LONG-DISTANCE TRAVEL IMPACTS OF AUTOMATED VEHICLES: A SURVEY OF AMERICAN HOUSEHOLDS

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ABSTRACT

This research assesses long-distance (LD) travel demand in near-future scenarios where automated vehicles (AVs) emerge within the marketplace. Stated and revealed preference data were obtained from 1,004 American adults (with 45% sampled within the State of Texas). The survey includes questions about LD trip-making behavior, while investigating the possibility of using AVs to substitute for respondents' recent LD trips (over 75-miles one-way) prior to the COVID-19 pandemic. A statistic summary is provided after cleaning and weighting the responses, and respondents' business and non-business LD trip frequencies prior and during the pandemic are modeled with a negative binomial count model. 55% of American adults are likely to shift to AVs if AVs can offer a 50% cost reduction. About 55% population-weighted respondents suggested they may choose to sleep through the night while their AV keeps moving, instead of stopping to overnight in a hotel and delaying arrival at their destination. Results of the negative binomial trip counts model predict that people aged 25 to 64 living in the Western US with higher annual income take more LD business trips prior to the pandemic, compared to other demographic categories. Under the impact of the pandemic, the aged 65+ variable is more significant because these people are more vulnerable to COVID-19 and thus are predicted to have much fewer LD trips. For the non-business model, full-time employed people would make fewer non-business LD trips compared to those who can afford more time (e.g., part-time employed people) on such trips, especially during the pandemic.

Keywords: long-distance, COVID-19, autonomous vehicles, trip frequency model, negative binomial count model

INTRODUCTION

Long-distance (LD) passenger trips are a key component of most nations' traffic volumes, congestion levels, emissions, crashes, noise, and pavement damage. According to the 2017 National Household Travel Survey (NHTS), 43.3% of U.S. person-miles traveled (PMT) comes from one-way trips over 50 miles. These are just 2.5% of all person-trips made in the U.S. each year, but almost half of all person-miles traveled (McGuckin, 2018; US Department of Transportation, 2017). Fully-automated or "autonomous" vehicles (AVs) reduce the burden of travel for drivers and may improve the quality and safety of travel for others. Business travelers, for example, may elect to work en-route, while families and friends traveling together may have more quality interactions en route, along with more flexible departure times and perhaps lower trip costs than flying or taking a train.

Thanks to easier "driving," the value of travel time (VOTT) of the driver, or their willingness to pay (WTP) to save travel time, is expected to fall by 20 to 50% or more, so the generalized cost of travel can decrease by several dollars per hour to $10 or more per hour, for different drivers and trip types. LaMondia et al. (2016) explored long-distance mode choices originating in Michigan and forecasted that over 25% of airline trips under 500 miles will shift to AVs. Such changes will have important impacts on airlines, infrastructure planning and future land use (especially on and around long-distance transportation facilities), highway congestion, and the travel industry more generally. Gurumurthy and Kockelman (2020) designed, disseminated, and then analyzed a nationwide survey on AVs' impacts on Americans' passenger travel choices, and found that AV-sharing and dynamic ride-sharing should rise over time, for a variety of reasons, with shared AVs (SAVs) particularly popular for long-distance business travel. To analyze the impacts of AVs in the United States, Perrine et al. (2020) added a new AV mode to a subset of the rJourney mode and destination choice models. With a base scenario assuming AV operating costs to be 20% higher than those of conventional vehicles, AVs reduced U.S. airline revenues from domestic travel by a dramatic 53%. Availability of SAVs and AVs also shifted destination choices, for an overall 6.7% decline in U.S. PMT from existing long-distance trip-generation rates. Such research needs much further development, and can be supplemented with newer Texas- and long-distance-focused surveys, incorporating more complete details on Texas airport offerings, airline response, and a thoughtful prediction of market shares over time (rather than simply a "before" vs. long-term "after" scenario comparison). Kim et al. (2020) surveyed more than 3000 Georgians regarding their expectations on 16 potential changes brought by AVs. Results show that more than half of the respondents expressed enthusiasm for changing their activity patterns due to AVs, in terms of conducting more leisure and long-distance travel, as well as traveling to farther destinations.

However, the COVID-19 pandemic has greatly impacted LD travel around the world in 2020. The global landscape in 2020 has experienced a reduction of about 50% in terms of the scheduled flights compared with the same time in 2019 (OAG Aviation Worldwide, 2021). Since people hesitate to use shared modes during COVID-19, public transit has also been extensively affected (Beck and Hensher, 2020; Wang et al., 2020). The statistics and studies surrounding the impacts of COVID-19 indicated that air travel greatly decreased during the height of the pandemic but has since returned to near-normal levels, with the number of longer work trips not bouncing back as quickly as the number of shorter trips and an overall heightened concern for shared modes of transportation (Mokhtarian and Grossman, 2020; Conway et al., 2020).

The survey conducted in this paper allows examination of people's preference for traveling a long distance (over 75 miles, one-way) in an AV, and how AVs can impact people's travel choices, such as travel mode, trip purpose, travel party size, departure time of day, trip frequency and overnight stay decisions. Despite these efforts made to understand the impacts of AVs, there is no nationwide travel survey targeting inter-regional AV impacts on LD travel. The survey aims to discuss the impacts of AVs on LD travel in-depth, especially in a post-pandemic world when people may have various options on how they would conduct LD travel with automation technology.

SURVEY DESIGN AND DATA COLLECTION

The survey consists of 70 questions (15–25 minutes), divided into three main topics involving seven sections, targeting different aspects of long-distance travel, AV and SAV usage, and effects of the COVID-19 pandemic. It includes a mix of declared and stated preference questions for current or recent trips and future scenarios. Questions related to the effects of COVID-19 are also included, and different scenarios are tested for a future COVID-19-like virus to understand the impacts of possible future pandemics.

The survey starts with definitions of relevant concepts such as self-driving vehicles, one-way trips and round trips, and long-distance travel before respondents are shown in the questions. For this study, long-distance travel is defined as a one-way trip over 75 miles from the origin to the destination (or a round trip over 150 miles in total distance travel). The first main topic investigates the general LD trip-making pattern of people during 2019 and 2020. This offers a detailed comparison of the LD trip pattern between the years with and without the impacts of the pandemic. The second main topic inquires about details of the most recent pre-pandemic LD trip made by the respondent, followed by questions focusing on how their travel behavior would change if they can travel with an AV. The third main topic provides future scenarios when AVs are widely used, exploring respondents' preference on future LD trip-making. The survey then ends with collecting demographic information.

The response collection process lasted three weeks, with rigorous scrutinizing of the respondents over time. The targets were set up to match 50% Texas and 50% the rest of US, with individual targets for both Texas and non-Texas samples, concerning gender, age, census region, and education. The responses were analyzed during the collection process so that the targets were adjusted daily based on data cleaning results.

RESPONSE CLEANING AND WEIGHTING

To preserve accuracy and reduce bias in the survey results, the responses were heavily monitored to ensure that only complete responses were examined. The cleaning procedures include visual inspection of data format, value range, and consistency checking to help identify incomplete records, invalid field entries, and inconsistent field entries. Responses were kept based on completion within a reasonable amount of time (longer than 13 minutes), no inconsistencies in responses (e.g., inconsistent zip code and state of residence), legibility, and reasonableness. A total sample of 1,004 responses were obtained after the filtering and cleaning process described. The final pool includes 451 (45%) Texans and 553 (55%) respondents from the rest of the nation, allowing both a detailed representation of the Texas region and a comparison with the rest of the continental US. This approach helps to comprehensively depict the long-distance travel preferences for AVs across the US. Figure 1 shows the location of the respondents across the nation.

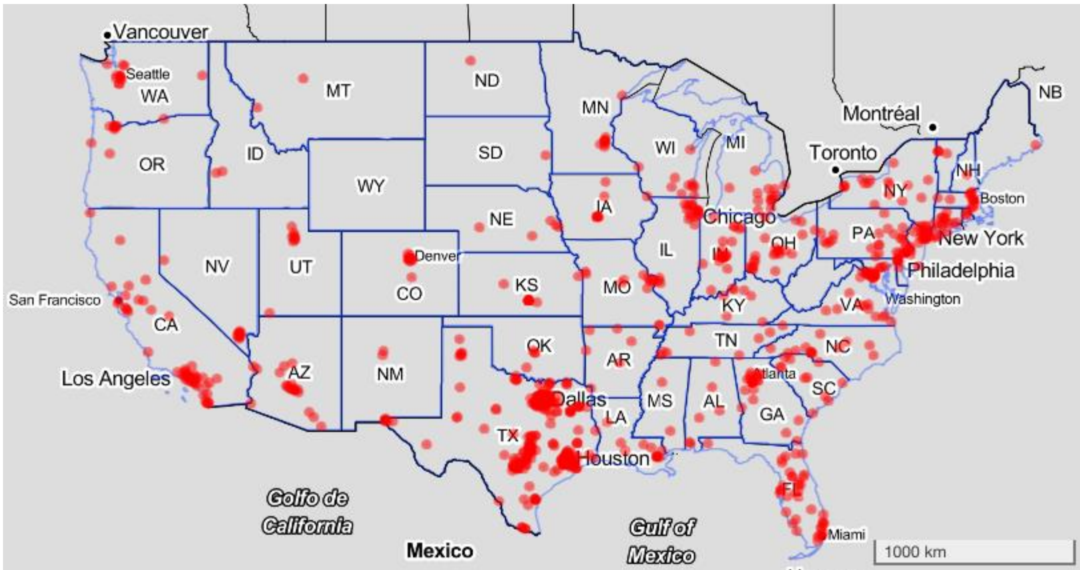


Figure 1. Respondents across the continental US

The collected data were further weighted using the iterative proportional fitting (IPF) method (Roth et al., 2017) to match the most recent five years of data from the American Community Survey (ACS). The weighting targets incorporated the demographic distribution of age, region, and gender. The southern US area was separated into two parts: Texas and the rest of the Southern US, such that Texas as well the continental US as a whole both match the ACS demographic distribution using the same weight set. The results of the following sections are all weighted results across the US.

