Estimating the Costs of New Mobility Travel Options: Monetary and Non-Monetary Factors

August 2020

A Research Report from the National Center for Sustainable Transportation

Lewis Fulton, University of California, Davis

Junia Compostella, University of California, Davis

Alimurtaza Kothawala, University of California, Davis

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NCST-UCD-RR-20-23	N/A	N/A

4. Title and Subtitle Estimating the Costs of New Mobility Travel Options: Monetary and Non-Monetary Factors	**5. Report Date** August 2020 **6. Performing Organization Code** N/A
7. Author(s) Lewis Fulton, Ph.D., https://orcid.org/0000-0001-8292-3420 Junia Compostella, https://orcid.org/0000-0002-5668-8161 Alimurtaza Kothawala, https://orcid.org/0000-0002-3916-4534	**8. Performing Organization Report No.** UCD-ITS-RR-20-43
9. Performing Organization Name and Address University of California, Davis, Institute of Transportation Studies 1605 Tilia Street, Suite 100 Davis, CA 95616	**10. Work Unit No.** N/A **11. Contract or Grant No.** USDOT Grant 69A3551747114
12. Sponsoring Agency Name and Address U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology 1200 New Jersey Avenue, SE, Washington, DC 20590	**13. Type of Report and Period Covered** Final Report (October 2018 – March 2020) **14. Sponsoring Agency Code** USDOT OST-R

15. Supplementary Notes

DOI: https://doi.org/10.7922/G20R9MN8
Dataset DOI: https://doi.org/10.25338/B8Q04H

16. Abstract

UC Davis researchers have developed a cost model of travel choices that individuals make related to urban vehicle travel. These choices can include deciding to own, ride in, and drive a private vehicle or use pooled or solo ridesourcing (e.g., Uber). The model considers both monetary and non-monetary factors that affect travel choice. Monetary factors include the costs of purchasing, maintaining, and fueling different types of privately owned vehicles; and the cost of using ridesourcing services. Non-monetary (or "hedonic") factors include travel time, parking time/inconvenience, willingness to drive or be a passenger in a driven or automated vehicle, and willingness to travel with strangers. The travel choices affected by these factors impact broader society through traffic congestion, pollution, greenhouse gas emissions, accidents, etc. and thus may be an important focus of policy. This report reviews recent literature, considers factors affecting travel choices, and reports, on a conjoint pilot survey or stated preferences. Finally, it considers approaches to apply time value to factors that are not typically associated with specific trips, such as time spent on vehicle maintenance and parking. The results should enable a deeper understanding of the likelihood that individuals will own and use private vehicles or use shared (solo and pooled) ridesourcing, and how automated vehicle services could affect these choices in the future. The study also highlights additional research needs, such as a large scale stated preference study covering more factors than have been included in previous studies.

17. Key Words	18. Distribution Statement
Travel costs, value of time, mode choice, cost estimating, hedonic costs, non-monetary costs	No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	44	N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

About the National Center for Sustainable Transportation

The National Center for Sustainable Transportation is a consortium of leading universities committed to advancing an environmentally sustainable transportation system through cutting-edge research, direct policy engagement, and education of our future leaders. Consortium members include: University of California, Davis; University of California, Riverside; University of Southern California; California State University, Long Beach; Georgia Institute of Technology; and University of Vermont. More information can be found at: ncst.ucdavis.edu.

Disclaimer

Acknowledgments

This study was funded, partially or entirely, by a grant from the National Center for Sustainable Transportation (NCST), supported by the U.S. Department of Transportation (USDOT) through the University Transportation Centers program. The authors would like to thank the NCST and the USDOT for their support of university-based research in transportation, and especially for the funding provided in support of this project. The study was co-funded by the UC Davis STEPS+ consortium; we would like to thank a range of sponsors in this regard.

