CAN SAVs BEAT BUSES? TRAVEL TIME IMPACTS OF USING SHARED AUTOMATED VEHICLES ALONG A FIXED-ROUTE TRANSIT CORRIDOR

Yantao Huang
Graduate Research Assistant
Department of Civil, Architectural and Environmental Engineering
The University of Texas at Austin
yantao.h@utexas.edu

Kara M. Kockelman
(Corresponding Author)
Dewitt Greer Professor in Engineering
Department of Civil, Architectural and Environmental Engineering
The University of Texas at Austin
kkockelm@mail.utexas.edu
Tel: 512-471-0210

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ABSTRACT

Shared automated vehicles (SAVs) offering a fixed-route transit may compete well against privately operated vehicles. This paper analyzes the system costs of all travelers along a 4-mile corridor under different penetration rates for 10-seat SAVs. The work prices out walking, waiting, riding, and driving times for all travelers in the corridor, along with vehicle ownership, parking, and operating costs. Results show that such self-driving mini-buses or SAVs lower total costs per passenger-mile traveled when SAV mode split exceeds 30 percent, even though walking and waiting are valued at relatively high cost. Such vehicles dramatically free up pavement (and parking) space, and perform even better parking costs at drivers' destinations are high.

KEYWORDS

Shared Automated Vehicles, Public Transportation, Total System Cost, Transit Corridor.

QUESTIONS

Shared automated vehicles (SAVs) are expected to draw users from all modes, including traditional transit systems (Huang et al., 2021; Haboucha et al., 2017). SAV-based systems are likely to be far more demand responsive (including door to door) and physically nimble when stopping to pickup and dropoff passengers, relative to standard buses, thanks to smaller sizes. Without a human driver and with lower crash costs, they can be far more cost-effective than traditional transit, as the technology matures (USDOT, 2018a; Loeb and Kockelman, 2018). While various surveys (Etzioni et al., 2021; Gurumurthy and Kockelman, 2020) predict SAVs' future market penetration, actual traffic conditions and total system costs are missing, for this kind of new "transit" service.

METHODS

This work specifies detailed behaviors of human-driven cars or "background vehicles", SAVs, and SAV users using Simulation of Urban Mobility (SUMO) software for a suite of detailed outputs, every half-second. All vehicles and riders share a straight one-way 2-lane, 4-mile corridor with a speed limit of 30 mi/hr. During the 2-hour simulation period, both SAVs and background vehicles traverse the entire 4-mile corridor while riders use SAV services for 1-mile trips in the corridor. Riders walk to the nearest stop, take the next available SAV and alight at stops closest to their final destinations. If riders are waiting or have almost arrived at a stop, or there are onboard riders who plan to alight, SAVs must stop and then dwell at those locations, which which are evenly placed (every quarter mile), in the mid-point of each quarter-mile road segment (Figure 1). The TraCI Python module was used to ensure real-time control of vehicles and travelers. Each scenario required about 5 to 60 minutes of run-time, depending on the SAV penetration rate.

Figure 1. Corridor Settings

This simulation uses 10-seat SAVs, which is a common SAV size for public AV demonstrations (USDOT, 2018b). 4-seater, 6-seater, 20-seater and even 40-seaterer AVs (with some pasengers also standing) are possible as well, with different cost, service frequency, and traffic implications (Huang et al., 2021). Different SAV penetration rates are specified here, as different shares from a fixed 12,000 person-miles traveled (PMT) background demand. Travelers shifting from privately owned or used vehicles to SAVs with dynamic ride-sharing (DRS) en route still results in the same 12,000 total PMT, in the corridor, as each of the private-vehicle occupants or drivers (for a 4-mile total-corridor trip) results in 4 separate 1-mile trips in the SAVs. More boardings and alightings will add more complexity and congestion delays to the corridor, but may still beat the private car rides, thanks to higher vehicle occupancies in 10-seat SAVs. Here, SAVs are dispatched in order to provide 1.5 times the PMT demanded of them, in order to deliver an average load factor of 2/3 (or 6.7 seats occupied on average).

Background vehicles are assumed to have an average vehicle occupancy (AVO) of 1.2 persons (US DOT, 2017) and values of travel time (VOTT) for drivers and passengers in these private vehicles are $15 and and $7.50 per person-hour, respectively. SAV riders are assumed to have a high VOTT ($30 per person-hour) while waiting at stops, but just $7.50 per person-hour once they are on board (Liu et al., 2017; Fan et al, 2016). Background vehicles are assumed to have ownership and operating costs of $0.58 per mile (AAA, 2020) plus a $3 parking fee at their destination (Litman, 2012). 10-seat SAVs are assumed to cost $1.10 per mile driven (Bösch et al., 2018). Finally, SAVs are assumed to stop in the outside lane of this 2-lane (one-way) corridor, so they create congestion every time they stop. For other vehicle sizes and corridor designs, please see Huang et al. (2021).