LONG-DISTANCE TRIP-MAKING BEFORE, DURING, AND AFTER PANDEMIC

This section presents the first main topic in the survey. Respondents revealed how their trip-making behavior changed between the years 2019 and 2020 (pre-pandemic vs. during the pandemic) regarding trip purposes, mode of transportation, and travel frequency with additional consideration of how the COVID-19 pandemic impacted these responses.

Table 1 shows the demographic distribution of the respondents who made LD non-business and business trips during 2019 and 2020. Business trips accounted for about one-third of the total LD trips, for both years 2019 and 2020. Although LD trip-making across the US decreased during COVID-19, business and non-business trips suffered equally from the impacts of COVID-19, seen from the same percentage share. For non-business trips, females and males made about the same number of LD trips (with 1 to 2% more made by females) in years 2019 and 2020, but males had more business trips, about twice the amount made by females before the pandemic. People aged 25 to 34 years were shown to contribute more to the LD trips, about over a quarter for non-business trips and over half for business trips. Non-business trips did not show a large discrepancy between different age groups, but people aged 25 to 54 years accounted for 81% of the business LD trips prior to the pandemic, and the percentage reached 88% during the pandemic. In terms of the trip-making by different residents across four census regions, the Western population made more business trips on average compared to the other regions before the pandemic, while Northeastern people made more non-business trips. The split remained similar during the pandemic in 2020, while the South LD trip-making tendencies were less impacted by COVID-19 compared to the other three regions.

Table 1. Demographic distribution of long-distance trip occurrence in 2019 and 2020 in the US

Calendar year		2019		2020	
Trip purpose		**Non-Business**	**Business**	**Non-Business**	**Business**
		66%	34%	67%	33%
Gender					
Female		52%	34%	51%	38%
Male		48%	66%	49%	62%
Age					
18 to 24 years		5%	5%	6%	7%
25 to 34 years		26%	52%	27%	55%
35 to 44 years		15%	12%	17%	13%
45 to 54 years		15%	19%	18%	20%
55 to 64 years		19%	9%	20%	4%
65 or more years		20%	3%	11%	1%
Region	***2019 Population (%)**				
Northeast	17%	28%	14%	26%	15%
Midwest	21%	12%	5%	11%	4%
South	38%	31%	35%	34%	41%
West	24%	30%	47%	29%	41%

Note: 2019 population statistics were obtained from US Census Bureau, 2021

Figure 2 charts the pandemic's effects on long-distance trip frequency. COVID-19 had a clear impact on trip-making, as seen from the increase in the population that did not made a single long-distance trip during the pandemic; this accounted for almost one-third of the US population. Before the pandemic, a frequency of one long-distance trip per 3 months was the most common, followed by one long-distance trip every half year. During the pandemic, a huge reduction was observed for those who used to take about two to six long-distance trips per year. The situation is expected to be mitigated after the pandemic, and more people will make 12 to 24 long-distance trips, even compared to the case before the pandemic. However, the weekly long-distance commuters are expected to be fewer, with more people preferring to work from home.

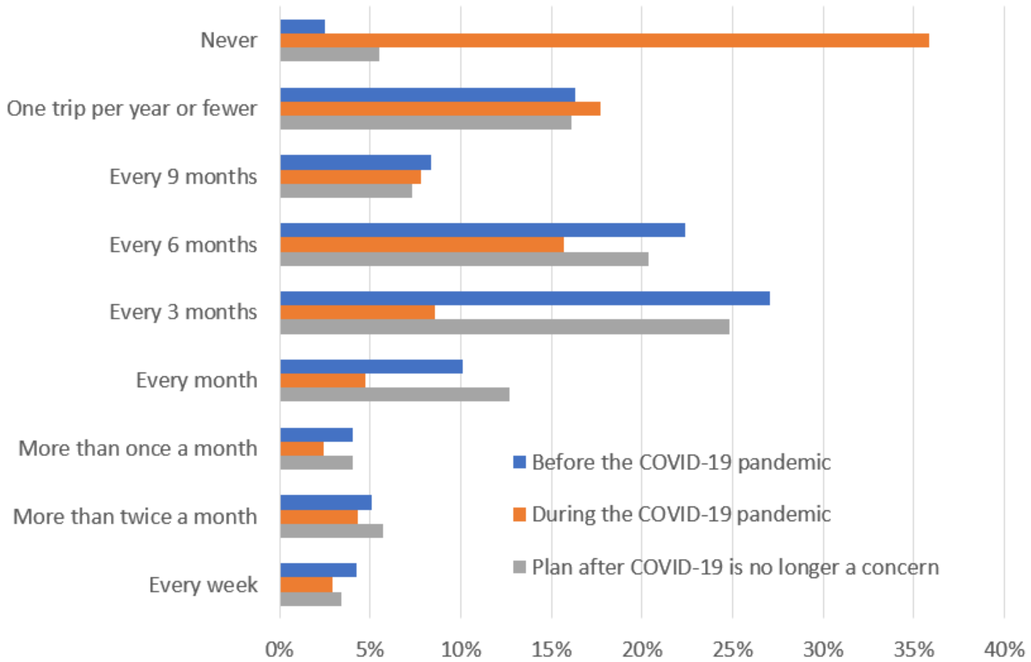


Figure 2. Long-distance trip frequency under the impacts of COVID-19

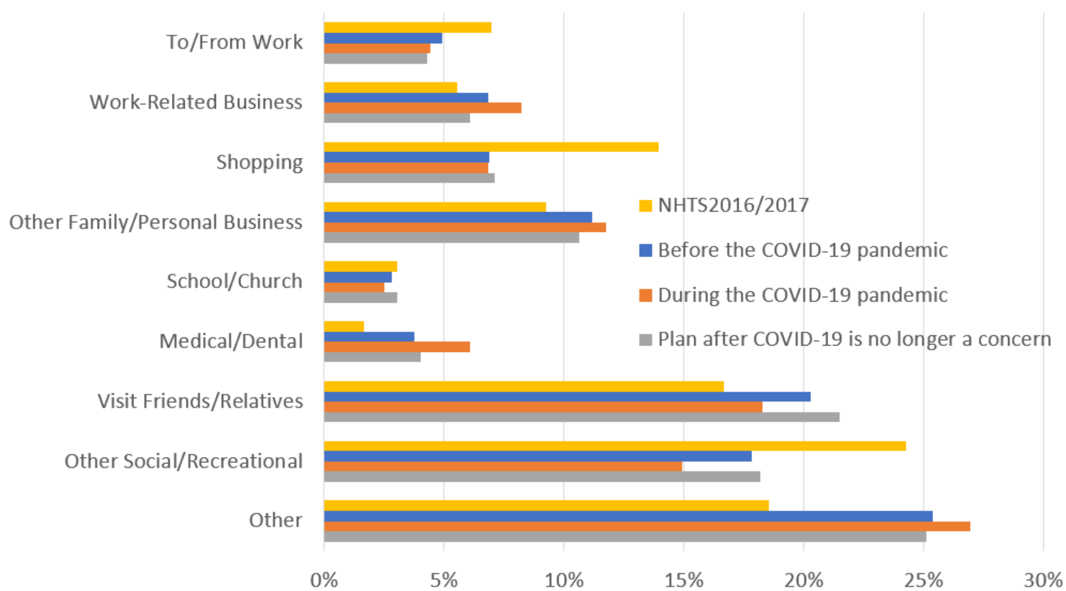


Figure 3. Long-distance trip purpose under the impacts of COVID-19

Figure 3 shows the split among different trip purposes. Information was collected only from those who made long-distance trips during the pandemic. This depicts people's shifts in LD trip purposes before and during the pandemic, as well as long-distance travel plans when the pandemic is no longer a concern. Since this figure does not involve the trip frequency associated with the purposes, the work-related trip shares are underrepresented. Therefore, the insight from this figure mainly lies in the change of trip purpose under different impacts of the pandemic. During the pandemic, there were more work-related business, family/personal business, and medical/dental trips, while trips for visiting friends/relatives and other social/recreational trips decreased. However, respondents'' plans showed that the trend would recover to levels observed before the pandemic, with an even higher trip rate. The NHTS 2016/2017 LD trip (over 75 miles one-way) data are also included in this figure for comparison. The comparison is straightforward since the survey in this study leveraged the same trip purpose categories as in NHTS 2016/2017. For the LD trip details of a specific day, NHTS data show more commuting and shopping trips, and other social or recreational trips while having fewer LD trips in medical trips and other categories. This is because NHTS takes record of one-way travel, and details of daily travel patterns are more likely to be provided. This is different from the survey conducted in this study, where respondents recalled the most recent LD trips, the pattern of which is more balanced over the days of the trip. The features of the LD trip (or sometimes a chain of trips) over a few days may be difficult to determine due to multiple purposes and destinations, and therefore many trip purposes fell in the "other" categories.

Respondents also indicated their primary travel mode for LD trips as well as those that were longer (over 500 miles) in the years 2019 and 2020. Personal car was shown as the main mode choice for long-distance trips between 75 and 500 miles, especially for non-business modes, accounting for over 70% of mode share. Business trips are more often constrained to time and typically subsidized by employers, so airplane modes were used more, accounting for over 50%. Train and bus were also popular with LD business trips over 500 miles, compared to non-business trips or those LD trips shorter than 500 miles. Rental cars, which can offer more flexibly in the trip itinerary, turned out to be favored by LD trips over 500 miles. Figure 4 charts the long-distance trip mode share.

