

Shared Autonomous Vehicles as a Sustainable Solution to the Last Mile Problem: A Case Study of Ann Arbor-Detroit Area

Aditi Moorthy
 Univ of Michigan - Ann Arbor

Robert De Kleine
 Ford Motor Company

Gregory Keoleian, Jeremy Good, and Geoff Lewis
 Univ of Michigan - Ann Arbor

ABSTRACT

The problem of accessibility to public transit is well-documented in transportation theory and network literature, and is known as the *last mile* problem. A lack of first and last mile transit services impairs access to public transit causing commuters to opt for private modes of transit over public modes. This paper analyzes the implications of a shared autonomous vehicle (AV) taxi system providing last mile transit services in terms of environmental, cost, and performance metrics. Conventional public transit options and a hypothetical last-mile shared autonomous vehicle (SAV) system are analyzed for transit between Ann Arbor and Detroit Wayne County Airport for life cycle energy, emissions, total travel time, and travel costs. In the case study, energy savings from using public transit options with AV last mile service were as high as 37% when compared to a personal vehicle option. Energy and greenhouse gas burdens were very sensitive to vehicle powertrain and ridership parameters. The results suggest that an AV taxi service providing last-mile transit services could enhance the sustainability of transit by influencing a mode shift from private modes to public modes of transit. Wait times associated with public transit options, as well as high AV technology costs, could be obstacles for a last mile service.

CITATION: Moorthy, A., De Kleine, R., Keoleian, G., Good, J. et al., "Shared Autonomous Vehicles as a Sustainable Solution to the Last Mile Problem: A Case Study of Ann Arbor-Detroit Area," *SAE Int. J. Passeng. Cars – Electron. Electr. Syst.* 10(2):2017, doi:10.4271/2017-01-1276.

INTRODUCTION

Public transportation plays a critical role in reducing traffic congestion, gasoline consumption, and carbon emissions, especially in major cities [1]. Public transit is an important strategy for achieving more sustainable transportation systems, but access to public transit remains a challenge in many areas in the U.S. Americans logged 57 billion passenger miles on public transit compared to 4,919 billion passenger miles traveled in cars and personal trucks in 2012 [2,3]. A key obstacle to public transit utilization is the *first mile, last mile problem* [4,5], which will henceforth be referred as the *last mile problem* in this paper. This refers to the lack of transit services for the first and last segment of a journey, which hampers access to public transit and causes more travelers to opt for private modes over public modes of transit. The last mile problem poses a significant challenge to increasing public transit ridership and thus reducing the energy and greenhouse gas intensity of passenger transportation systems in the United States. Autonomous vehicles could be a solution to the last mile problem in the U.S. by easing access to public transit hubs.

Vehicle automation is an area of active research and development. As of October 2016, Google's self-driving cars had driven over 2 million miles since the beginning of the project [6]. Multiple car manufacturers and technology companies are developing autonomous vehicle technologies, with Ford and BMW pledging to produce fully autonomous vehicles targeted toward ridesharing services in 2021 [7].

Partially automated features such as cruise control, collision avoidance, and assisted parking are already available on some vehicles. The National Highway Traffic Safety Administration (NHTSA) set five different "levels" of automation [8]. An autonomous vehicle (AV) in this paper refers to a NHTSA level 4 fully self-driving vehicle.

Several researchers have sought to understand the environmental implications of AV systems. MacKenzie et al. modeled the multiple combined effects of vehicle automation on energy consumption and emissions [9]. They concluded that vehicle automation offers the potential for substantial reductions in energy consumption; however, these reductions were not a direct consequence of automation. Instead, they follow from other changes in vehicle and system level

operation and design, facilitated by automation. They also suggest that total automobile travel and fuel consumption could increase significantly from rebound effects if automation sharply reduces the cost of drivers' travel time by enabling the driver to engage in other activities. Brown et al. also estimated the potential environmental impact of AVs using ten potential energy effects of AVs such as platooning, efficient driving and routing, lighter vehicles, efficient parking, increased speed, and increased travel demand [10]. Across various scenarios, the total impact on energy consumption ranged from more than a 90% reduction to a 150% increase.