NCST

Report Estimating the Costs of New Mobility Travel Options: Monetary and Non-Monetary Factors

A National Center for Sustainable Transportation Research Report

August 2020

Lewis Fulton, Director, Sustainable Transportation Energy Pathways, Institute of Transportation Studies, University of California, Davis

Junia Compostella, Ph.D. Candidate, Transportation Technology and Policy, University of California, Davis

Alimurtaza Kothawala, Research Engineer, Institute of Transportation Studies, University of California, Davis

NCST

[page intentionally left blank]

TABLE OF CONTENTS

List of Tables

List of Figures

Estimating the Costs of New Mobility Travel Options: Monetary and Non-Monetary Factors

EXECUTIVE SUMMARY

In this project we developed a travel cost model and considered a range of factors in travel choices that have not received much attention to date. The project is exploratory in nature and this report presents the initial findings. The scope is urban travel with a focus on choices between private vehicle trips, on-demand "ride sourced" trips, with and without ride sharing, and, finally, how vehicle automation may change the attractiveness of these various options. The effort includes consideration of both monetary and non-monetary factors, but the primary emphasis is on non-monetary factors, including factors that vary with trip length, are fixed for a given trip length, do not occur on every trip, or do not occur in any regular pattern related to trips.

Non-monetary factors are here considered mainly along the dimensions of time, such as the amount of time it takes to park a car, wait for an on-demand vehicle to arrive, or load and unload possessions from that vehicle. The travel choices affected by these factors impact broader society through traffic congestion, pollution, greenhouse gas emissions, accidents, etc. and thus may be an important focus of policy. This report reviews recent literature, considers factors affecting travel choices, and describes a conjoint pilot survey of stated preferences. Finally, it considers approaches to apply time value to factors that are not typically associated with specific trips, such as time spent on vehicle maintenance and obtaining registration and insurance.

We first present specific generalized cost estimates derived from literature and previous analysis—these cover the main monetary cost categories and several time-related categories. We then present several other factors affecting travel choices, that are difficult to quantify. We present literature related to these, and how they could be quantified via conjoint-style analysis. Next, we present a conjoint type survey approach and some findings from our own pilot survey. Finally, we attempt to quantify some additional factors, by converting them into time costs.

Overall we find that: (a) there are many factors that may affect trip choices; we have identified over two dozen, but we do not claim to have created an exhaustive list; (b) most of these factors are basically activities that require time to complete and thus can theoretically be measured as a time cost; however we have not undertaken empirical work on whether time is the best metric for some of these, or what time value should be attached; (c) using standard values of time, many of the factors will have some impact, but few appear important enough to significantly change the overall relative costs of various trip choices. However, we acknowledge that they could be very important for some travelers and in some situations.

The study results should enable a deeper understanding of the likelihood that individuals will own and use private vehicles or use shared (solo and pooled) ridesourcing, and how automated vehicle services could affect these choices in the future. The study also highlights additional

research needs, such as a large scale stated preference study covering more factors than have been included in previous studies.

Introduction

This report explores a range of costs associated with travel, including monetary and non-monetary, or “hedonic,” costs. It builds directly on two other recent reports by this UC Davis research group (Compostella et al, 2020, Fulton et al, 2020). The information provided here can help analysts and policy makers assess the relative costs of different modes and give some indication of the likely mode and vehicle choices travelers might make in different situations in the near and longer term. For example, how might travelers consider and weigh different factors in choosing between private vehicle vs ridesourcing travel options, and how might this shift with increased availability of automated vehicles. This report is exploratory: it considers a range of information and studies, and considers strategies for obtaining estimates of factors affecting trip choices that may be more difficult to obtain. It presents one stated-preference approach to collecting data and a more ad hoc, time-based cost approach that can give a rough sense of the time cost for various difficult-to-quantify trip choice factors.

The report is focused on trip choices mainly in the context of “three revolutions”: electrification, sharing (of vehicles and rides), and automation. The report examines the first two of these in the context that they have already begun, and the last with a view to anticipated developments and market availability. All of these revolutions were covered in our previous two reports, but many of the potential factors influencing ridesourcing choices, and the impacts of automation (driverless vehicles) on those choices, were beyond the scope of those studies. These factors include avoiding various hassles associated with driving one’s own vehicle, vs. hassles associated with traveling in something other than one’s own vehicle. This report also considers more general concepts such as “car pride” (pride of ownership) though it does not attempt to quantify this value.

Overall the report is a combination of building on previous work by adding new estimates, reporting on the literature, and considering methods for estimating parameters in the future.