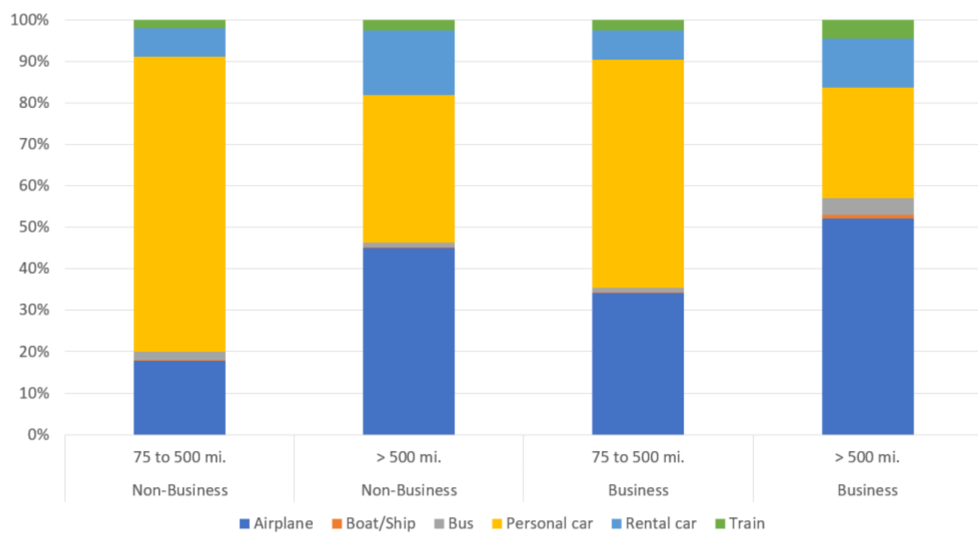
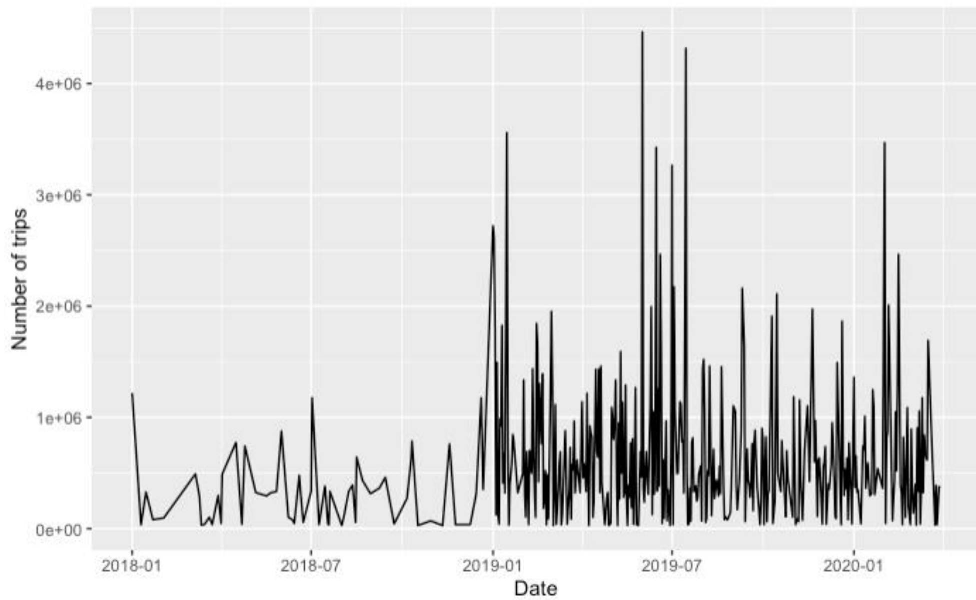


Figure 4. Long-distance trip mode share

REVEALED AND STATED PREFERENCES OF LONG-DISTANCE TRIP-MAKING

The next main part of the survey asked respondents to answer a series of questions relating to a specific long-distance trip taken before the pandemic. This portion revealed crucial information about respondents' trip duration, trip chaining, and expenses of both time and money for all modes taken to complete the LD trip. All of these details are critical to the modeling and prediction of future travel and its impact on the market share of various modes. Respondents were further asked to consider a hypothetical scenario where this trip were made with an AV. By offering various options of costs and time savings, the survey presented respondents' perceptions of how AVs would change their trip in terms of the amount paid, duration of travel, duration of stay, and party size.



Note: People who did not make long-distance trips in 2019 offered trip information from 2018

Figure 5. Long-distance trip departure date

Figure 5 shows the departure date of the most recent long-distance trip taken by the respondent before the pandemic. Most of the long-distance trip-makers traveled in 2019 and early 2020, but some of the trips described occurred in 2018. Most of the travel occurred in summer (around July). The trip destinations are shown in Figure 6. New York, California, Texas, and Florida were the top four attractive coastal destinations; Florida was the most popular overall.

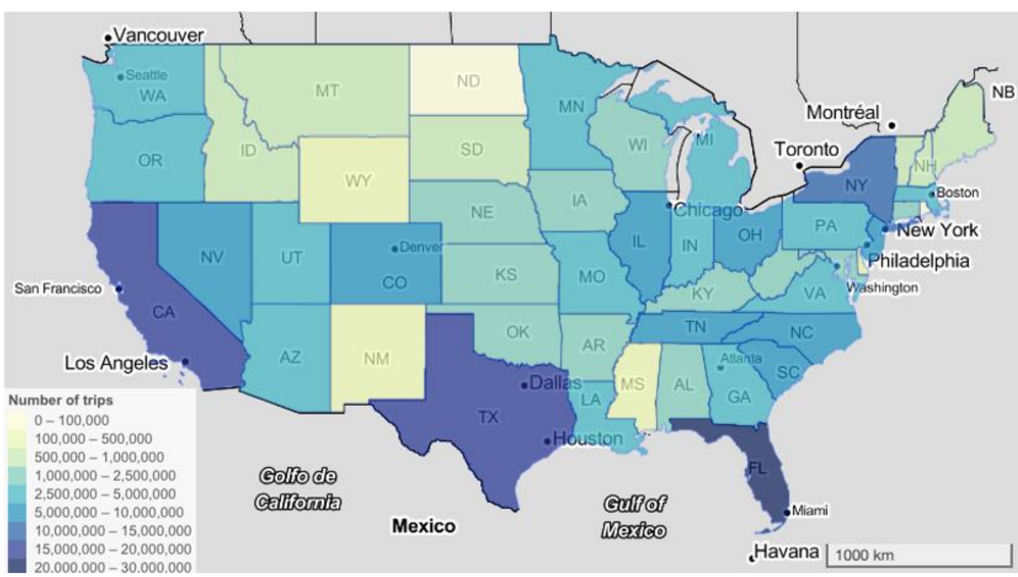


Figure 6. Long-distance trip non-home destinations

According to the responses, about 76.3% of the long-distance trips were round trips, while chain trips accounted for 13.1%, followed by one-way trips (10.6%). Here, a round trip is defined as a journey to a destination and directly back again, while a one-way trip is a trip from one place to another without a trip back. A chained trip is one trip journey during which the traveler makes at least one intermediate stop while traveling from the origin to the destination. Among these LD trips indicated by the respondents, 47.5% were shorter than 500 miles, with about 26.1% were longer than 500 miles but shorter than 1000 miles, and only 26.3% were over 1,000 miles. This shows that over half of the long-distance trips are actually over 500 miles, which is usually inter-state LD travel.

The mode choice pattern for this specific LD trip follows the general pattern that was obtained for the years 2019 and 2020 (Figure 7). Personal car is the leading mode choice across the US, followed by air travel, which accounted for 25%. Rental car is the third favored choice, compared to bus, train, or boat/ship. The NHTS 2016/2017 LD trip data shows a clearer pattern of daily travel compared to this study, seen from 18% more use of personal cars, but fewer by rental car (just 7%) or air (about half).

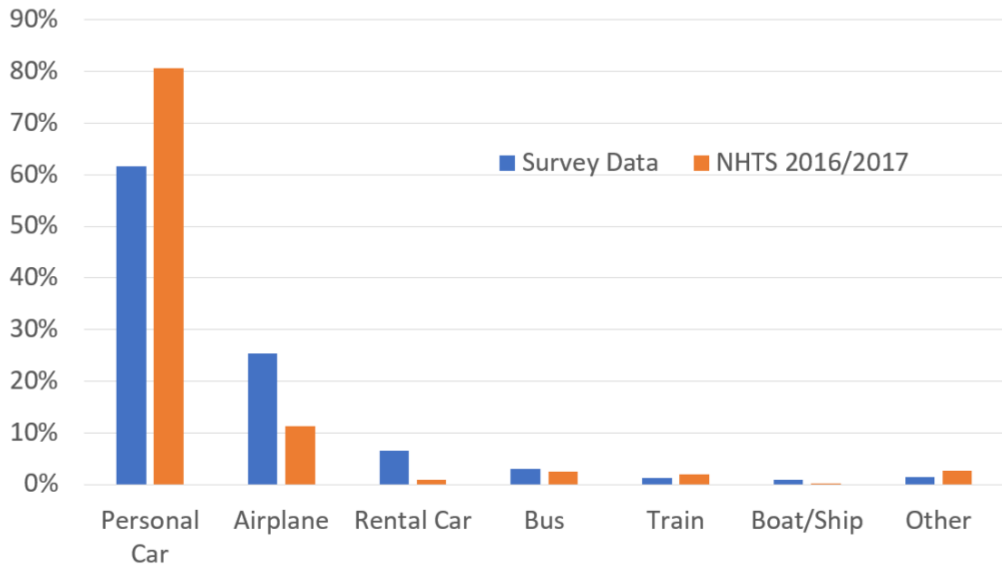


Figure 7. Long-distance trip mode choice

For those who took an airplane as the primary travel mode for this specific trip, the travel times of different legs of the trip were collected. The average travel time was about 7.86 hours across the US (a figure that encompasses door-to-door time elapsed, not merely the in-air component). As Table 2 indicates, the time onboard and in the air accounted for just over half of the total travel time, since a great deal of time is spent accessing, waiting at, and egressing the airport.

Figure 8a and Figure 8b show the respondents' willingness to use AVs for long-distance trips under different travel time and travel cost assumptions. Table 2 shows four different travel time assumptions to ascertain the willingness to use AVs, and a longer travel time question was asked only if the respondent replied "Yes" or "Maybe" to a shorter-travel time scenario. By looking at the answers of "Yes" or "Maybe", it turns out that 57% of the respondents may substitute their trip with an AV when the total travel time does not change. Even when the travel time increased by 50%, 9% of the respondents still chose to travel with an AV. Normally, the travel time would increase when compared to an air trip, since AVs usually travel faster than human-driven vehicles due to the elimination of rest time. Therefore, more people may shift to use an AV if the travel time falls further, so at least over 60% of the respondents may prefer an AV compared to the current travel mode.