Previous research using case studies on the shared use of AVs has concentrated on deployment of shared AV taxi services. Ford modeled a shared autonomous taxi system servicing suburban areas of Mercer County, NJ and found that shared AV systems could provide benefits in areas where travel demand is highly concentrated [11]. Using agent based modeling, Fagnant and Kockelman concluded that a system of shared autonomous taxis may provide a ten-fold reduction in the number of cars as compared to privately-owned personal-vehicle travel, but would increase the travel demand by 11% [12]. They expected there to be significant emissions and energy savings due to reduced personal vehicle ownership, as well as quicker fleet turnover to more energy efficient automobile technologies. Burns et al. developed a network model that determines system performance and cost for a shared AV transit system [13]. They concluded that a purpose-built AV fleet consisting of two- passenger, autonomous, fully electric vehicles would result in a radically enhanced personal mobility experience with significantly lower costs. Greenblatt and Saxena considered impacts from the operation of a fleet of small, electrified autonomous taxis [14]. They estimated that an 87-94% reduction of GHG emissions on a per mile basis could be achieved in 2030 compared to emissions from current ICEVs.

While previous work has largely focused on AV transportation, this work considers AV impacts as part of multimodal transportation systems. The objective is to examine shared AVs from the perspective of improving access to transit hubs. This paper analyzes the environmental, cost, and performance implications of a shared electric AV taxi system providing last mile transit services in southeast Michigan.

METHODS

Goal and Scope

The basis for analysis is a case study analyzing transit options between Ann Arbor and Detroit Metropolitan Wayne County Airport (DTW), including a motor coach bus, a van shuttle, and a shared AV taxi. The Ann Arbor to Detroit airport trip was chosen because it offers several modes of public and private transit options to the traveler. Ann Arbor is a medium density urban area with a population of 117,025 and a density of 4,094 persons per square mile in 2010 [15]. It has a large student population that relies on public transit.

Conventional public transit options along with a hypothetical last-mile shared AV system were modeled. All trips use the Interstate 94 highway, which represents the majority of the distance for trip, regardless of mode. Trip options were evaluated for their life cycle

energy and emissions, traveler costs, and performance in terms of travel and wait time. Five mode combinations were analyzed in our study. The trip options were evaluated for five origin-destination (OD) pairs, with the destination of all trips being the airport. Central Ann Arbor was divided into six geographical zones (map provided in appendix). Approximate centroids of these zones were chosen as trip origins. The central zone with a centroid that is a three-minute walk from the transit depot for the motor coach that serves the airport was excluded. That leaves five origins in Ann Arbor, ranging from 22.6 miles to 31.2 miles in driving distance from the airport (using the shortest on-road route). The mean distance was 26.5 miles.

We analyzed the energy and emissions with a life cycle assessment (LCA) perspective. LCA is an environmental assessment technique that measures the impacts of a product through all its life cycle stages, from cradle to grave. The functional unit of this study is the service of transporting a single traveler from his or her starting location in Ann Arbor to the airport. It is assumed that luggage will not impact fuel efficiency or exceed the cargo capacity of a given vehicle. Life cycle energy, emissions, and travel times associated with each trip option were calculated individually for each origin-destination pair and averaged over all five pairs. These averages are representative of a traveler taking a trip from the Ann Arbor area to DTW airport.

Trip Options, Trip Segments and Trip Modes

A trip option is defined as a combination of multiple trip segments that a traveler uses for a given origin-destination pair. A trip segment is defined as a portion of a trip option, composed of a single trip mode. A trip mode is the transit mode the traveler chooses for a particular trip segment. For example, the rail-personal vehicle trip option is composed of two trip segments, the personal vehicle trip segment and the rail trip segment. The five different modes used for trip options are detailed below.

Passenger Car

As a base case, the passenger car mode was modeled as a typical mid-size sedan with an internal combustion engine (ICE) with a fuel economy of 35 mpg. A 25 mpg sedan and an PHEV with a 60 mile all electric range were also examined as an alternative personal vehicle options in an additional scenario considering energy and GHG impacts. A maximum capacity of four passengers was assumed. The vehicle is assumed to be parked by the driver at the end of the trip segment in anticipation of a future return trip.

Ann Arbor Area Transit Authority (AAATA) Bus

The AAATA bus mode is the fixed-route service operated by the Ann Arbor Area Transportation Authority in and around Ann Arbor. The AAATA fleet consists of 65% hybrid electric buses [16].

AirRide

AirRide is a bus transit service between Ann Arbor and DTW. It is a public-private partnership that provides 13 daily trips between Ann Arbor and DTW [17]. The AirRide mode was modeled as a bus.

Airport Van Shuttle

Several shared ride airport shuttle services are offered between Ann Arbor and DTW. This analysis assumed shuttle service was provided by a commercial ICE passenger van.

