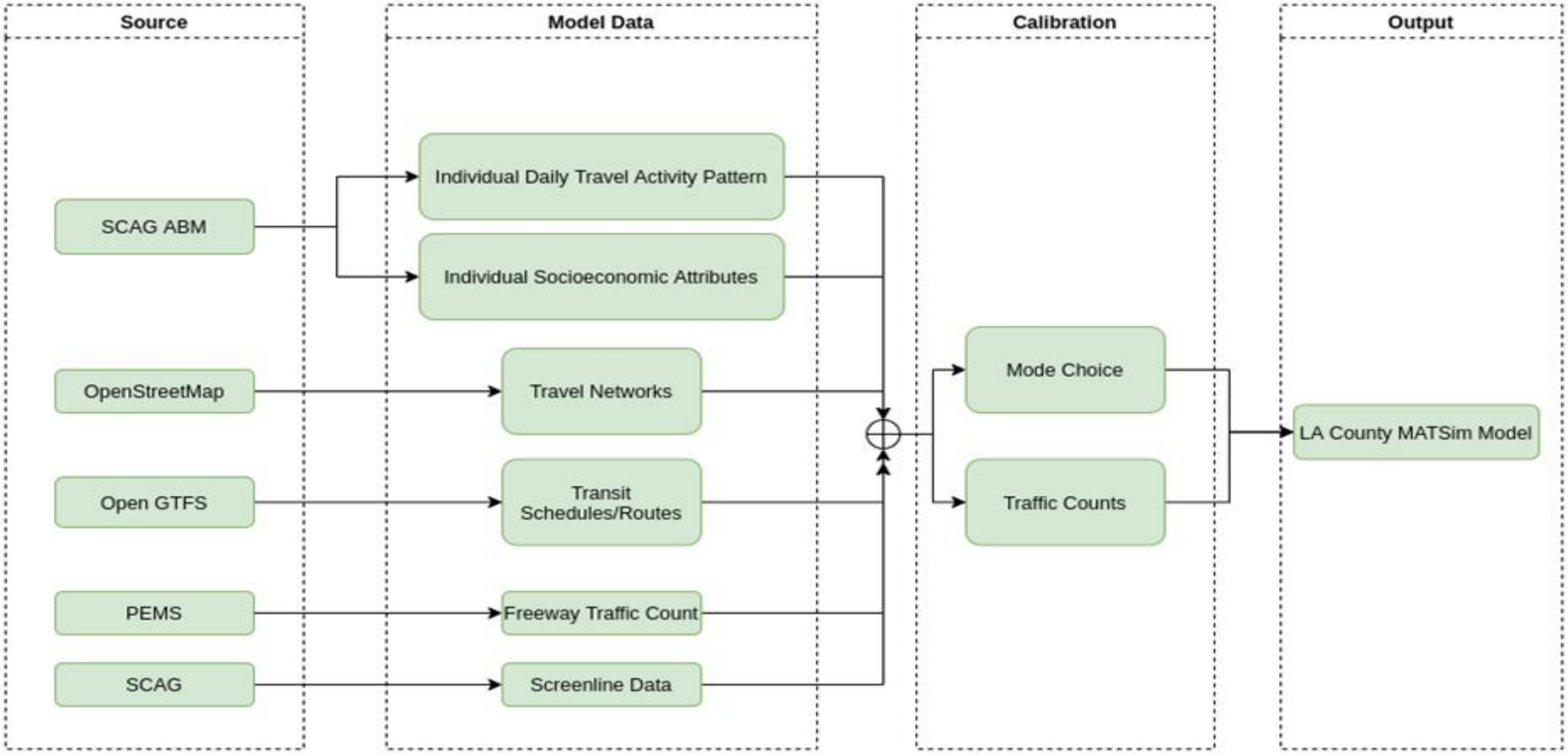

Figure 3. Calibration of the LA County MATSim Model

We calibrated the LA County MATSim model's base case to reasonably match base-case mode choice estimates from the SCAG model and base-case traffic count data from the California Department of Transportation's Performance Measurement System (PeMs) database and the SCAG model calibration dataset. The focus of calibration efforts was on examining individual scoring parameters, adjusting parameters, and refined variables to improve model calibration. Figure 4 illustrates highway (red) and local (blue) traffic count stations.

