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The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios

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ABSTRACT

Carsharing programs that operate as short-term vehicle rentals (often for one-way trips before ending the rental) like Car2Go and ZipCar have quickly expanded, with the number of US users doubling every 1–2 years over the past decade. Such programs seek to shift personal transportation choices from an owned asset to a service used on demand. The advent of autonomous or fully self-driving vehicles will address many current carsharing barriers, including users' travel to access available vehicles.

This work describes the design of an agent-based model for shared autonomous vehicle (SAV) operations, the results of many case-study applications using this model, and the estimated environmental benefits of such settings, versus conventional vehicle ownership and use. The model operates by generating trips throughout a grid-based urban area, with each trip assigned an origin, destination and departure time, to mimic realistic travel profiles. A preliminary model run estimates the SAV fleet size required to reasonably service all trips, also using a variety of vehicle relocation strategies that seek to minimize future traveler wait times. Next, the model is run over one-hundred days, with driverless vehicles ferrying travelers from one destination to the next. During each 5-min interval, some unused SAVs relocate, attempting to shorten wait times for next-period travelers.

Case studies vary trip generation rates, trip distribution patterns, network congestion levels, service area size, vehicle relocation strategies, and fleet size. Preliminary results indicate that each SAV can replace around eleven conventional vehicles, but adds up to 10% more travel distance than comparable non-SAV trips, resulting in overall beneficial emissions impacts, once fleet-efficiency changes and embodied versus in-use emissions are assessed.

1. Introduction

Autonomous vehicles may very well be on our streets and highways by the end of the decade. As of September 2013, Google had logged over 500,000 miles driven on public roadways using cars equipped with self-driving technology (Fisher 2013). California, Nevada and Florida have issued enabling autonomous vehicle legislation, with Washington, D.C. and nine other states following close behind (CIS 2013). This new technology has the power to dramatically change the way in which transportation systems operate. While autonomous vehicle impacts for traffic safety and congestion have been predicted in some detail, potential behavioral shifts and resulting environmental impacts have received little attention.

Once such avenue for behavioral shifting is carsharing. Carsharing programs (such as ZipCar and Car2Go) exist around the globe, and the number of US users has grown from 12 thousand in 2002 to over 890 thousand in January of 2013 (Shaheen

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and Cohen 2013). Car sharing programs operate as short-term rentals, where members are able to rent a vehicle, typically located at an on-street parking location, drive to a nearby destination, and then release the rental when finished with their trip. Some programs like Car2Go allow rentals by the minute, while others like ZipCar require longer rental intervals, and additional annual membership and/or applications fees are often required.

US National Household Travel Survey (NHTS) data (FHWA 2009) suggest that less than 17% of newer (10 years old or less) household vehicles are in use at any given time over the course of an ‘‘average’’ day, even when applying a 5-min buffer on both trip ends; this share falls to just 10% usage when older personal vehicles are included and no buffers applied. In short, *Americans have many more cars than they need* to serve current trip patterns in most locations. Yet carsharing members still face nearby vehicle availability barriers: if a person is worried that he may be stranded, wait a long time, or walk a great distance in order to access a vehicle, he may opt to drive his own car instead.

Shared autonomous vehicles (SAVs), also known as autonomous taxis or aTaxis (Kornhauser et al., 2013), provide a solution, with members able to call up distant SAVs using mobile phone applications, rather than searching for and walking long distances to an available vehicle. Moreover, they provide carsharing organizations with a way of seamlessly repositioning vehicles in order to better match demand. These SAVs are assumed to be fully self-driving without any need of human operation, other than information regarding a traveler's destination. In this way, SAVs could transform transportation for many: from an owned asset to a subscription or pay-on-demand service, at least in areas where population densities make such systems economically viable.