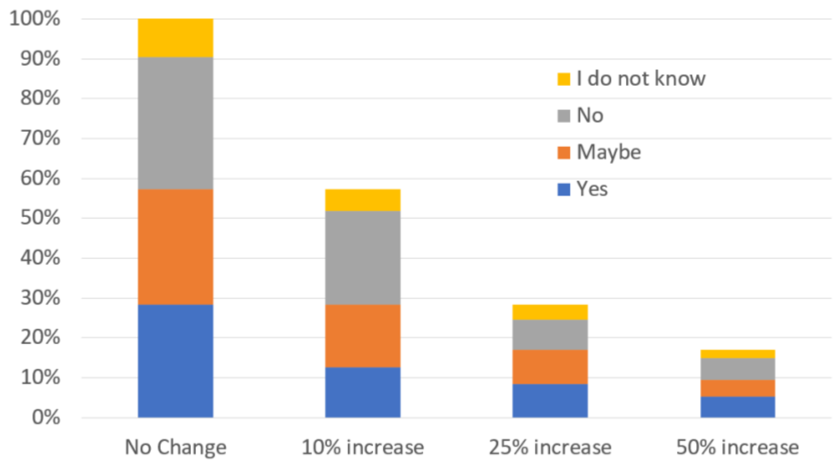
Table 2. Average time spent on different legs for air travel (25% of weighted samples to be air-based trips)

	Travel time (hours)

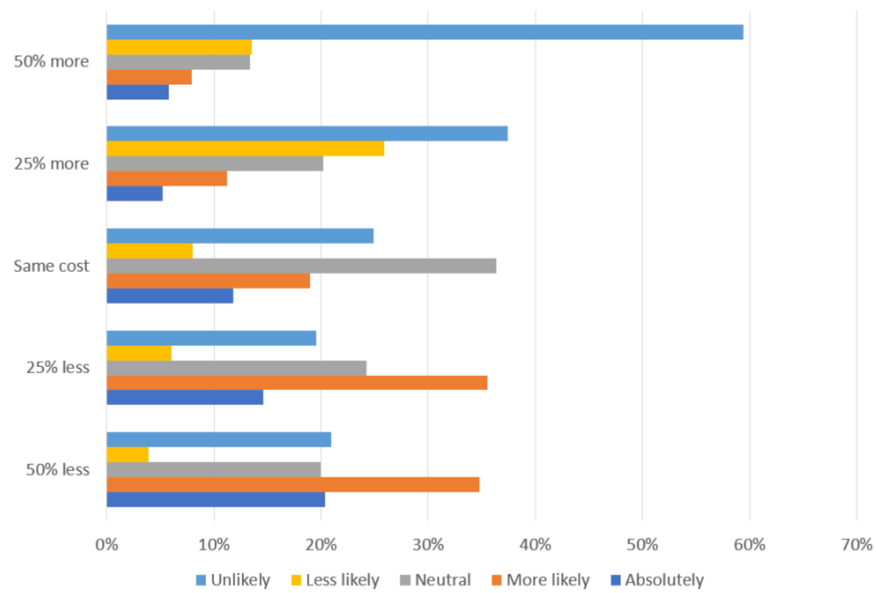
Time scheduling the trip to the airport (e.g., reserving a van or calling Uber/Lyft, renting a car)	0.38 hours
Time traveling to the airport (driving or being driven by someone else)	0.65
Time parking at the airport	0.13
Time spent going through airport security	0.38
Time waiting at the airport	0.87
Airplane onboard time	4.66
Time scheduling the trip from the airport (e.g., reserving a van, calling Uber/Lyft, renting a car)	0.22
Time traveling from the airport to your destination (driving or being driven by someone else)	0.57
Time parking at your destination	0.08
Total	7.86

In terms of the cost variations, about 60% of the respondents were "unlikely" to travel in an AV if the AV long-distance trip costs 50% more compared to traveling with a human-driven vehicle. Over 30% would travel in an AV if the travel cost remained the same as what the respondents had spent. Since AVs may cost less and bring more environmental benefits in the future, it is good to see that many people would shift to AVs (over 50%) if they experience a reduction in total travel cost. However, it is worth noting that about 20% of the respondents would not use AVs in any case. These people would probably be concerned primarily with safety or other issues, so they are indifferent about AVs' potential cost savings.

Figure 9 and Figure 10 show respondents' destination choice and willingness to include more stops during long-distance travel if AVs are used. This factor was included because AVs may bring changes in how travelers structure their long-distance travel. For example, long-distance trip-makers may want to make more stops (such as for leisure or family visits), because AVs lighten the driving burden and also minimize the time otherwise needed for drivers to take a break. AVs may also make it possible for long-distance trip-makers to travel to destinations farther away than they would consider when traveling using a human-driven vehicle. Moreover, since AVs can drive overnight, people may just stay in the AV to avoid another overnight stop at hotels, which would reduce the number of involuntary stops along the way. Therefore, these two figures show people's willingness to adjust the trip itinerary.



a) Change in travel time



b) Change in travel cost

Figure 8. Willingness to use AVs for long-distance trips by the change in travel time

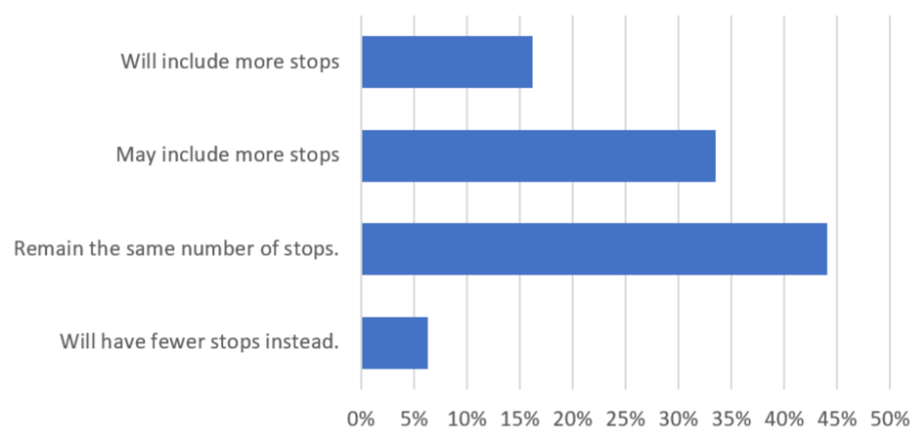


Figure 9. Willingness to include more stops in long-distance trips with AVs

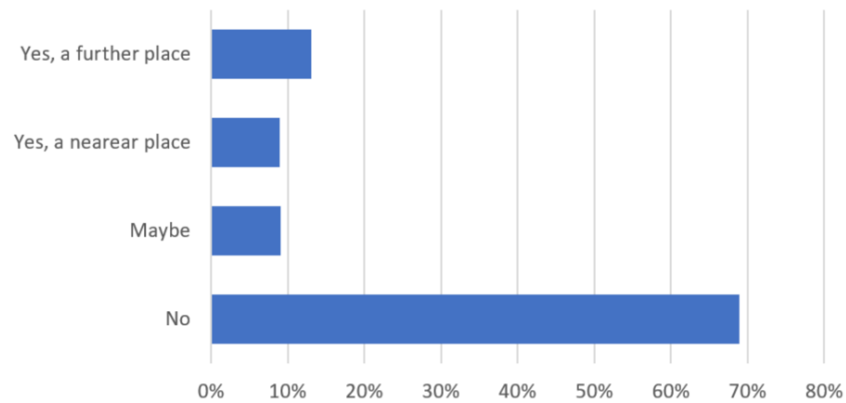


Figure 10. Change in destination choice for long-distance trips with AVs

The results show that over 40% of the respondents expressed the willingness to make more stops during their long-distance trip if an AV was used. However, their willingness to change may depend on how they experienced this LD trip. If their LD trips had already been well planned and experienced, respondents may not want to expect or imagine the changes that AVs can bring. However, they did not pay a visit to someplace they had planned or had severe delay at the airport, they would be more likely to use AVs to substitute the trips. The rest of the respondents would like to make such changes due to the availability of AVs, by either including more stops (50%) or having fewer stops (6%). Similarly, people's destination choice is robust (Figure 10), since almost 70% of the population would not change the destination with an AV. Among those people who would like to change destinations, 22% indicated that they would like to change to either a farther place or nearer place.

Trip duration was also investigated in terms of whether respondents would like to extend or shorten their stay, due to the flexibility that AVs can offer. Although many people would like to include additional stops along the way, at least 60% do not want to shorten or extend their stay, perhaps due to the time constraint on the vacation or other reasons (Figure 11).