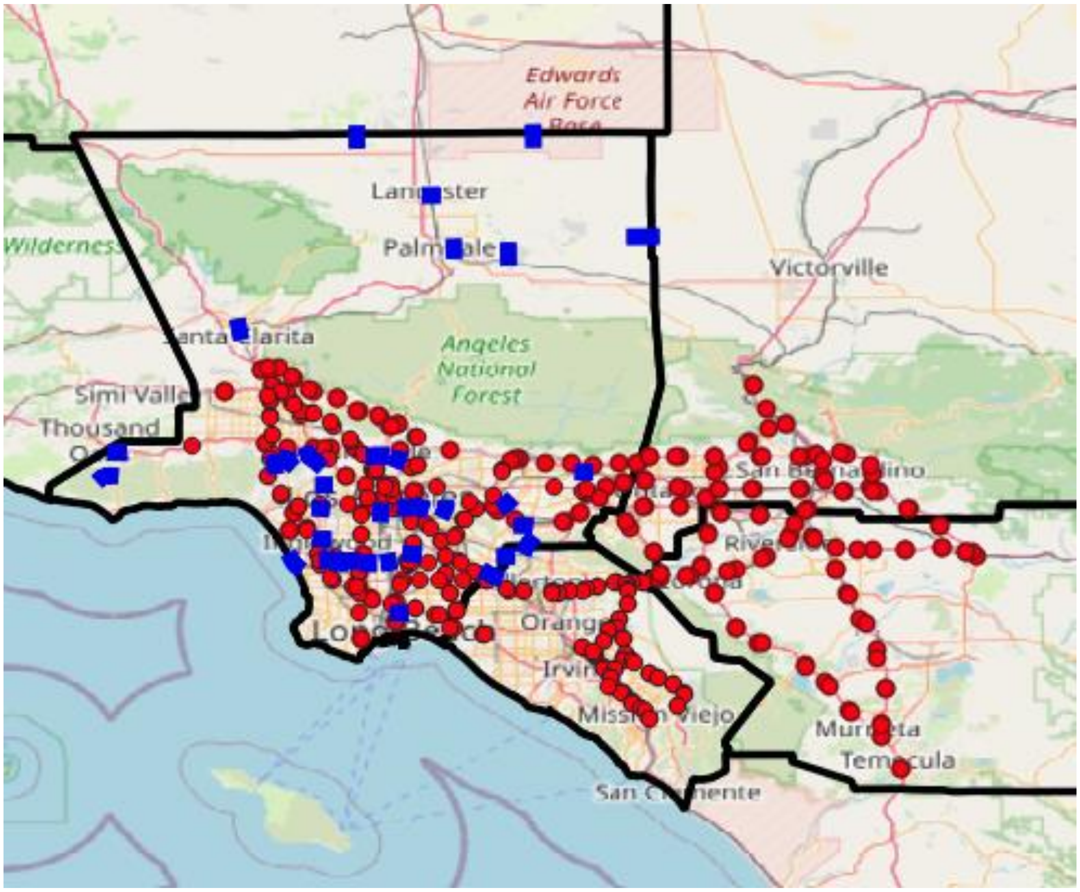

Figure 4. Traffic Count Stations for the Calibration of LA MATSim (Background map: © OpenStreetMap contributors).

3.2.1 Parameters and Variables

Calibrated parameters include mode-specific constants, the marginal utility of time spent traveling by mode, and the marginal utility of money. The marginal utility of time and money is specific to individual travelers based on the continuous household income data from the SCAG model dataset. We based the mode-specific monetary distance rates by mode on SCAG model values (e.g., about 16 cents per mile for gas for a personal vehicle). Model estimates are based on travel time and distance values by mode for each trip.