The report is organized as follows.

- Section 1 provides a general framework for considering costs of travel choices, and how these may be considered for the particular set of travel choices of interest in this analysis.
- Section 2 presents a general literature review of the topic and key aspects specific to this subsequent analysis.
- Section 3 provides the results of two previous studies of values of various factors in making travel choices.
- Section 4 presents the results of a new survey effort, applied in a pilot fashion, that can help generate ideas for additional research.
- In section 5, we propose some interim values of various key variables using a simplified methodology.
- Finally, we present conclusions and recommendations for future research.

Categorization of Cost Factors that Affect Travel Choices

Trip choices are decisions that travelers make related to where, when, and how they move about. Subcategories of trip choices include both mode choices (e.g., between automobile, transit, walking, bicycling, scooter use, etc.), and vehicle choices (e.g., between ridesourcing, carsharing, driving one's own car, and, more generally—separate from specific trips—owning vs. not owning a vehicle). There has been much study of mode choices in an urban context. In recent years there has been considerable attention given to vehicle choices—such as the choice between driving one's own vehicle or taking "ridesourcing" on-demand taxi-like services. Within this trip choice is a secondary choice between a solo or a shared (pooled) trip. In the context of ridesourcing, a shared trip usually involves the driver making separate stops to pick-up and drop-off passengers who are strangers. Finally, in the future, there is the possibility of driverless cars, either owned by the traveler or as part of a mobility service. In this paper we consider the subset of overall choices involving these newer phenomena—namely ridesourcing with and without other passengers, and with or without a driver, compared to driving one's own car (and in the more general picture, whether or not to own a car).

There are many cost-related factors that will influence decisions among these choices. There are factors related to a particular trip (distance, available choices, traffic, parking), and more general factors, such as the price of fuel or the price of a ridesourcing service. Some factors can be measured monetarily, some cannot. There may be important factors affecting trip decisions that we are generally unaware of, or that we have not systematically considered, such as various phobias.

The full set of factors influencing trip choices, whether monetary or not, create what is known as a "generalized cost" for that choice, often measured as a cost per trip or per unit distance (Bruzelius, 1981; Koopmans et al, 2013). We define generalized cost (GC) as the sum of monetary costs and non-monetary costs, such as travel time costs and other factors that influence choices. In this paper, we compare many of the factors and provide some initial estimates of their potential values, without attempting to estimate their net effects on specific micro or macro choice behavior (as might be reflected in travel mode share estimates).

In Table 1 we attempt to identify a range of relevant trip choice factors and create a typology that can be used to categorize these factors. This set of factors is by no means exhaustive, and the grouping system used here is one of many that could be constructed. The point is to organize our thinking and help others think about how various factors might be measured and what types of impacts they may have on trip decisions.

Table 1. A typology of travel choice cost factors (black roman type applies to vehicle owners/drivers; bold blue type applies to TNC passengers)

Cost category	Separate from/unrelated to specific trips	Proportional to trips but not paid specifically for each trip	Paid once or twice per trip	Lumpy (paid only on some trips)	Paid (or can be measured) per-mile
Monetary	• Insurance • Registration and other annual or monthly fees	• Vehicle amortization/ per-mile depreciation • Maintenance/repair cost • Vehicle cleaning	**• TNC "first mile" fee**	• Tolls • Parking cost • Parking/speeding fines	• Fuel cost **• TNC per-mile fees** • Per-mile road user fees (taxes)
Non-monetary: value of time-related	• Car ownership nuisances: annual registration, insurance, parking stickers	• Maintenance/repair and inspections events (time and in some cases loss of vehicle use)	• Time spent parking and searching for parking • Time walking to/from vehicle to "door" **• Time spent waiting for vehicle to arrive/risk of cancelation**	• Time spent refueling • Time spent cleaning • (For EVs) recharging time • Recharging station search time, anxiety • Time spent loading/unloading vehicle	• Travel time (main trip) • Uncertainty of arrival (traffic related) **• Uncertainty of arrival (extra pickups/drop-offs for pooled trips)**
Non-monetary: other	• Car ownership pride • Per-vehicle environmental impacts (vehicle production, disposal) • Ability to keep items in own vehicle (storage value) • Vehicle/mode availability (confidence in, option value)	•General crash/safety risks •Safety/security concerns related to specific modes or technologies such as automation •General "range anxiety" about an electric vehicle		• Risk of vehicle damage/theft (locational)	• Driving stress or enjoyment **• Ride sharing (pooling) stress or enjoyment** • In-ride productivity • In-ride entertainment and other hedonic factors • Per-mile environmental impacts (CO2, air pollutants)