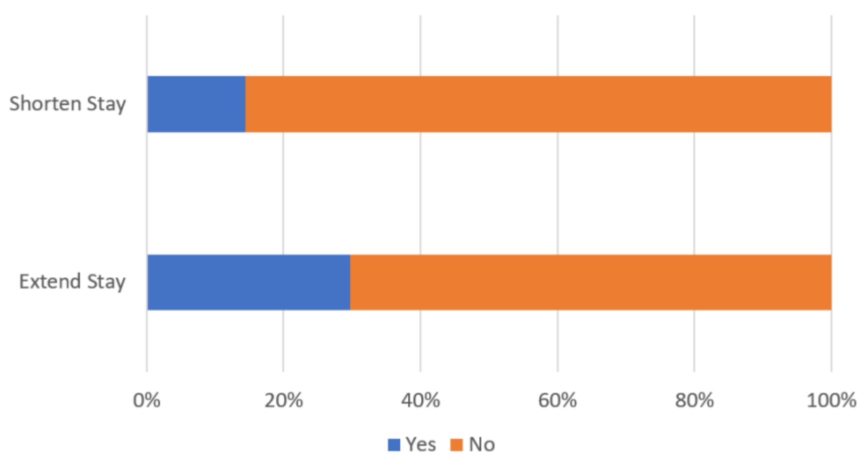


Figure 11. Willingness to change stay duration in long-distance trips with AVs

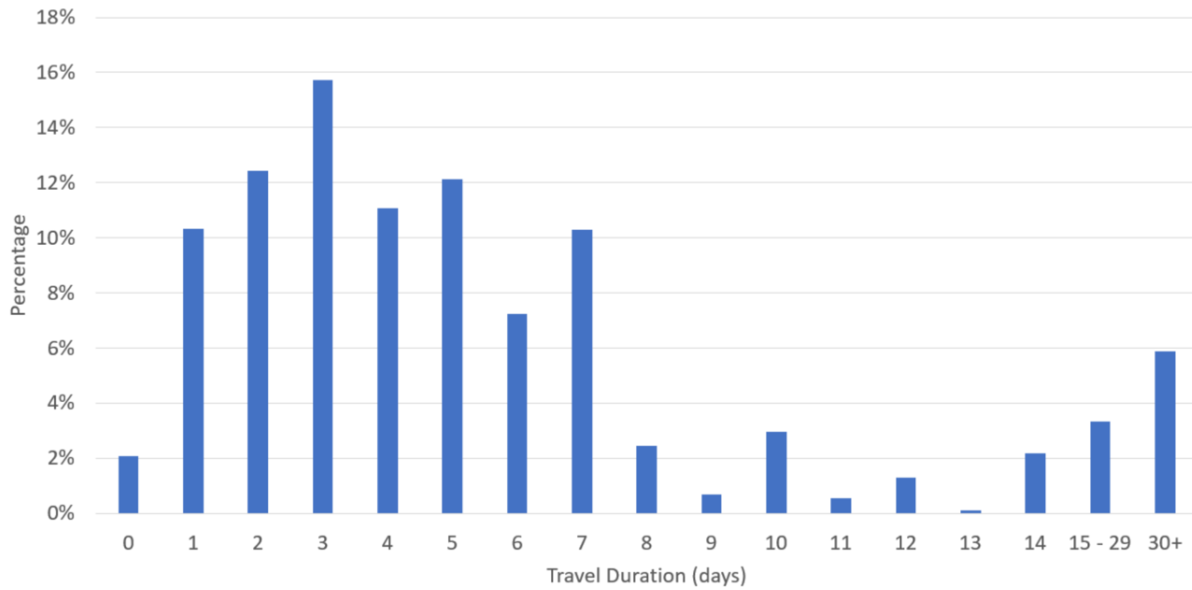


Figure 12. Long-distance total journey duration

Figure 12 further shows the total journey duration distribution (including stay at the destination and trip travel time) of respondents' long-distance trips. The "0-day" point on the axis means it is an overnight trip. 81% of the long-distance trips lasted less than one week, with three days being the most common total journey duration. Few long-distance trips were observed for more than two weeks and less than one month. However, there were some one-way trips due to home relocation (they never returned) or internships that took longer than two months, which contributed to the travel durations that were over one month. The average trip duration was 4.88 days, excluding the home-relocation trips (which typically last months, if not years, with people never returning).

Travel party size is another key feature of long-distance travel, but one rarely captured by prior surveys. The collected long-distance travel data revealed some details about travel party size. Respondents were more likely to travel with family members (67%) and friends (17%) for non-business trips as the most preferred companions. Only 5% of the respondents traveled with colleagues or associates for business trips. The average party size of family members is 1.5, with 0.4 friends and only 0.3 colleagues or associates. The most common travel party size was two (about 33%), followed by traveling alone, which accounted for 23% of total LD trips. Therefore, less than 45% of the total LD trips had a party size of 3 or more, and the average travel party size was shown to be 2.8 (Figure 13). This differs from the NHTS LD data, which show a party size of 1 as the most common, reflecting more solo-driving trips (42%) to/from work and other shopping trips within a day. Moreover, NHTS LD trip data had an average travel party size of 2.1 travelers, without reporting party sizes greater than 9.

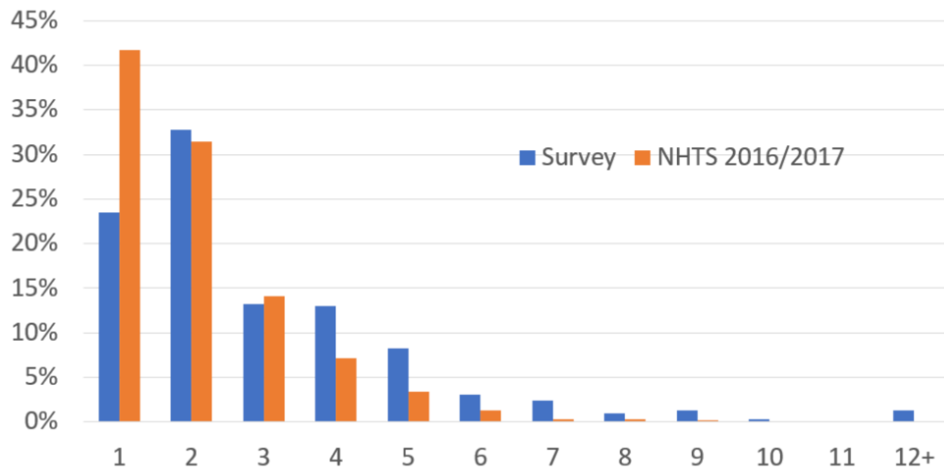
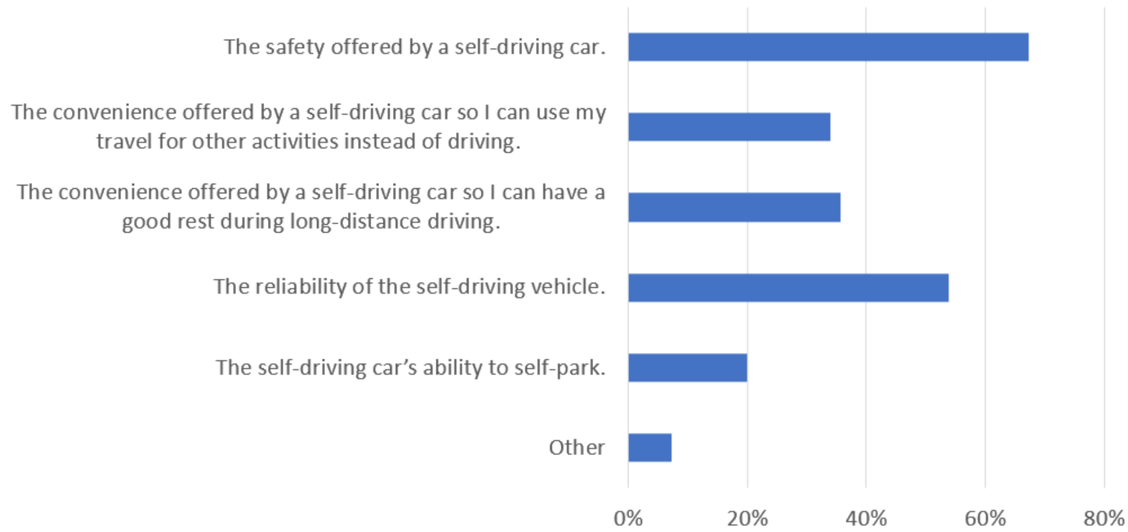


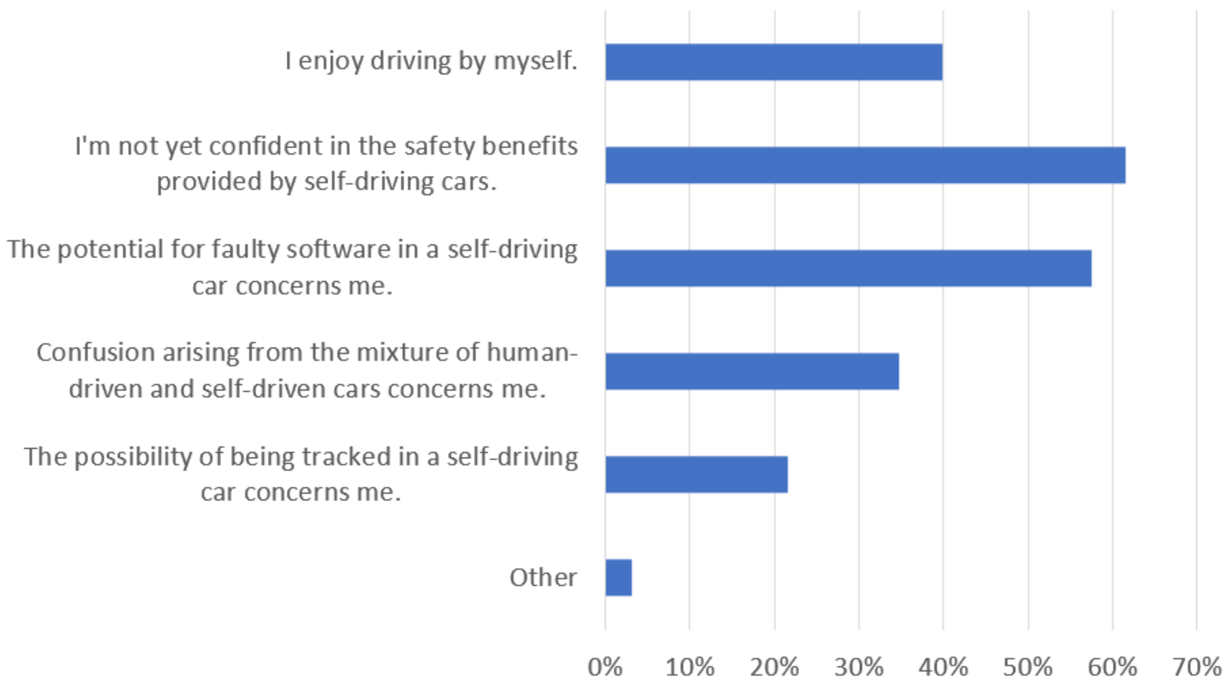
Figure 13. Travel party size distribution

Since the majority of the long-distance trips were non-business family trips, children were often involved. Results show that more than 40% of the families traveled with at least one child. With self-driving vehicles, households may also bring more children since AVs allow parents to better attend to their children. About 16% of the respondents (also considering those who do not have children in the family) indicated that they would bring children if they could travel with an AV. About 24% of American households have children under 18 years old (US Department of Transportation, 2017), which means that almost two-third of households having children may be able to bring children with them for long-distance travel. When the interest shifts from children to anyone they would like to travel with, 22% of the respondents would travel with more people in an AV for long-distance trips.