We include constant daily monetary costs for transit and car ownership. For transit, we use an average value of $7, which represents the cost of a daily transit pass for the base case. We use the daily fare because it was difficult to estimate an average transit fare for all the different transit services provided in the Westside Cities area. To represent the potential cost savings of giving up a personal vehicle in the automated taxi scenarios, we use the average perceived fixed daily cost of $15.47 for car ownership (or $480 per month). Like most travel models, MATSim uses a 24-hour framework, and this adjustment was a practical way to implement the personal vehicle savings from using automated taxis.

To represent the time savings from avoided parking search time and walk access and egress, we included time penalties for non-work and non-home activities accessed by private vehicles (excluding drop-offs rides). We used an average parking search time of 12 minutes and an average walk time of 6 minutes access or egress from parking to the final destination. The LA MATSim model uses average parking cost (first hour, extra hour and maximum per day) from SCAG model data.

3.2.2 Simulation of Automated Taxis

We simulate automated taxis with modules available from the MATSim model framework (Weekly release 13.0-2020w24). These include the Dynamic Vehicle Routing Problems module or DVRP contribution (Maciejewski and Bischoff 2016; Maciejewski et al. 2017) and the Demand Responsive Transit module or the DRT service (Bischoff et al. 2018). The modules simulate shared automated vehicles with one or more passengers (or automated taxis) ordered on-demand through a smartphone or computer. Inside the study area, the model dispatches automated taxis to the pick-up location and drops off passengers at their final destination. In addition, the model diverts multi-passenger automated taxis to pick up other passengers as long as the diversion does not increase direct travel time by more than 70% plus two minutes and the waiting time is less than five minutes (Bischoff et al., 2017).

The size of the automated taxi fleet is dynamically re-adjusted to keep 90% of all wait times below 10 minutes (single-passenger) and 15 min (multiple-passenger) using a novel approach developed by Kaddoura et al. (2020), which significantly reduced scenario run times and guarantees a constant service quality for different demand levels throughout the iterative simulation process. Initially, the model randomly distributes the automated taxis within the service area. Then, vehicles remain on the link where the last drop-off took place in the prior iteration in each iteration. Vehicles do not return to depots, and there is no vehicle rebalancing. We set the pick-up and drop-off time to one minute. Automated taxis interact with other automated taxis and private vehicles.

As described above, the MATSim framework is well suited to simulate automated taxis because of its dynamic framework and existing modules available in MATSim to simulate automated taxis without developing additional code. In addition, the LA MATSim model represents how all three policies described above affect individual travel time of day, mode, and route choices; however, it does not represent higher-level effects on destination choice or discretionary trips. As a result, scenarios that reduce travel time and cost will tend to underestimate vehicle travel and GHG emissions, and scenarios that increase travel time and cost will overestimate vehicle travel and GHG emissions.

3.2.3 Operation

The LA County MATSim model described above represents travel that begins and ends in LA County and from the greater SCAG region that begins, ends, or passes through LA County. Since the focus of this study was the Westside Cities area, we limited the representation of travel demand to all travel that begins and ends in the Westside Cities and travel from the greater SCAG region that ends, begins, or passes through the Westside City area.

Even with the limited geography described above, the travel volume included in the simulation proved to be computationally time-consuming, even on a server with 12 cores and 120 GB memory. We used a one percent population sample for the scenario simulations to address this problem. The MATSim simulator has a built-in flow capacity factor and storage capacity factor, adjusting link flow capacities and storage capacities given the population sample size. This mechanism ensures that the simulated traffic pattern with a reduced population sample is a realistic and accurate representation of travel activity (Llorca and Moeckel, 2019). However, even with this approach, the base case scenario simulation took four days and 12 hours.

4. Scenarios

As described above, we simulate three policies with the LA MATSim model.