NCST

The table groups and breaks-out various trip choice factors in a number of ways. One is whether these occur during each trip (e.g., fuel cost) or only for some trips (e.g., tolls), or are unrelated to specific trips (e.g., vehicle registration cost). There is a strong basis in the literature (e.g., Litman, 2016) to indicate that travelers pay closer attention to costs that vary per trip when making each trip—for example, the variable cost of that trip is more important than other fixed costs (such as the "sunk cost" of owning an automobile). Some costs occur only occasionally or are weakly linked with individual trips. Even fuel cost, which is listed here as a per-trip cost, is generally only paid weekly or less frequently. Further, even frequently paid costs may not be perceived as a cost that must be paid for every trip. Thus, there are many subtleties to how costs are paid and how they may impact trip choices, that are not well reflected in this table.

Another division between rows in the table is whether costs are monetary—clearly measured by financial cost—or non-monetary. Some non-monetary costs can be measured as a time cost—the amount of time someone must spend on the factor in order to undertake and complete trips. Searching for parking is an example. Finally, some factors cannot easily be measured in terms of time and are more general. These include the pride of car ownership (or driving that car), or the stress of driving. In theory, if these costs/benefits can be measured at all, they might be convertible into values per unit time, but this may be difficult to do in a meaningful way.

The table also organizes factors by whether they apply to vehicles owned by the traveler or they only apply to trips in shared or ridesourced vehicles (as fees), or whether they apply to both. Actually, all monetary costs to ridesourcing vehicle drivers can be expected to be passed through to customers, in order for the driver to earn a "normal" return on their own cost. However, these costs certainly vary, and since trip rates are generally fixed, variations in driver cost do not translate into changes in what they can charge, and this becomes problematic in assuming that all driver/owner costs are passed through. In a perfect market, even non-monetary costs would be passed through, though this cannot be assumed. What is true is that if monetary and nonmonetary costs become too high to the driver, they can decide to stop offering the service as the rate of fee and overall income do not compensate them for their costs and labor adequately.

As noted in the title of the table, those factors specific to commercial, ridesourced travel appear in boldface, blue type. Ride-sourcing travelers benefit by not having to worry about many factors that drivers/owners must, such as driving stress, fueling/maintenance/vehicle cleaning time, etc. Many of these costs, borne by the owners/drivers of such vehicles, may or may not be passed through to ride-sourcing travelers.

The table represents one attempt to list and organize decision factors and provides a foundation for thinking about different types of decision factors and costs. There are certainly other possible approaches and important factors that are not in the table. Thus, it is a work in progress and should be advanced as more thinking goes into developing this typology. The next section considers the above types and some of the literature that exists around them.

Review of Our Recent Work and the General Literature

There is an extensive literature on travel behavior, including how individuals choose transportation modes and make selections when buying vehicles. It is well established that while individuals take into account the monetary cost of trips, they also consider many other factors. As mentioned, these amount to a set of generalized costs. The non-monetary cost factors are often termed hedonic costs, since they matter to the individual from the point of view of time (e.g., travel time), comfort, convenience, safety, security, or other non-monetary impact. If a monetary value can be estimated for these, they can be included in a monetary-based generalized cost function. We have considered some of these in our previous work discussed here.

Our Studies

Two of our recent publications (Compostela et al, 2020 and Fulton et al, 2020) explore these monetary and hedonic costs. These reports are specifically drawn on in our analysis here and provide a set of estimates of what these costs may be for different types of trips, and, to some degree, for different types of people. We refer the reader to our review of literature in these reports. Here we build on that review, focusing on literature that treats some unusual aspects of travel choice and the use of stated preference and "conjoint" (using matched pairs of choices to consider multiple variables simultaneously) methods for eliciting hedonic costs and utility values. But first we restate some of the key results and findings from those reports.