The reasons for respondents' preference for and against taking long-distance trips by AVs were also surveyed (Figure 14). People who would like to travel in an AV for long-distance travel enjoyed the safety of an AV most, followed by the reliability. The convenience offered by AVs came next, which was more enjoyed than AVs' ability to self-park. However, safety was also the main reason that people opted not to use AVs for long-distance travel, citing concerns about the potential for faulty software. Interestingly, enjoying the act of driving was another key point for those not wanting to travel in an AV, even though driving for long periods of time may be tiresome and tedious.



a) Reasons for AVs



b) Reasons against AVs

Figure 14. Reasons informing preference using AVs

FUTURE SCENARIO OF LONG-DISTANCE TRAVEL

In the future scenario section of the survey, respondents were given a future scenario to imagine where AVs are widely available and affordable. The questions were designed to provide insights on how this future mode choice of a self-driving vehicle would impact the frequency, duration, distance, destination, and departure time of possible long-distance trips.

Figure 15 shows respondents' mode choice considering two new AV choices: personal AVs and AVs for rental. Personal self-driving cars dominate the market for long-distance trips shorter than 500 miles, for non-business trips. After the personal self-driving car, the conventional car is the second choice for non-business travel (shorter than 500 miles). Air travel is favored for business trips instead of non-business trips. In terms of rental options, respondents preferred AVs much more over conventional cars.

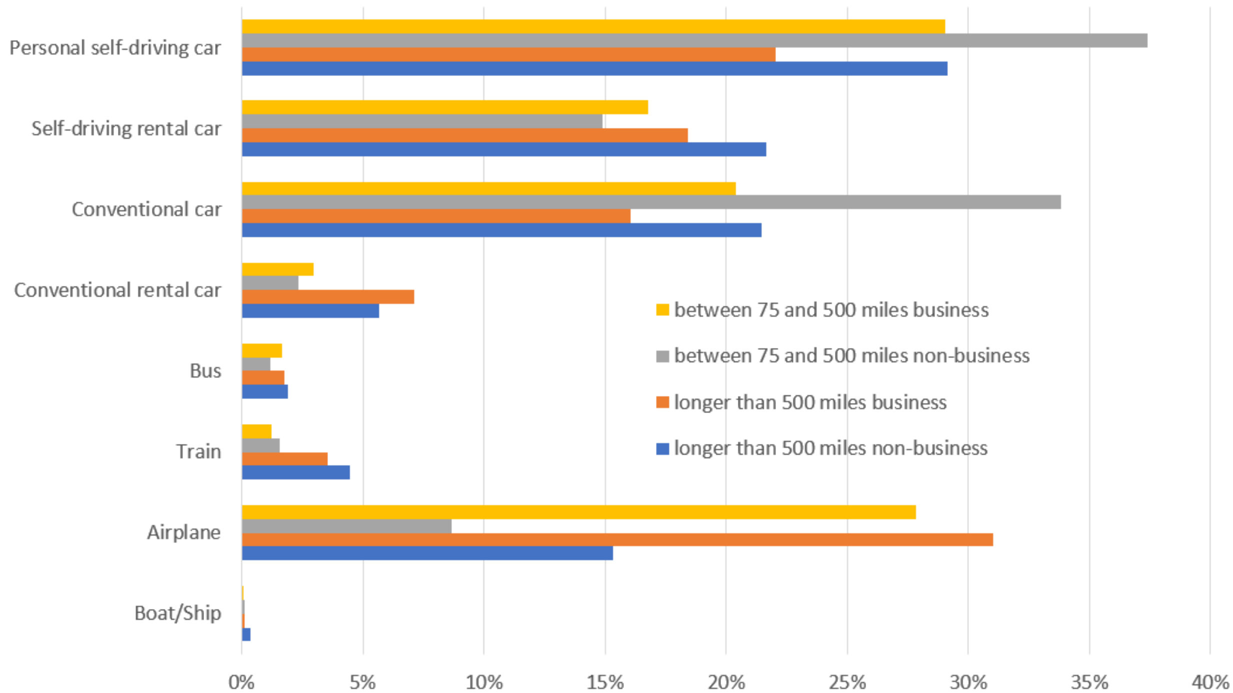
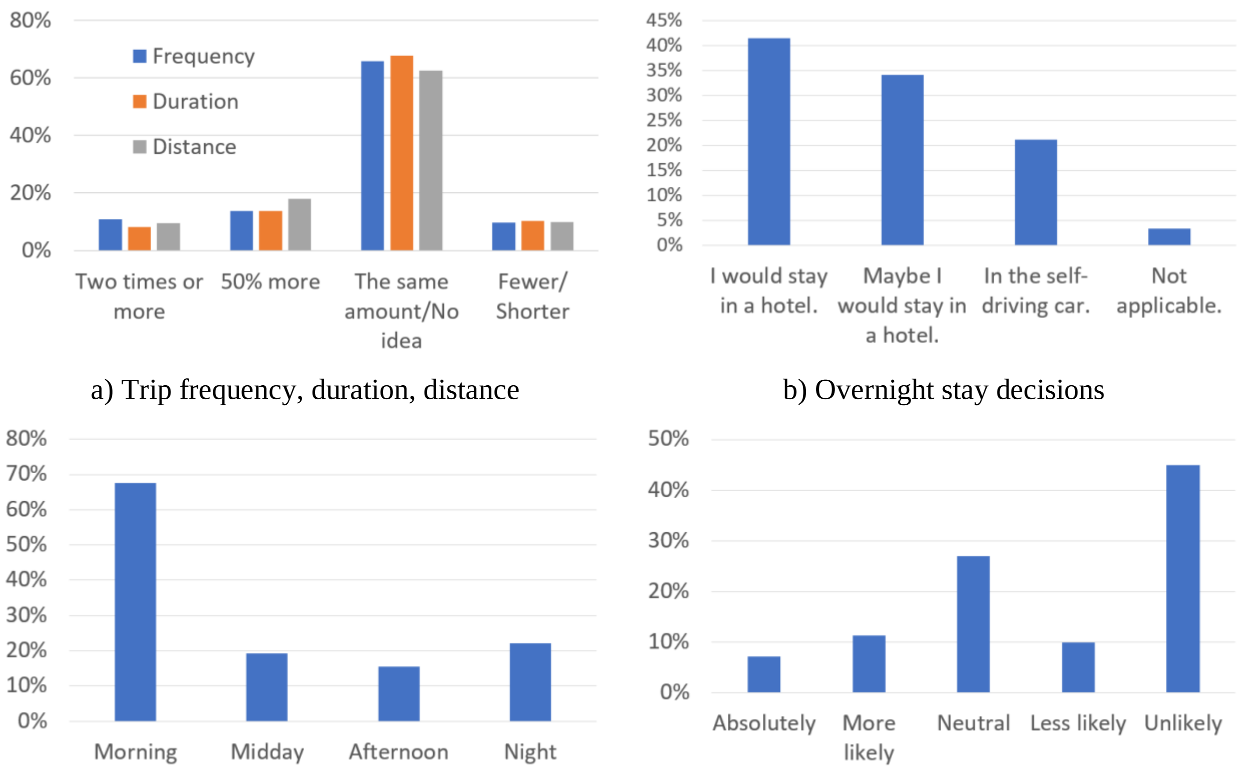


Figure 15. Mode choice for long-distance trips with AV choices

For long-distance trips that exceed 500 miles, the airplane is the most popular mode for business trips, followed by personal AVs and rental AVs. This is because such long-distance business trips are often subsidized and people tend to free their hands from driving, so that they can rest or work along the way. For non-business trips, the self-driving car is still the first choice, and the self-driving rental car is even slightly preferred over a conventional car.

Figure 16 presents different aspects of long-distance trip-making preferences when traveling in AVs. Figure 16a depicts the trip frequency, duration, and distance preference if the respondents can travel with an AV. Results show a similar pattern for the change in trip frequency, duration, and distance brought by AVs. The majority of respondents (over 60%) chose to maintain the same number of trips per year and the same trip duration and distance, or did not have a preference. About a quarter of the population would like to increase the trip frequency, duration, and distance, while about 10% of the population expected a reduction.

Figure 16b shows the respondents' decision about where to stay overnight when AVs are available. With an AV, one can just stay in the car overnight while the vehicle is still driving to the destination. However, about 40% of the population still preferred to stay in a hotel, while 50% would at least possibly remain in a self-driving car overnight. Figure 16c shows the departure time choice with AV travel. Although morning is the top choice, night turned out to be a preferred departure time choice compared to the afternoon, a more congested and busy time. Driving at night is a challenge for people who suffer from night vision problems—but AVs are anticipated to have technology that adequately supports night travel. The last question asked about people's willingness to share a ride with someone they do not know under a social-distancing policy during a pandemic like COVID-19. As Figure 16d shows, over 40% of respondents would not like to share the ride, while about 20% may share.



a) Trip frequency, duration, distance

b) Overnight stay decisions

c) Departure time

d) Willingness to share rides in pandemic

Figure 16. Long-distance trip-making preference with AVs

The survey found that passengers of a self-driving car were most likely to spend their time watching the landscape, listening to music, and eating or drinking (Figure 17). This is consistent with Lenz's (2016) findings, which indicated that users would most likely use the time to enjoy the landscape and talk to other passengers, and be least likely to work, as opposed to Das et al.'s (2017) study, which found that users would most likely use the time to perform tasks related to their main job. Some studies also argue that, based on how we see transit users engaging in non-work activities to simply pass time, we may not see AV users devoting their in-vehicle time to work (Singleton, 2019).