1. Automated taxis: We simulate a single-passenger automated taxi service with a minimum fare of $4 and a distance-based fare of $0.55 per mile. We also simulate a multiple-passenger automated taxi service that allows up to four people to share a ride with a minimum fare of $2 and a distance-based fare of $0.15 per mile. We base fare values on the Rodier et al. (2020) review. Automated taxis service is a door-to-door service for trips inside the Westside Cities area, and it provides access and egress travel to public transit inside the Westside Cities. We calculate GHG impacts with and without electric automated vehicles.
2. Free transit: We simulate free transit by reducing the daily cost of transit from $7 in the base case scenario to $0.
3. VMT Tax: We simulate the VMT tax policy by doubling the distance-based fee for personal vehicle travel ($0.16 per mile) in the base case scenario to $0.32 per mile.

These policies are simulated in different combinations, as described in Table 1 below.

Table 1. Scenarios simulated with the LA MATSim model.

Scenario	Single-Passenger Automated taxi fare	Multiple-Passenger Automated taxi fare	Transit Cost	Personal vehicle VMT tax
Base Case	None	None	\$7.00/day	None
Automated Taxis	\$0.55/mile Minimum \$4	\$0.15/mile Minimum \$2	\$7.00/day	None
Free Transit & Automated Taxis	\$0.55/mile Minimum \$4	\$0.15/mile Minimum \$2	\$0.00	None
VMT Tax, Free Transit & Automated Taxis	\$0.55/mile Minimum \$4	\$0.15/mile Minimum \$2	\$0.00	\$0.16/mile

5. Results

5.1 Travel

The figures below show total percentage point change (Figure 5) and relative percentage change (Figure 6) in daily trip mode choice (or shares) for the alternative scenarios compared to the base case scenario for travel that begins and ends inside the Westside Cities study area. Along the horizontal access, we group travel results by scenarios. The “Auto-Taxi” scenario is the automated taxi scenario that includes both single- and multiple-passenger services. The "+Free Transit” scenario adds free transit fares to single- and multiple-passenger automated taxi scenario. The “+VMT Tax” scenario introduces a VMT tax (doubles existing operational costs) to the free transit with single- and multiple-passenger automated taxi scenario. We list the vehicle travel outcomes at the bottom of the figure.