Autonomous Vehicle (AV)

The AV was modeled as a PHEV60 plug-in hybrid vehicle with a maximum capacity of four passengers. The vehicle can operate in electric-only mode for up to 60 miles with a fully-charged battery, relying on gasoline for any remaining distance. It was assumed that the AV is a mid-size sedan with additional sensing and control equipment providing autonomous navigation capabilities.

The trip segments and trip options are listed in [Table 1](#). There are five trip options, with single or multiple trip segments, comprising various modes. The shared AVs were assumed to serve the AirRide transit hub. The personal vehicle parking scenario assumes that the traveler parks the car at the airport.

Table 1. Trip options modeled

Trip Options	Trip Segment - 1	Trip Segment - 2
Personal vehicle: parking	Personal vehicle	-
Airport Shuttle	Airport Shuttle (Van)	-
AV - AirRide	Autonomous Vehicle	AirRide (Motorcoach)
Personal vehicle - AirRide	Personal Vehicle	AirRide (Motorcoach)
AAATA - AirRide	AAATA (City Bus)	AirRide (Motorcoach)

Life Cycle Model

System Boundary

The system includes vehicle material and manufacturing burdens, fuel production, vehicle operation, and infrastructure burdens. Vehicle and infrastructure end of life burdens were excluded. Vehicle manufacturing includes the upstream material production impacts for the components of the vehicle. Fuel production includes the well to pump fuel cycle impacts. Infrastructure burdens for on-road modes include roadway construction and maintenance, parking construction and maintenance, roadway lighting, herbicides, salting, and repair facilities.

Vehicle Production

Vehicle production data were sourced from Chester and Horvath [18,19]. Vehicle production burdens for the passenger car were assumed to be equivalent to a typical midsize sedan. Manufacturing data for the AAATA and AirRide buses were also drawn from Chester and Horvath [18]. The autonomous vehicle was assumed to be equivalent to a plug-in hybrid with 60-mile battery-only operation (PHEV60). The van shuttle option manufacturing data were based on manufacturing a pickup truck as a proxy [18]. Vehicle manufacturing burdens were allocated on a per passenger mile basis for each trip segment.

Infrastructure

Infrastructure burdens were included for each of the trip modes based on results from Chester and Horvath [18,19]. Each mode includes upstream burdens that include roadway construction and lighting, herbicides, salting, and parking.

Operation

Operation data for passenger vehicles were sourced from Chester and Horvath [18,19] and adjusted when necessary to reflect the specific scenarios. Energy data for a conventional diesel bus [18] were modified to represent an AAATA hybrid bus using the ratio of hybrid to conventional bus energy and GHG emission values from GREET2 [20]. AAATA's transit bus fleet is 65% hybrid, so the operation and energy production phases were adjusted accordingly. Energy data for a conventional bus [18] were modified to represent an AAATA hybrid bus using the ratio of hybrid to conventional bus GHG emission results from McKenzie [21]. We made these simplifying assumptions: 1) Vehicle weight with differing passenger and luggage loadings did not affect fuel economy; 2) There were no seasonal impacts on energy use and emissions.

Fuel Production

Gasoline and diesel fuel production impacts were sourced from Chester and Horvath [18,19] and include refining and distribution. AAATA uses a 10% biodiesel blend fleet-wide, which includes urban buses and the AirRide motor coaches. The proportional upstream energy and GHG emissions were adjusted for this phase for both bus types using GREET2.

Ridership and Lifetime VMT

Ridership data for AAATA and AirRide modes were obtained from AAATA performance data [22,23]. For all fixed local routes there is bus service every 30 minutes, so ridership per service hour figures are halved to estimate average ridership for the trip segment. Transit bus ridership varies by route used from 9.6 to 13.8 and averages 12. Ridership for the personal vehicle and autonomous vehicle is assumed to be one. Ridership for the airport shuttle van is assumed to be four. Vehicle lifetime data and yearly VMT data were sourced from Chester and Horvath [18]. [Table 2](#) details ridership assumptions for baseline, peak, and off peak scenarios across all modes.

Table 2. Ridership parameters for trip modes

Mode	Ridership		
	Baseline	Off Peak	Peak
Personal Vehicle	1	1	4
AAATA (City Bus)	12	5	40
AirRide (Motorcoach)	9	5	40
Airport Shuttle (Van)	4	1	8
Autonomous Vehicle	1	1	4