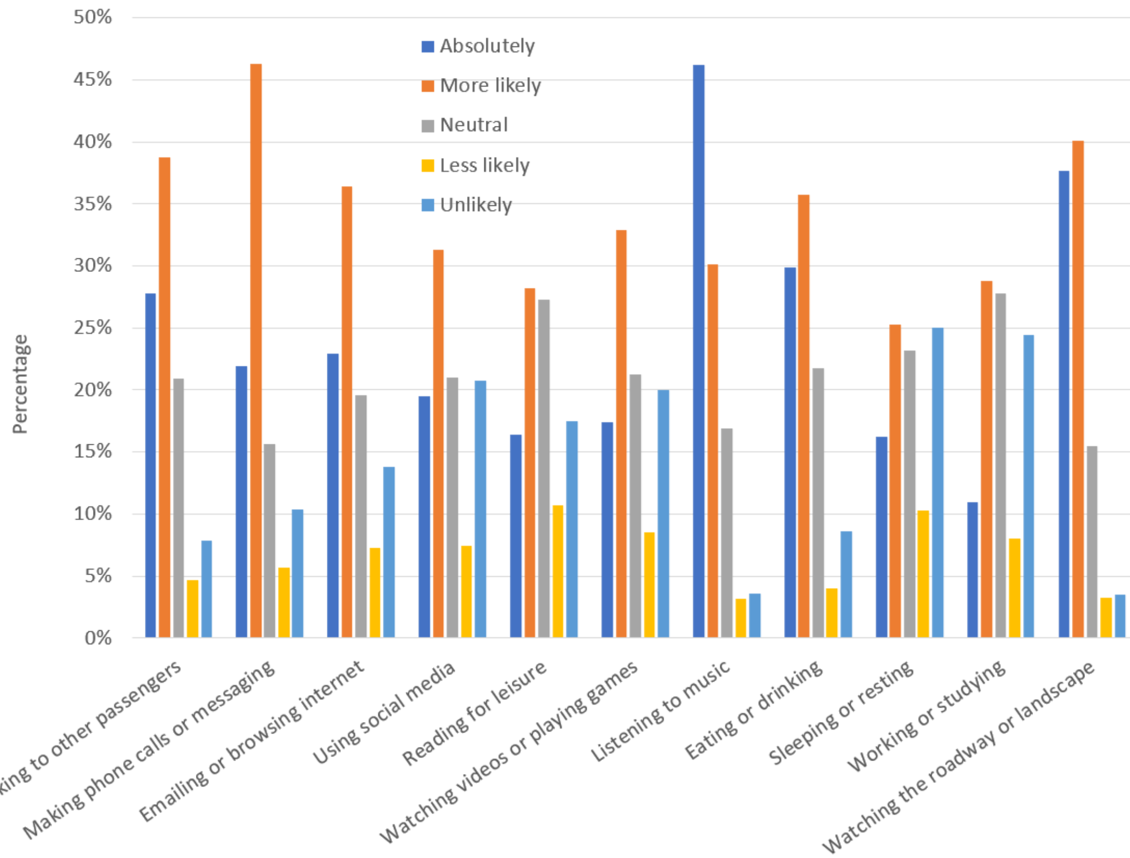


Figure 17. Attitudes towards different activities in a self-driving car

LONG-DISTANCE TRIP FREQUENCY MODEL

To understand the impacts of factors on LD trip-making frequency, a negative binomial regression model was used to predict the average number of LD business and non-business trips in the years 2019 and 2020. The year 2019 is considered to have no COVID-19 pandemic impacts, which is contrary to the year 2020. Table 3 shows the model results, for two different trip purposes in different pandemic situations (i.e., year 2019 and year 2020). The model for 2019 and 2020 was kept the same to reflect the impact of the pandemic, but the variables are different for business and non-business models.

A total of 1,004 samples were used to estimate the business model, with the base case as a single, aged 25 to 64, unemployed male, having an education level lower than high school and living in the Southern US. Other numerical variables were also included, such as income, number of workers, and number of children. Model results show that age under 24 years, residence in the Western and Midwestern US, number of workers and children, employment, and marital status are statistically significant at a 95% confidence level in LD-distance trip making before the pandemic. However, only the variables of residence in the Midwestern US, number of workers, and employment status were significant for the model during the pandemic. Looking at the model estimates, more workers and higher employment status (full-time employment vs. part-time or unemployed) led to more LD business trips in both 2019 and 2020. When LD trip-making was not impacted by the pandemic, people aged 25 to 64, living in the Western US with higher annual income were predicted to take more LD business trips. Interestingly, people with more children were predicted to make more LD business trips, which could be due to pursuing more household income to raise children, although taking care of children may often make one forsake the business travel plan.

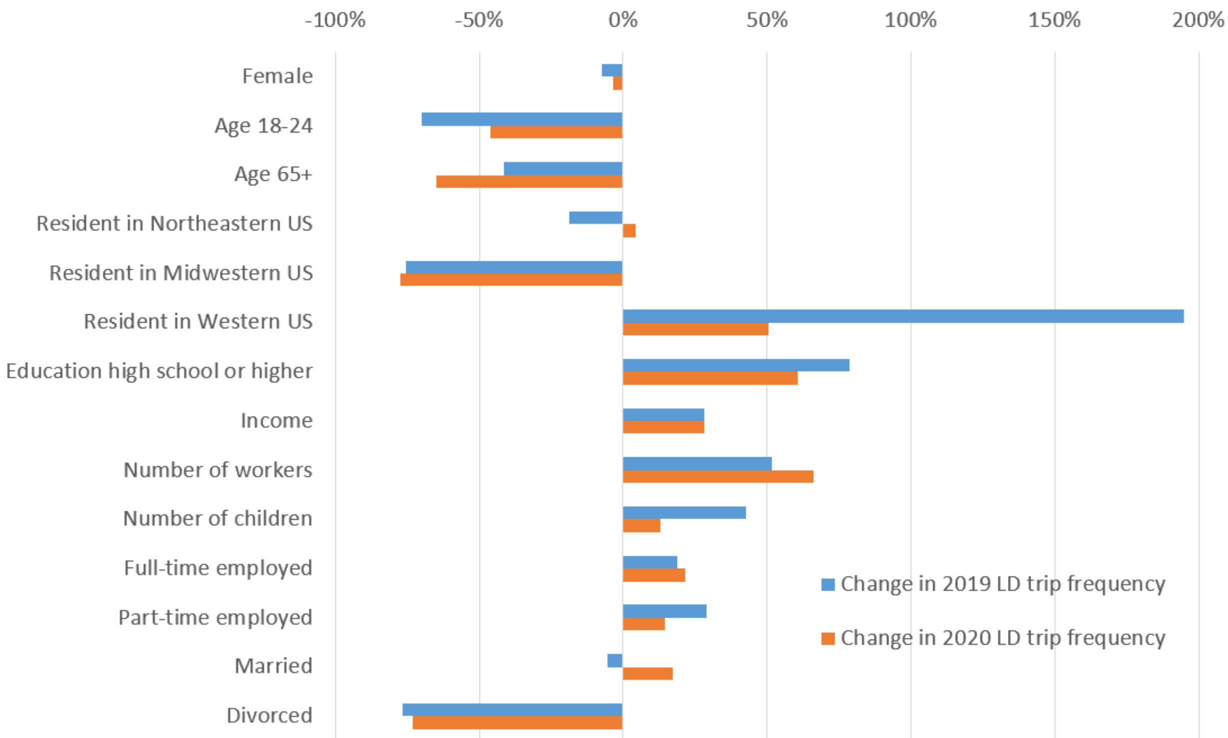
Table 3. Parameter estimates in annual business and non-business trip counts prediction in 2019 and 2020 (using population-weighted negative binomial count model)

	Business trip frequency in 2019			Business trip frequency in 2020		
	Estimate	Std. Error	P-value	Estimate	Std. Error	P-value
(Intercept)	-1.528	0.327	0.000	-2.385	0.444	0.000
Female	-0.147	0.194	0.449	-0.067	0.261	0.796
Age 18-24	-1.373	0.317	0.000	-0.722	0.411	0.079
Age 65+	-0.702	0.335	0.036	-1.150	0.459	0.012
Resident in Northeastern US	-0.025	0.268	0.927	-0.021	0.352	0.952
Resident in Midwestern US	-1.228	0.279	0.000	-1.553	0.372	0.000
Resident in Western US	1.264	0.234	0.000	0.347	0.319	0.276
Education high school or higher	0.660	0.265	0.013	0.533	0.355	0.134
Income (in $10k)	0.461	0.207	0.026	0.462	0.277	0.095
Number of workers	0.375	0.094	0.000	0.458	0.126	0.000
Number of children	0.369	0.109	0.001	0.126	0.146	0.390
Full-time employed	1.367	0.271	0.000	1.655	0.360	0.000
Part-time employed	1.448	0.334	0.000	1.596	0.447	0.000
Married	-0.460	0.233	0.048	0.398	0.317	0.210
Divorced	-1.863	0.408	0.000	-1.078	0.530	0.042
No. of observations	**1,004**			**1,004**		
Dispersion Parameter (ρ):	0.159			0.087		
McFadden's R2:	0.332			0.304		
Likelihood ratio test (χ2)	212			128		
Prob > χ2	0.000			0.000		
2 x log-likelihood	-2,261			-1,608		
	Non-business trip frequency in 2019			**Non-business trip frequency in 2020**		
	Estimate	Std. Error	P-value	Estimate	Std. Error	P-value
(Intercept)	1.094	0.155	0.000	0.992	0.217	0.000
Female	-0.069	0.089	0.442	-0.181	0.125	0.147
Age 18-24	-1.062	0.153	0.000	-0.801	0.206	0.000
Age 65+	-0.399	0.127	0.002	-0.967	0.181	0.000
Resident in Northeastern US	0.563	0.121	0.000	0.501	0.170	0.003
Resident in Midwestern US	-0.422	0.120	0.000	-0.584	0.167	0.000
Resident in Western US	0.252	0.112	0.024	0.074	0.157	0.634
Education graduate school or higher	0.240	0.096	0.013	0.344	0.135	0.011
Income (in $10k)	0.000	0.000	0.000	0.000	0.000	0.036
Number of adults	-0.129	0.056	0.021	-0.238	0.078	0.002
Number of workers	0.152	0.052	0.003	0.165	0.073	0.023
Number of children	0.136	0.069	0.048	0.154	0.096	0.111
Number of vehicles	0.234	0.052	0.000	0.308	0.073	0.000
Full-time employed	-0.614	0.107	0.000	-0.606	0.149	0.000
Married	-0.274	0.108	0.011	0.001	0.152	0.996
Divorced	-0.608	0.159	0.000	-0.334	0.220	0.129
No. of observations	**1,004**			**1,004**		
Dispersion Parameter (ρ):	0.693			0.335		
McFadden's R2:	0.198			0.114		
Likelihood ratio test (χ2)	231			110		
Prob > χ2	0.000			0.000		
2 x log-likelihood	-4,635			-3,719		