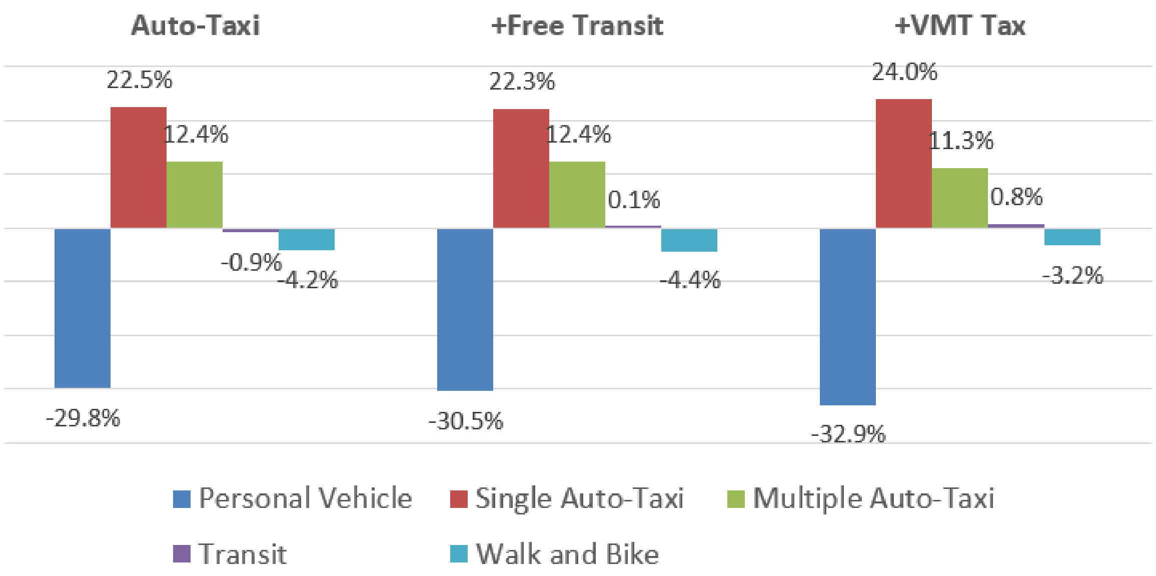

Figure 5. Total Mode Share Change (Percentage Point) from the Base Case

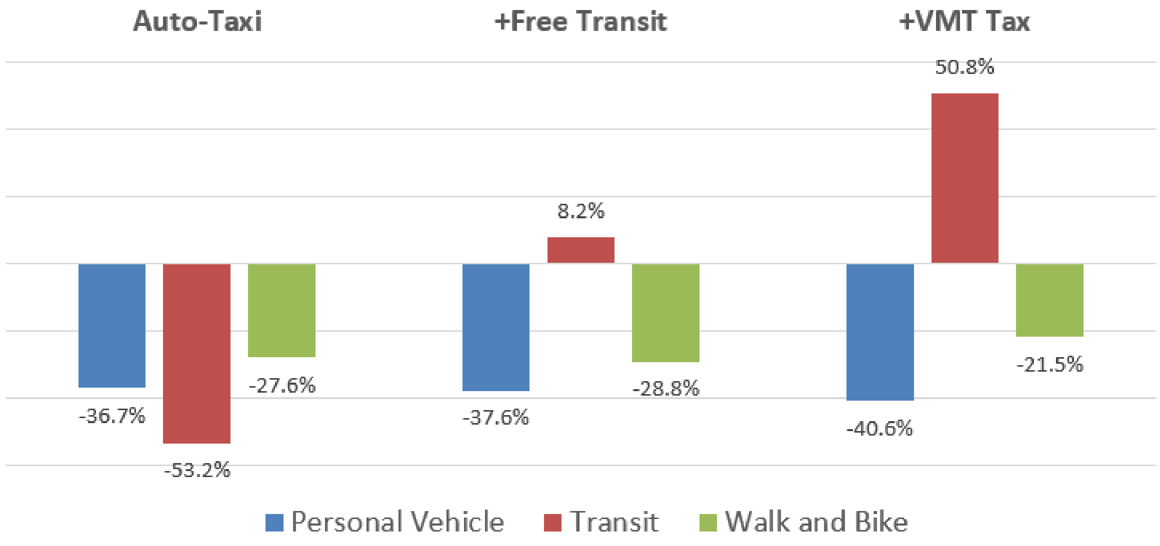

Figure 6. Relative Model Share Change (Percentage Change) from the Base Case

The time and cost attributes of the new automated taxi services (Auto-Taxi) produce a mode share of about 35% for both the single- and multiple-passenger automated taxis. About two-thirds belong to the single-passenger automated taxis mode and about one-third to the multi-passenger automated taxis mode. The new mode share for automated taxis draws significantly from personal vehicles (29.8 percentage points) and less significantly from transit (0.9 percentage points) and walk and bike modes (4.2 percentage points). While the total value of transit and walk and bike mode shifts are small, the relative reductions are large compared to the base case. Transit mode share declines by over half (53%), and walk and bike mode share decreases by almost a third (28%).

However, when we add free transit fares to the automated taxi scenario (+Free Transit), transit ridership rebounds, and the increase in the transit share compared to the base case is 8.2 percent. The free fares have little impact on the automated taxis share, which differ by only -0.2 percentage point. The free transit scenarios attract riders mainly from the personal vehicle mode (-1.7 percentage point) and walk and bikes mode (-0.2 percentage point) compared to the automated taxi scenario.