In the first paper (Compostela et al, 2020), we reviewed a range of cost studies and consolidated the results regarding the monetary costs of vehicle travel (private vehicles and ridesourced trips), taking into account different vehicle sizes, drivetrain types (internal combustion, electric), and trip lengths. We considered a near-term (e.g., 2020) and longer-term (2030-35) case, with the later time frame focused on automated vehicles. We considered a range of sensitivity assumptions and cases.

The overall results for the near and long-term cases are reproduced here in Figure 1 and 2.

Figure 1 shows the average cost per passenger mile traveled, taking into account the average occupancy of vehicles and typical fares paid for solo and pooled ridesourcing services in the near term (circa 2020). Figure 2 shows a similar comparison for the long term (circa 2030-35), focused on automated vehicles.

In the near term, the relative cost estimates suggest that the use of pooled and especially solo ridesourcing services must typically reflect high benefits, given their much higher costs. These benefits would tend to be largely in the form of time savings or convenience. The value of these time savings (lower time costs) are considered further below. In the long term, this cost decreases mainly due to automation, with pooled driverless ridesourcing cheapest and driverless solo ridesourcing competitive with or cheaper than individually owned vehicles. These results can change depending on specific assumptions, such as trip length and the type of owned vehicle being compared to.

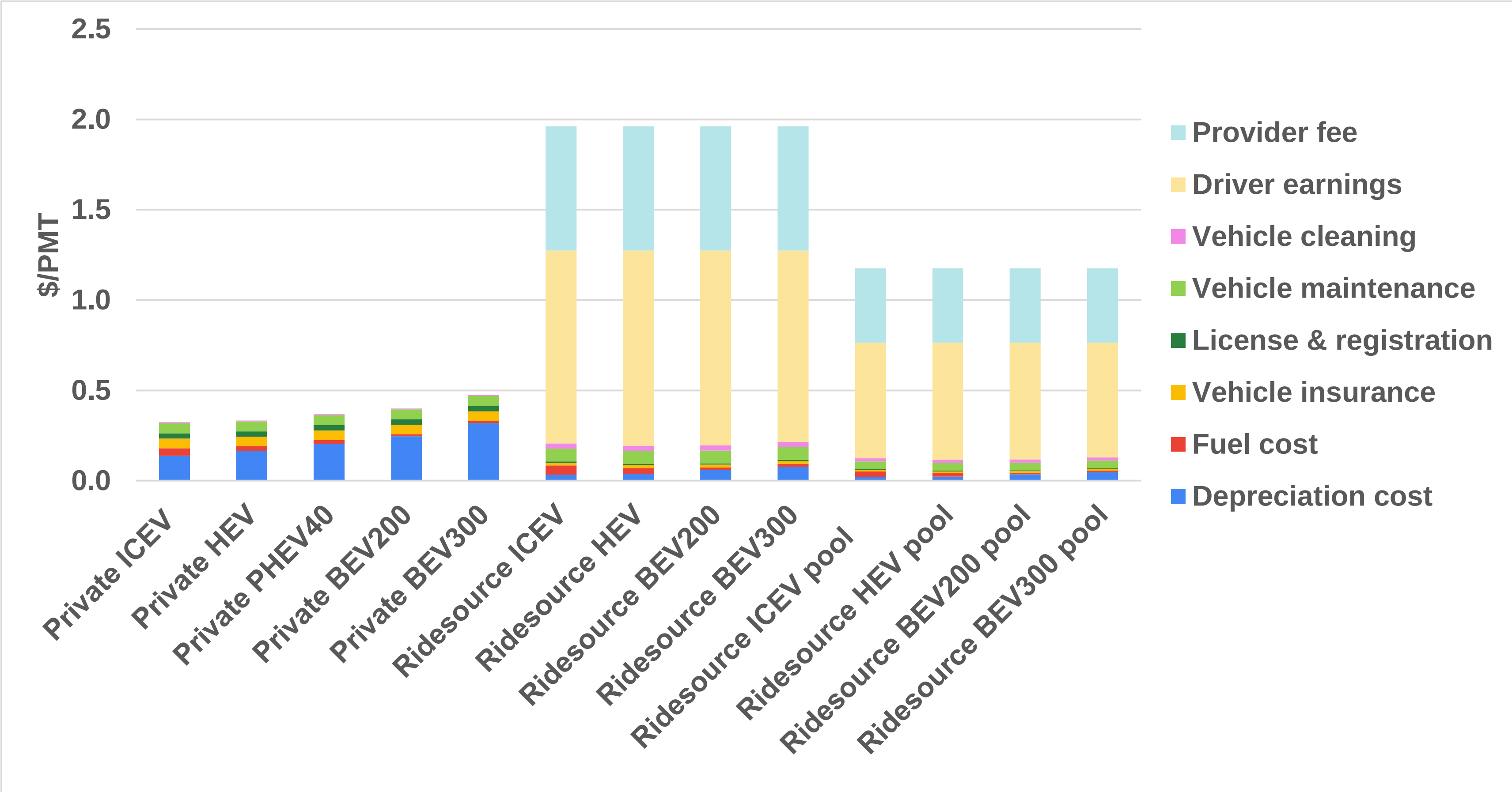


Figure 1. Near-term (circa 2020) costs ($/PMT) for private and ridesourcing midsize vehicles (source: Compostella et al., 2020). (Abbreviations: ICEV, internal combustion engine vehicle; HEV, hybrid electric vehicle; PHEV40, plug-in hybrid electric vehicle with 40-mile electric range; BEV200, battery electric vehicle with 200-mile range; BEV300, battery electric vehicle with 300-mile range.)

