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Operations of a shared, autonomous, electric vehicle fleet: Implications of vehicle & charging infrastructure decisions

T. Donna Chen [a], Kara M. Kockelman [b,*], Josiah P. Hanna [c]

[a] Department of Civil & Environmental Engineering, The University of Virginia, United States
[b] Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin, United States
[c] Department of Computer Science, The University of Texas at Austin, United States

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ABSTRACT

There are natural synergies between shared autonomous vehicle (AV) fleets and electric vehicle (EV) technology, since fleets of AVs resolve the practical limitations of today's non-autonomous EVs, including traveler range anxiety, access to charging infrastructure, and charging time management. Fleet-managed AVs relieve such concerns, managing range and charging activities based on real-time trip demand and established charging-station locations, as demonstrated in this paper. This work explores the management of a fleet of shared autonomous electric vehicles (SAEVs) in a regional, discrete-time, agent-based model. The simulation examines the operation of SAEVs under various vehicle range and charging infrastructure scenarios in a gridded city modeled roughly after the densities of Austin, Texas.

Results based on 2009 NHTS trip distance and time-of-day distributions indicate that fleet size is sensitive to battery recharge time and vehicle range, with each 80-mile range SAEV replacing 3.7 privately owned vehicles and each 200-mile range SAEV replacing 5.5 privately owned vehicles, under Level II (240-volt AC) charging. With Level III 480-volt DC fast-charging infrastructure in place, these ratios rise to 5.4 vehicles for the 80-mile range SAEV and 6.8 vehicles for the 200-mile range SAEV. SAEVs can serve 96–98% of trip requests with average wait times between 7 and 10 minutes per trip. However, due to the need to travel while "empty" for charging and passenger pick-up, SAEV fleets are predicted to generate an additional 7.1–14.0% of travel miles. Financial analysis suggests that the combined cost of charging infrastructure, vehicle capital and maintenance, electricity, insurance, and registration for a fleet of SAEVs ranges from $0.42 to $0.49 per occupied mile traveled, which implies SAEV service can be offered at the equivalent per-mile cost of private vehicle ownership for low-mileage households, and thus be competitive with current manually-driven carsharing services and significantly cheaper than on-demand driver-operated transportation services. When Austin-specific trip patterns (with more concentrated trip origins and destinations) are introduced in a final case study, the simulation predicts a decrease in fleet "empty" vehicle-miles (down to 3–4% of all SAEV travel) and average wait times (ranging from 2 to 4 minutes per trip), with each SAEV replacing 5–9 privately owned vehicles.

* Corresponding author.
E-mail addresses: tdchen@virginia.edu (T.D. Chen), kkockelm@mail.utexas.edu (K.M. Kockelman), jphanna@cs.utexas.edu (J.P. Hanna).

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1. Introduction

Recent transportation trends in increasing electric vehicle (EV) sales and growing carsharing membership have important impacts on greenhouse gas emissions and energy use. Incentivizing plug-in EV adoption and shared-vehicle use may be key strategies for helping regions achieve national- and state-level air quality standards for ozone and particulate matter, and ultimately carbon-emissions standards. At the same time, with the rise of the shared-use economy, carsharing is emerging as an alternative mode that is more flexible than transit but less expensive than traditional private-vehicle ownership. However, the growth of EVs and carsharing are both hindered by technological and social factors. For EVs, the most significant hindrance may be "range anxiety," a user's concern for being stranded with a fully discharged battery and no reasonable recharge option (Bartlett, 2012). Meanwhile, as EVs penetrate the private and commercial vehicle fleets, they are also gaining ground in the carsharing world. EVs are a natural match for carsharing operations as existing members of carsharing operations tend to drive smaller and more fuel efficient vehicles than non-carshare members (Martin and Shaheen, 2011). Cutting-edge carsharing operators (CSOs) are already employing EVs in their fleets (such as Daimler's Car2Go and BMW's DriveNow operations), but the manual relocation of fleets in one-way carsharing systems continues to present profitability challenges to CSOs. The introduction of autonomous driving technology would remove the challenge of manual vehicle relocation and presents a driver-free method for shared EVs to reach travelers' origins and destinations as well as charging stations. In a carsharing setting, a fleet of shared autonomous electric vehicles (SAEVs) would automate the battery management and charging process, and take range anxiety out of the equation for growth of EVs. With the recent popularity of on-demand transportation services through transportation network companies, it is possible to imagine a future travel system where autonomous vehicle (AV) technologies merges with carsharing and EVs in a SAEV fleet. But can self-driving vehicles be shared, self-charged, and right (battery-) sized for the trip lengths that travelers desire?