When we added the 16 cents per mile personal vehicle travel tax to the free transit and automated taxi scenario (+VMT Tax), personal vehicle and multiple-passenger automated taxis mode shares decline by 2.4 and 1.1 percentage points, respectively, and single-passenger automated taxis, transit, and walk and bike mode shares increase by 1.7, 0.7, and 1.1 percentage points, respectively. Overall, in the +VMT Tax scenario, more trips are made by automated taxis, transit, and walk and bike modes than the Auto-Taxi and +Free Transit scenarios. Compared to the base case scenario, the increase in transit use is about 51 percent, and the decrease in personal vehicle use is about 41 percent and in walk and bike trips is about 22 percent.

Figure 7 shows the percentage change in vehicle travel and GHG emissions relative to the base case scenario for travel that begins and ends inside the Westside City area. In the automated taxi scenario, we see increases in vehicle trips (6%), VMT (21%), and GHG emissions (18%) when automated taxis are not battery electric vehicles (BEVS). Despite significant reductions in personal vehicle use in this scenario, the mode shifts from the transit and the walk and bike mode to automated taxis increase overall vehicle trips and VMT. Empty vehicle travel associated with automated taxis (see Figure 8), which includes travel shifted from personal vehicles, adds to the impact of mode shifts on VMT. The increase in overall vehicle travel reduces mean travel speeds somewhat (-2%) compared to the base case. When automated taxis are BEVs, GHG emissions are significantly reduced (-23%) compared to the base-case scenario.