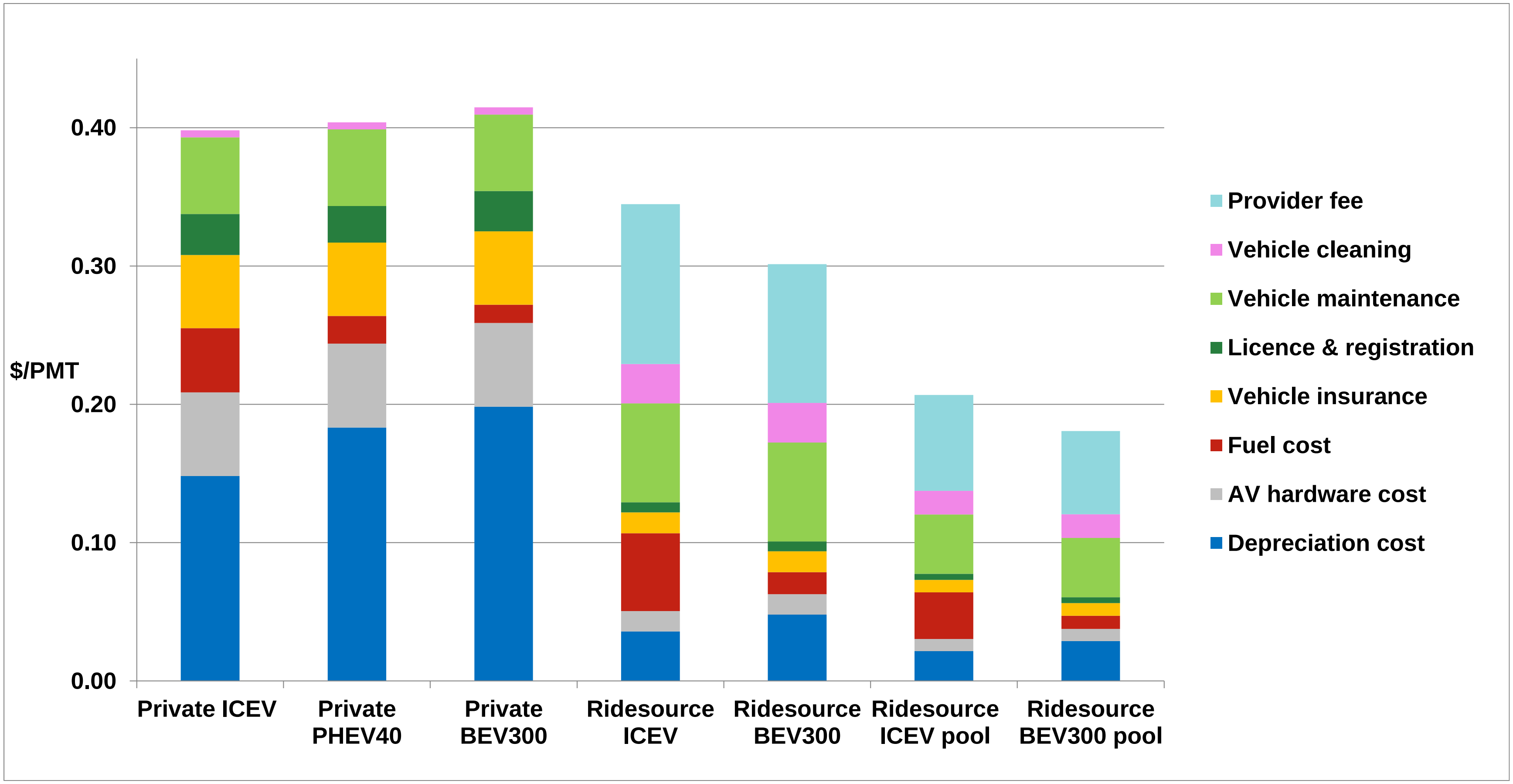


Figure 2. Long-term (circa 2030-35) costs ($/PMT) of driverless midsize cars. (source: Compostella et al., 2020) (Abbreviations: ICEV, internal combustion engine vehicle; PHEV40, plug-in hybrid electric vehicle with 40-mile electric range; BEV300, battery electric vehicle with 300-mile range.)

Figure 1 and 2 make clear the types of costs included in the study—most of the significant monetary costs of owning and operating vehicles, and costs associated with specific trips (such as parking). These cover most of the top (monetary cost) section of Table 1. The estimates also indicate that in both the short- and long-term, the cost of operating battery electric vehicles (BEVs) is similar to that for operating internal combustion engine vehicles (ICEVs), especially for ridesourcing trips.

The second paper (Fulton et al, 2020) extended this work to cover a range of non-monetary costs, namely several that are logically characterized by "value of time." This value varies with the time and distance of a trip, and it increases as a function of one's overall value of travel time (VTT), or conversely the travel time cost (TTC). This included the main trip travel time, time spent waiting for a vehicle to arrive, time spent parking a vehicle, and time spent walking to and from a vehicle and initial/final destination. These cover most of the middle section of Table 1. The basic near- and long-term results of this analysis, for a 25-mile suburban-to-urban trip, are shown in Figure 3 and 4.