This study attempts to answer this question through the simulation of a SAEV fleet in a discrete-time agent-based model, examining fleet operations in a 100-mile by 100-mile gridded metropolitan area. Scenarios combine short-range and long-range electric vehicles with Level II and Level III charging infrastructure to look at the impacts of vehicle range and charging time on fleet size, charging station sites, ability to meet trip demand, user wait times, and induced vehicle-miles traveled (VMT). Following the discussion of the simulation results, a financial analysis highlights the tradeoffs between capital investment in vehicles and charging infrastructure and user benefits.

2. Prior research

There is a wealth of literature examining carsharing, electric vehicles and charging infrastructure planning, and autonomous vehicles as separate topics. Studies looking at gasoline-propelled and (especially) electric AVs in a shared setting are more limited. Wang et al. (2006) proposed a dynamic fleet management algorithm for shared fully automated vehicles based on queuing theory. In a simulative environment with five stations and five vehicles, the average passenger waiting time was 3.37 min with average vehicle usage rate of 4.3 vehicles, compared to a fixed dispatch algorithm where average passenger wait time was 4.89 min and vehicle usage rate 3.7 vehicles. Spieser et al. (2014) modeled a fleet of shared self-driving vehicles in Singapore in the absence of any private vehicles, and found that each shared vehicle can replace three privately owned vehicles and serve 12.3 households. In Kornhauser (2013), aTaxiStands (autonomous taxi stands) are placed in every half mile by half mile pixel across New Jersey, and passengers walk to taxi stands rather than allowing AVs to relocate. Douglas (2015) uses the base model proposed in Kornhauser (2013) to size the fleet of an autonomous taxi system in a 5-mile by 5-mile subset of the New Jersey model and found a minimum of 550 vehicles was needed to serve the trip demand. Burns et al. (2013) examined the performance of a shared autonomous fleet in three distinct city environments: a mid-sized city (Ann Arbor, Michigan), a low-density suburban development (Babcock Ranch, Florida), and a large densely-populated urban area (Manhattan, New York). The study found that in mid-sized urban and suburban settings, each shared vehicle could replace 6.7 privately owned vehicles. Meanwhile, in the dense urban setting, the current taxi fleet could be downsized by 30% with the introduction of autonomous driving technology with average wait times at less than 1 min. The International Transport Forum (2015) looked at the application of shared and self-driving vehicles in Lisbon, Portugal, and found that with ride-sharing enabled, each shared vehicle can replace approximately 10 privately owned vehicles and induces 6% more VMT than the current baseline. Without ride-sharing, each sequentially shared vehicle can replace 6 privately owned vehicles but induces 44% more travel distance. This study also looked at the impact of electrifying shared self-driving vehicles, assuming an electric range of 175 km (108 miles) and a recharge time of 30 min, and found that the fleet would need to be 2% larger. Fagnant and Kockelman (2014) presented an agent-based model for Shared Autonomous Vehicles (SAVs) which simulated environmental benefits of such a fleet as compared to conventional vehicle ownership and use in a dense urban core area. Simulation results indicated that each SAV can replace 11 conventional private owned vehicles, but generates up to 10% more travel distances. When the simulation was extended to a case study of low market penetration (1.3% of trips) in Austin, Texas, each SAV was found to be able to replace 9 conventional vehicles and on average, generated 8% more VMT due to unoccupied travel (Fagnant et al., 2015).

Charging/refueling in a fleet of shared self-driving vehicles has remained a missing component in all of the prior studies mentioned here except ITF (2015) and Fagnant and Kockelman (2014), both of which model the refueling process rather simplistically. Fagnant and Kockelman (2014) modeled the logistics of refueling by assuming the 400-mile range SAVs could