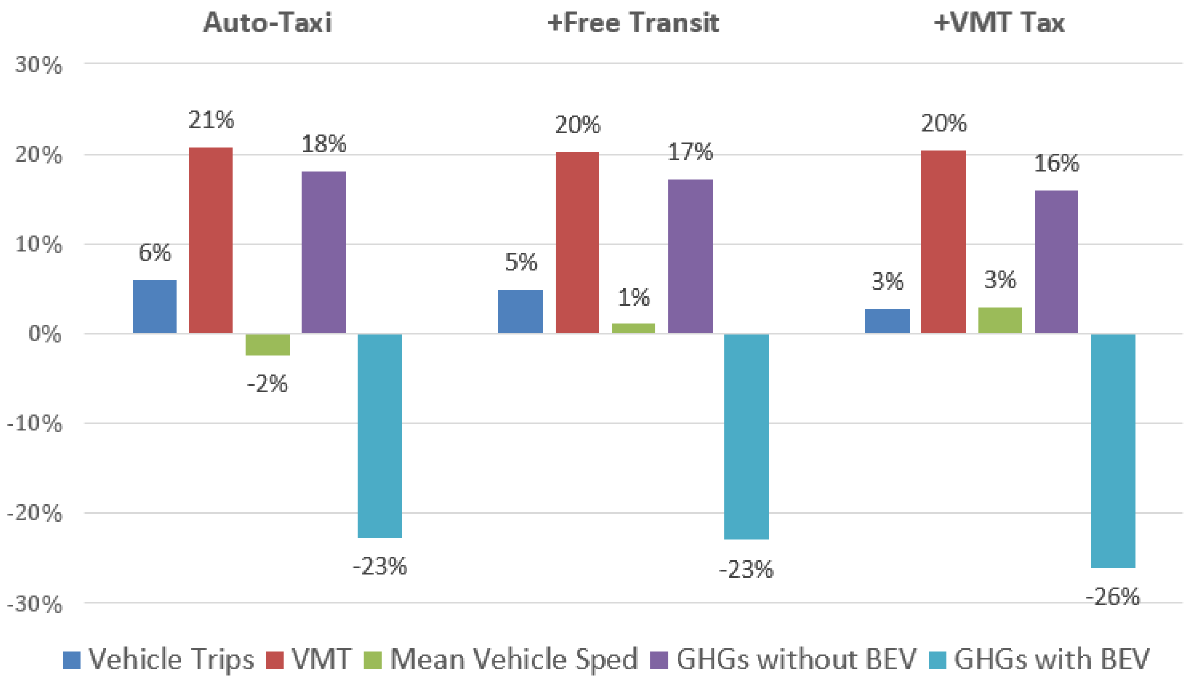

Figure 7. Percentage Change in Daily Vehicle Travel Compared to Base Case

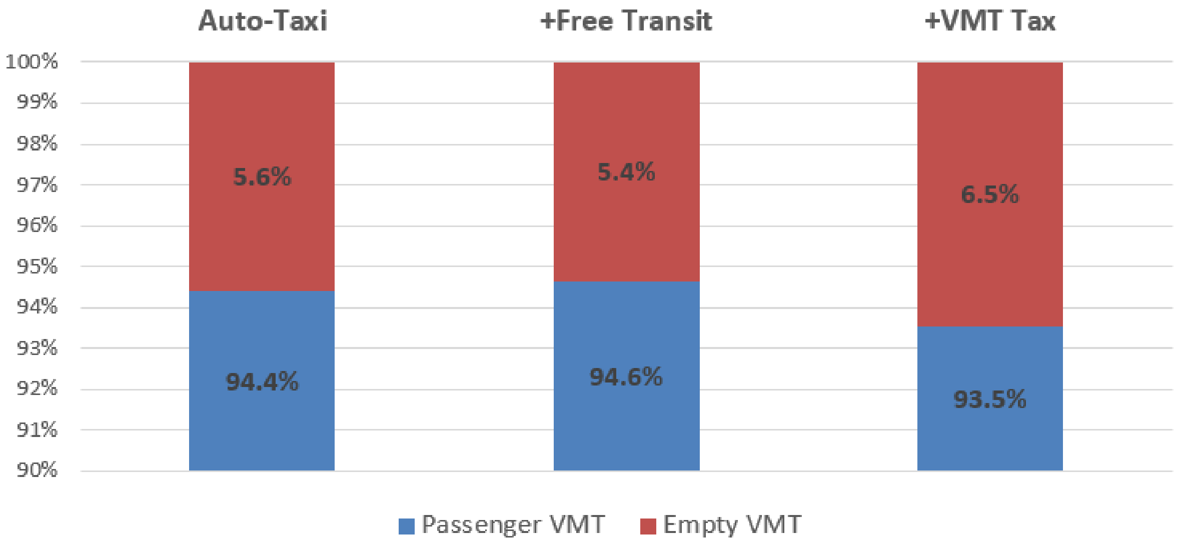

Figure 8. Shares of Automated Taxi Vehicle Miles Traveled with and without Passengers

The addition of free transit to the automated taxi scenario somewhat dampens the increase in vehicle trips and VMT (by one percentage point), increasing average vehicle speeds by one percent. When automated taxis are not BEVs, we see small reductions in GHG emissions compared to the Auto-Taxi scenario. When automated taxis are BEVs, there is no change in GHG emissions compared to the Auto-Taxi scenario.

When adding the VMT tax to the +Free Transit scenario, vehicle trips are reduced by three percent, and average vehicle speeds by three percent. VMT is constant at 20 percent due to the increased share of empty automated vehicle travel (see Figure 8). As a result, GHG emissions increase by 16 percent without BEVs and decrease by 26 percent with BEVS.

5.2 Equity

Table 2 below examines the equity impacts of the scenarios simulated in this study using the US Department of Housing and Urban Development (HUD) income limits for eligibility for Los Angeles County assisted housing programs. HUD income categories, defined by household income and household size, include the following categories: extremely low-income, very low-income, and low-income. We were able to provide changes in benefits by HUD categories because of the continuous household income and household size variables in the SCAG model.