FINDINGS

Table 1 shows the results of the 2-hour peak-period simulations. As travelers shift from private vehicles to SAVs, the background vehicles' user costs fall and SAV system costs rise, but not per traveler. The total cost per PMT also rises, as SAV PMT share rises, at first. It peaks quickly, at approximately a 5% SAV-choice penetration rate. When the SAV PMT share reaches 20%, total travel costs in the corridor fall to the 100% private-vehicle (zero SAVs) scenario's cost. These results suggest that roadway systems may benefit from 10-seat SAVs at mode splits higher than 20%. Of course, if private vehicles are also driven "autonomously", their drivers' VOTT will fall. But, if we include the true costs of private vehicles accessing the corridor as short trips, the way the SAV users are assumed to, the breakpoint favoring SAVs may happen much earlier.

Table 1. Corridor Cost Results across Different SAV PMT Shares

SAV PMT Share	Background Vehicles					
	# Background-Vehicle (Private Car) Trips	Background Vehicles' Total Travel Time (hr)	Background-Vehicles' VOTT Costs ($)	Parking Cost for Background Vehicles ($)	Ownership & Use Cost of Background Vehicles ($)	Background Vehicles' Total Travel Costs($)
0%	2,500 car trips	353 hr	$5,095	$7,500	$5,800	$18,395
5%	2,375	337	4,854	7,125	5,510	17,489
10%	2,250	319	4,602	6,750	5,220	16,572
20%	2,000	285	4,104	6,000	4,640	14,744
50%	1,250	178	2,571	3,750	2,900	9,221
100%	-	-	-	-	-	-

SAV PMT Share	SAV Riders					SAV	
	# SAV Riders	SAV Rider Onboard Travel-Time Cost ($)	SAV Rider Wait Time Costs ($)	Average SAV User Wait Time (minutes)	Total Cost for SAV Users ($)	# SAVs Needed	SAV Use Total Cost ($)
0%	-	-	-	-	-	0 SAVs	-
5%	600 riders	$245	$1,272	4.2 min	$1,517	27	$119
10%	1,200	497	1,583	2.6	2,080	51	224
20%	2,400	977	2,380	2.0	3,357	106	466
50%	6,000	2,284	4,721	1.6	7,005	270	1,188
100%	12,000	4,221	8,634	1.4	12,854	520	2,288

SAV PMT Share	Total Cost for All Travel in Corridor ($)	Total Cost per PMT in Corridor ($)	SAV Average Vehicle Occupancy (AVO)	SAV AVO in Center 2-mile Section of Corridor
0%	$18,395	$1.53 per PMT in corridor	0	0
5%	19,125	1.59	56%	71%
10%	18,876	1.57	59%	75%
20%	18,568	1.55	57%	74%
50%	17,414	1.45	56%	66%
100%	15,142	1.26	58%	62%

In the extreme case, when all travelers are served by SAVs (and other, non-motorized modes, for example), total cost falls to $1.26 per PMT, which is 18% less than the “business as usual” (100% private vehicles) scenario. Importantly, only 520 SAV trips are needed along the corridor during the 2-hr simulation, lowering total vehicle footprints by about 80%, which is dramatic.