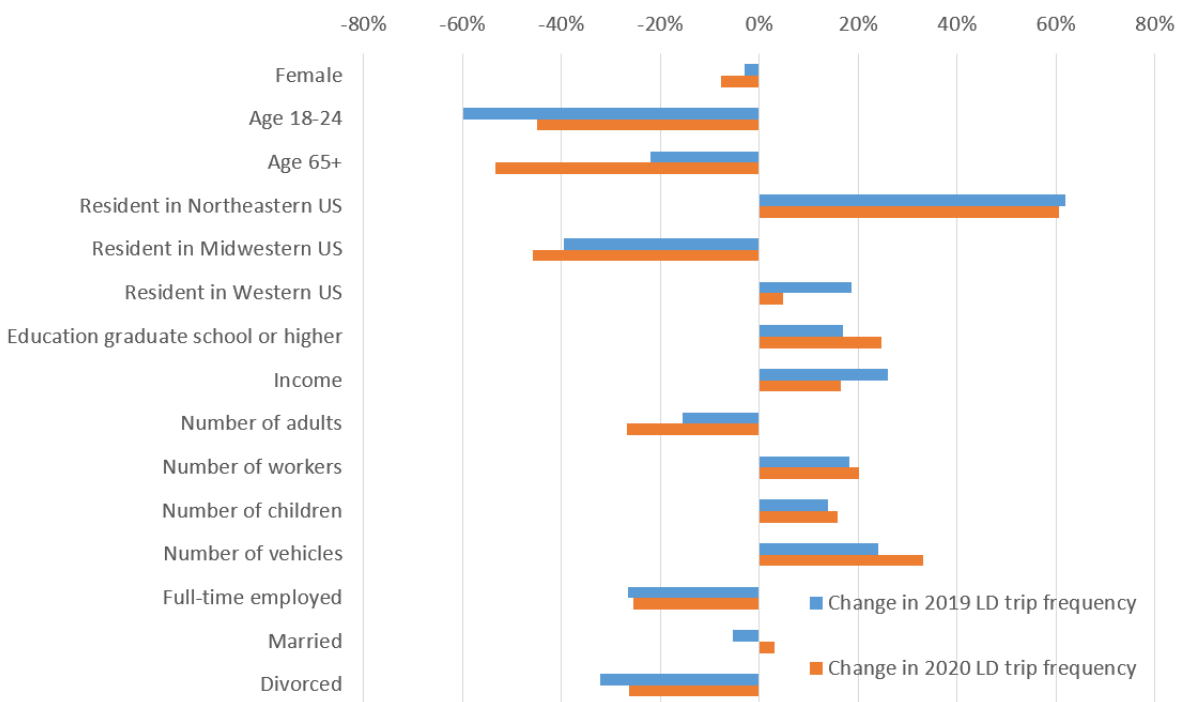
Figure 18a shows the practical significance of the model estimates, obtained by implementing a sensitivity analysis. The practical significance is shown as the value change of the estimated predictor by increasing the continuous variables by one standard deviation or shift from 0 to 1 for the categorical variables. The most practically significant variable before the pandemic was the residence in the Western US, where a lot of business companies are located. However, while it became less practically significant as many people worked from home, living in the Western US still led to a rise in LD business trip-making. Most of the variables were less practically significant because of fewer LD trips made on average during the pandemic. However, the aged 65+ variable was much more significant because the people in this group were more vulnerable to COVID-19 and thus were predicted to have much fewer LD trips.

For the non-business model, the base case is a single male, aged 25 to 64, not employed full-time, having an education level lower than high school, and living in the Southern US. Model results show that age, residence location, number of workers and children, income, number of vehicles, employment, and marital status were significant factors in LD-distance non-business trip making before the pandemic. Similarly, few variables were significant in the prediction model for the year 2020. Results show that people aged 25 to 64 years, living outside the Midwestern US, with higher education levels and more income, and more workers, children, and vehicles in the household would like to make more non-business LD trips. The young and mid-aged population may have more needs in LD trip-making for non-business purposes, such as visiting family and friends and for recreation. A higher education level, more vehicles, and more income would allow more trip-making. However, full-time employed people made fewer non-business LD trips compared to those who could afford more time (e.g., part-time employed people) on such trips.

Figure 18b charts the practical significance of the variables. The features of the non-business models show similar patterns to the business models, except for the following key changes. People aged 65+ making non-business LD trips were less practically significant compared to business LD trips because they still need trips to visit families or to engage in recreation even though they are retired (thus no business LD trips). One standard deviation ($51k) increment of the median income led to a 26% increase of the number of LD trips pre-pandemic, but only led to a 16% increase during 2020, likely because of people's unwillingness to make LD non-business trips when exposed to COVID-19 risks. Last, being employed full-time had a positive impact on LD trip frequency for business purposes, while it had the opposite impact on LD trip-making for non-business purposes.



a) Business trip frequency model



b) Non-business trip frequency model

Figure 18. The practical significance of variables in the trip frequency model

CONCLUSIONS

This research obtained stated and revealed preference data from 1,004 American adults (with 45% sampled within Texas). The survey asked for respondents' LD trip frequency (over 75 miles, one way), trip purposes, and mode choices in the years 2019 and 2020, along with their preference for activities while traveling in AVs for LD trips. Respondents' most recent LD trips before the pandemic were surveyed, including trip purpose, travel mode used, travel party size (number of persons), and willingness to use AVs. Their future travel choices were also investigated, in a scenario where AVs are widely available. After carefully cleaning and weighting the responses, the statistic summary was provided and respondents' business and non-business LD trip frequencies before and during the COVID-19 pandemic were modeled using a negative binomial count model.

Results show that over 60% of LD trips in years 2019 and 2020 were non-business in nature. During the pandemic, a 51% drop in LD travel occurred for those who used to take about four to six LD trips per year, while after the pandemic recedes, the number of those who used to take 12 to 24 LD trips per year during the pandemic would be expected to increase by 33%. Florida, California, Texas, and New York (given in ranked order) are the nation's top four state-level destinations, respectively (with Florida most popular overall). If AV travel were to cost half that of their prior LD trip, the share of American adults who would be "more likely" to travel in an AV jumped to almost 55%. And 22% of Americans felt they would travel with more people in an AV for their LD trips (presumably since the marginal cost of adding travelers to a rental car or privately owned AV is minimal, while buying a plane or train ticket is substantial). People who would like to travel in an AV for LD travel would enjoy the added safety most, followed by reliability. Safety was also the main reason respondents opted not to use AVs for LD travel, and they tended to consider faulty software to be a potential issue as well.

Results also suggest that American adults currently expect an increase in their long-term LD trip-making frequencies (29%), trip durations (28%), and/or travel distances (34%), thanks to AV availability. Roughly 45% predict unchanged LD travel behavior (43% for unchanged trip frequency and 46% for unchanged duration) for themselves. About 55% suggested they may choose to sleep through the night while their AV keeps moving, instead of stopping to overnight in a hotel (and delaying arrival at their destination). Respondents further indicated that if they were passengers of a self-driving car (AV) for LD trips, they would most likely spend their time watching the landscape, listening to music, and eating or drinking; they selected "work" as their least likely activity en route.

Results of the negative binomial trip counts model predict that people aged 25 to 64, living in the Western US with higher annual income take more LD business trips at times not affected by the pandemic. Under the impact of the pandemic, many of the variables become less practically significant in business trip frequency models because of fewer LD trips made on average. However, the aged 65+ variable is more significant because this group is more vulnerable to COVID-19, and thus are predicted to have much fewer LD trips. For the non-business model, results show that people aged 25 to 64 years, living outside the Midwestern US, with higher education levels and more income, and more workers, children, and vehicles in the household would like to make more non-business LD trips. However, full-time employed people would make fewer non-business LD trips compared to those who can dedicate more time (e.g., part-time employed people) on such trips.

It is also worth noting that international travels and LD trips over 500 miles substantially contribute to person-mile traveled (PMT) around the world (18% of overall PMT in NHTS 2016/2017 data). Although AVs may change people's destinations (to either a further or closer location), promoting shared rides in AVs can reduce VMT and emissions from long-distance travel. Furthermore, the COVID-19 pandemic has diminished interest in regular international travel, especially for work purposes, which can moderate background trends of rising PMT and VMT.

The survey has demonstrated many useful and interesting results that help anticipate Americans' LD travel choices. However, some limitations exist in the survey design and data collection process. The survey respondent pool represents a small sample of both Texas and US residents and has been scaled proportionally to represent the entire state and country. These responses may include outliers despite all efforts to be as representative as possible of the population. More samples can help reduce the sample bias, which also means a higher cost for data collection efforts.

Due to the total time constraint on the survey questionnaire, only approximately 70 questions were asked. Considering the multiple topics involved, including automated technology, the COVID-19 pandemic, and LD travel, additional questions would definitely help discover more in-depth results, but would also increase the burden for the respondents and thus produce an undesirable response quality.

Future work will incorporate statistical models to investigate the relationship between demographic variables and various other variables that impact LD trip-making decisions involving AVs, including LD travel frequency, travel distance, departure time, and destination choice. As more data emerges, the impact of the pandemic can also be modeled statistically, including trip frequency and purpose.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and survey design: Y. Huang, N. Zuniga-Garcia, and K. Kockelman; data collection: Y. Huang and N. Zuniga-Garcia; analysis and interpretation of results: Y. Huang and N. Zuniga-Garcia; draft manuscript preparation: Y. Huang, N. Zuniga-Garcia, and K. Kockelman. All authors reviewed the results and approved the final version of the manuscript.

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