Table 2 below includes the percentage change in the total daily value of travel time and cost, adjusted by the travelers' household income, for an alternative scenario relative to the base case. These results include changes in travel benefits that begin and end and begin or end inside the Westside City area. The automated taxi with and without free transit increased total benefits by six percent, and the addition of the VMT tax reduced these benefits to zero. For the middle to high-income populations, the results for the automated taxi with and without free transit are slightly less than total benefits (five percent); however, there is a two percent increase in benefits with the addition of the VMT tax. The increased travel speeds for middle to high-income travelers with high values of travel time offset the additional monetary cost of personal vehicle travel from the VMT tax. Note that we found slight variations in benefit levels for middle- to high-income categories above the three HUD low-income categories, and thus we merged them into one category. The change in benefits is larger for the HUD low-income categories, particularly for the extremely low-income category. Compared to the middle- to high-income category, the automated taxi scenario with and without free transit, the benefits are more than two times higher for the low-income category and more than four to six times higher for the very low-income category. For the extremely low-income category, benefits increase by 394 percent for the automated taxi only scenario and 1139 percent for the automated taxi and free transit scenario. Free transit dramatically increases benefits for extremely low and very low-income travelers who typically have limited disposable income after paying housing costs. Free transit appears to be more beneficial to extremely low-income households than access to the low-cost automated taxi service. The addition of the VMT tax reduces results in the economic losses to the low, very low, and extremely low-income categories on the order of -15%, -27%, and -1028%, respectively, even with the availability of the low-cost automated taxi service.

Table 2. Percentage Change in Benefits for all Simulated Travel.

	Auto-Taxi	+Free Transit	+VMT Tax
Total	6%	6%	0%
Mid to High Income	5%	5%	2%
Low Income	11%	11%	-15%
Very Low Income	22%	31%	-27%
Extremely Low Income	394%	1139%	-1028%

6. Conclusion

In this study, we use the Los Angeles County MATSim mode to evaluate the travel, GHG, and equity impacts of single- and multiple-passenger shared automated vehicle scenarios combined with a free transit fare and a VMT tax in the Westside Cities areas of Los Angeles.

The results indicate that automated taxis increase VMT by about 20 percent across scenarios, and the increase in automated taxi mode shares more than offset reductions in personal vehicle travel. In addition, the automated taxi scenario reduced transit travel by about 50 percent. However, the addition of free transit fares reversed this decline and increased transit use by about eight percent, and the VMT tax further increased transit travel by 51 percent. Finally, new empty passenger automated taxi travel compounds the impact of mode shifts in these scenarios and further increases VMT.

Concerning congestion, we see a small reduction in mean vehicles speeds (2%) in the shared automated vehicle scenario. However, the addition of the free transit and then the VMT tax policies to the automated taxi scenario increase mean vehicle speeds by one percent and three percent, respectively, because of smaller increases in vehicle trips and VMT. Overall congestion impacts are minor, which means that the failure to represent the destination choice and discretionary trip-making in the LA MATSim model would result in a small underestimation or overestimation of vehicle travel in the alternative scenarios.

When automated taxis are not battery electric vehicles (BEVs), GHG emissions increase, from 16 to 18 percent, across scenarios due to changes in vehicle travel. However, when automated taxis are BEVs, GHGs decrease from 23 to 26 percent.

The equity analysis shows that the automated taxi scenario provides significantly more accessibility benefits for travelers in the three low-income classes than total benefits and benefits for the middle- and high-income travelers. The extremely low-income category receives the greatest increase in low-income benefits. The addition of free transit to the automated taxi scenario dramatically increases benefits for extremely low-income travelers. However, the VMT tax eliminates almost all of the benefits gained from the automated taxi and free transit scenario, and creates losses for all three low-income groups. The middle- to high-income group benefit somewhat from this scenario, and total benefits are unchanged from the base-case scenario.

The results of this study have important implications for current transportation planning. First, transit service is essential to low-income travelers, and free transit fare policies for low-income travelers can significantly improve disparities in access between higher and lower-income travelers. Second, a distance-based VMT tax will negatively impact low-income travelers. Road pricing measures should be waived for low-income travelers or reinvested in easy-to-access programs that provide free or reduced-cost transit, microtransit, or ridehailing. Third, automated taxis (and by extension, low-cost ridehailing, and microtransit services) will tend to increase vehicle travel without a very significant road user charge (i.e., much larger than the doubling of distance-based costs for personal vehicles in this study). The size of such a road pricing policy may face strong opposition from the public. Finally, public policies should require zero-emission technology in automated vehicles in the long term and transit and ridesharing vehicles in the near term.

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