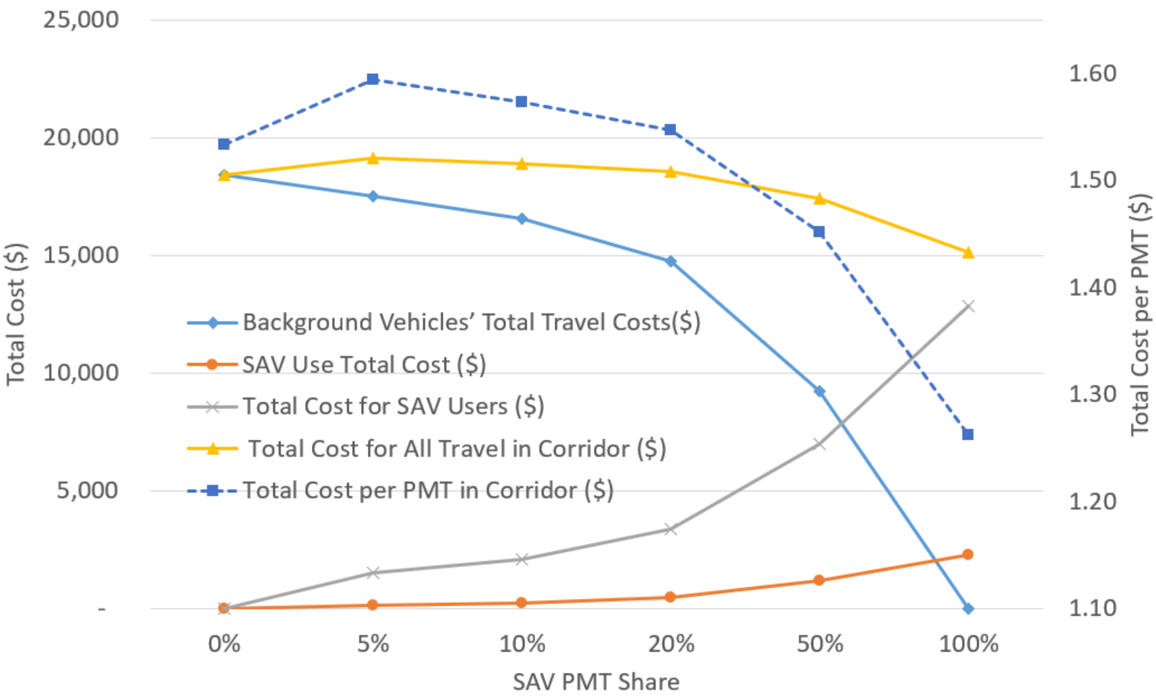

Figure 2. Total Travel Cost vs. SAVs’ Share of PMT

The corridor may experience slower traffic than simulated because the human-driven vehicles will create congestion when entering, exiting and stopping along the corridor, and may crash more often. Therefore, shifting to SAVs may bring more benefits than estimated here. But fixed-route SAVs service may not be accessible for everyone, because of walking (access) distances to access the stop or people with travel limitations who still need door-to-door service.

Overall, this analysis suggests that cities and corridors will benefit from higher SAV penetration rates, even with more short trips, and many stops along the way. Transit agencies using SAVs to serve fixed-route transit corridors can save society money, while dramatically reducing vehicles’ footprints, thereby freeing up pavement for other uses. Of course, incentives to ensure such mode splits (like congestion pricing of corridors, transit use subsidies, and higher gas taxes in undertaxed nations like the U.S.) will also be needed, to get the mode splits to shift so much from current conditions in many settings. Fortunately, smart, connected (to cellular) vehicles will have such capability, and conventional vehicles can be upgraded now for 5G-based pricing.

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REFERENCES

AAA, 2020. YOUR DRIVING COSTS: How Much Are You Really Paying to Drive? Retrieved from: https://exchange.aaa.com/wp-content/uploads/2019/09/AAA-Your-Driving-Costs-2019.pdf

Bösch, P.M., Becker, F., Becker, H. and Axhausen, K.W., 2018. Cost-based analysis of autonomous mobility services. *Transport Policy*, *64*, pp.76-91.

Etzioni, S., Daziano, R.A., Ben-Elia, E. and Shiftan, Y., 2021. Preferences for shared automated vehicles: A hybrid latent class modeling approach. *Transportation Research Part C: Emerging Technologies*, *125*, p.103013.

Fan, Y., Guthrie, A. and Levinson, D., 2016. Waiting time perceptions at transit stops and stations: Effects of basic amenities, gender, and security. *Transportation Research Part A: Policy and Practice*, *88*, pp.251-264.

Federal Transit Administration (FTA), 2016. National Transit Summaries and Trends 2015. Retrieved from https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/2015%20NTST%20Appendix.pdf.

Gurumurthy, K.M. and Kockelman, K.M., 2020. Modeling Americans' autonomous vehicle preferences: A focus on dynamic ride-sharing, privacy & long-distance mode choices. *Technological Forecasting and Social Change*, *150*, p.119792.

Haboucha, C.J., Ishaq, R. and Shiftan, Y., 2017. User preferences regarding autonomous vehicles. *Transportation Research Part C: Emerging Technologies*, *78*, pp.37-49.

Huang, Y., Kockelman, K., Truong, L., 2021. SAV Operations on A Bus Line Corridor: Travel Demand, Service Frequency and Vehicle Size. Presented at the 100th Annual Meeting of the Transportation Research Board (2021), and under review for publication at *Journal of Advanced Transportation*.

Litman, T., 2012. Parking Costs, Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications, Victoria Transport Policy Institute. Retrieved from: https:/www.vtpi.org/tca/tca0504.pdf.

Liu, J., Kockelman, K.M., Boesch, P.M. and Ciari, F., 2017. Tracking a system of shared autonomous vehicles across the Austin, Texas network using agent-based simulation. *Transportation*, 44(6), pp. 1261-1278.

Loeb, B. and Kockelman, K.M., 2019. Fleet performance and cost evaluation of a shared autonomous electric vehicle (SAEV) fleet: A case study for Austin, Texas. *Transportation Research Part A: Policy and Practice*, 121, pp.374-385.

U.S. Department of Transportation, 2017. Summary of Travel Trends 2017 National Household Travel Survey. Retrieved from: https://nhts.ornl.gov/assets/2017_nhts_summary_travel_trends.pdf

U.S. Department of Transportation, 2018a. Low-Speed Automated Shuttles: State of the Practice. Final Report. Retrieved from: https://rosap.ntl.bts.gov/view/dot/37060/dot_37060_DS1.pdf?

U.S. Department of Transportation, 2018b. Autonomous vehicle fleet ownership and operating costs are expected to be half that of traditional vehicles by 2030-2040. URL: https://www.itskrs.its.dot.gov/its/benecost.nsf/ID/52ada2ffac6ec4b4852582f00067a4e3#:~:text=Barclay's%20(2016)%20estimates%20the%20cost,conventional%2C%20privately%20owned%20vehicles%20today.