Such advances may provide significant environmental benefits, particularly in the form of reduced parking and vehicle ownership needs. Moreover, there is the potential for additional vehicle-miles traveled (VMT) reduction: Shaheen and Cohen (2013) estimate that North American carsharing members reduced their driving distances by 27%, with approximately 25% of members selling a vehicle and another 25% forgoing a vehicle purchase. It is not clear how much of these effects would apply to SAVs, which may be more convenient and potentially more used than human-driven shared vehicles. Each SAV also can/will move itself (unoccupied) to the next traveler or relocate while unoccupied to a more favorable location, for lower-cost parking and faster future passenger service.

Some researchers have sought to model this phenomenon. Ford (2012) developed a shared autonomous taxi model, and relied on travelers to walk to fixed taxi stands, rather than allowing the SAVs to travel driverless to their next passenger, or relocate to more optimal locations. Kornhauser et al. (2013) investigated this idea further, exploring dynamic ride sharing implications for all person-trips across New Jersey. In this model, one or more passengers boarded at fixed stations, where aTaxis wait a given time before departing, and all passengers having similar destinations share a ride (with an unlimited SAV fleet size assumed). Burns et al. (2013) also investigated this setup, with case study examples of travelers in Ann Arbor (Michigan), Manhattan (New York), and Babcock Ranch, a new small town in Florida. A number of Burns et al.'s modeling assumptions were similar to this paper's investigation, though their focus was on cost comparisons with personal cars. For example, they estimated that per-mile costs fall between $0.18 and $0.34 per mile when switching to SAVs, depending on annual mileage driven, in the Ann Arbor case study. Other benefits may be estimated using Fagnant and Kockelman's (2013) suggestions for AV savings (on insurance, parking, time value, and fuel), versus technology costs ($10,000), alongside an extra assumed $5000 per-shared-vehicle-year operating and management cost. In this scenario, when assuming a $5-per-hour travel-time benefit (from less burdensome travel, lowering one's effective VOTT) and $5-per-weekday parking costs, total realized added benefits over a 2-year SAV lifespan more than double the extra added technology and operating costs.

This paper focuses on SAVs' travel and environmental implications, and uses different assumptions to model a much smaller share of such trips (around 3.5%, rather than 100%), while also modeling directional distribution effects by time of day. The investigation tests four different SAV relocation strategies, seeking to relocate unused SAVs to more favorable locations in order to reduce future traveler wait times. This paper examines ownership and VMT questions, investigating how many household-owned vehicles may be replaced by a fleet of SAVs, how much new travel may be induced (due to unoccupied-vehicle travel, rather than more or longer trips, which may emerge from lower perceived travel-time costs or new travel by those currently without driver's licenses), what factors influence such outcomes, and the resulting travel and environmental implications across a variety of reasonable model scenarios. SAVs are assumed to be shared serially in this investigation by different travel parties, and future work could incorporate dynamic ride-sharing as well.

An SAV model was specified, programmed (from the ground up, in C++), and applied, to gauge the environmental impacts of this novel opportunity. Here, the model operates by generating person-trips in each zone, on 5-min intervals, over 100 days, with each trip having a destination and departure time. These trips are served by SAVs, which ferry travelers between origins and destinations as quickly as they can. Traffic congestion is modeled by time of day, with vehicle speeds slowed at peak hours. When individual SAVs are not in use, a virtual fleet manager uses a variety of strategies to relocate SAVs to more favorable positions, attempting to reduce wait times for future travelers. Travel implications and emissions inventories are assessed by estimating changes in life-cycle inventories, based on changes in the overall vehicle fleet (with any pickup trucks and SUVs substituted for mid-sized SAV sedans), Total VMT is tracked (with added VMT emerging from unoccupied SAVs travel, for relocation or new traveler pickup), along with cold-starts savings (thanks to busy SAVs) and parking benefits (thanks to a shared fleet).

Twenty-five scenario variations were also run, in order to appreciate the impacts of changing many of the base-case scenario assumptions. These scenario variations examine the impacts of altering trip generation rates, the degree of trip centralization (how many trips are generated in the city center versus the outlying areas), the size of the overall service area, the frequency by which travelers return home via SAV, the extent of peak congestion, the effects of various SAV relocation