Figure 3 shows two sets of results, for a higher and lower wage traveler (with commensurate differences in their value of time, as per the literature). In this near-term case, with a short urban trip example, for high income travelers, the time savings from solo ridesourcing almost fully offset its much higher cost, making it a competitive option. For lower income travelers this is far from the case. The figure includes various time-related costs as well as and the monetary costs included in Figure 1 and 2 above. Together these monetary and hedonic costs can be termed "generalized costs".

The basis for estimating the non-monetary, time-related costs are described in detail in the report. Briefly, the estimated time cost is calculated by multiplying different wages (based on labor statistics) by a percentage that varies slightly for different elements of travel (e.g., waiting for a ride, looking for parking, actual movement to destination, etc.). Figure 3 characterizes a 5-mile urban trip with an average speed of 15 miles per hour, for a traveler with a median wage (and thus median value of time). It also reflects relatively modest amounts of time spent waiting for a ride sourced vehicle (5 minutes), cruising for parking (3 minutes), and walking to and from the vehicle (6 minutes to-and-from combined). The private vehicle options reflect time cost from the driver's point of view; time spent as a passenger in a ridesourcing vehicle has a time cost that is 70% of that (30% less per mile). Of course, in reality all of these cost valuations vary by individual, by situation, etc. But these averages provide an approximation that is useful in our broad comparisons.

Figure 4 provides similar results for the long-term, with automated (driverless) vehicles.

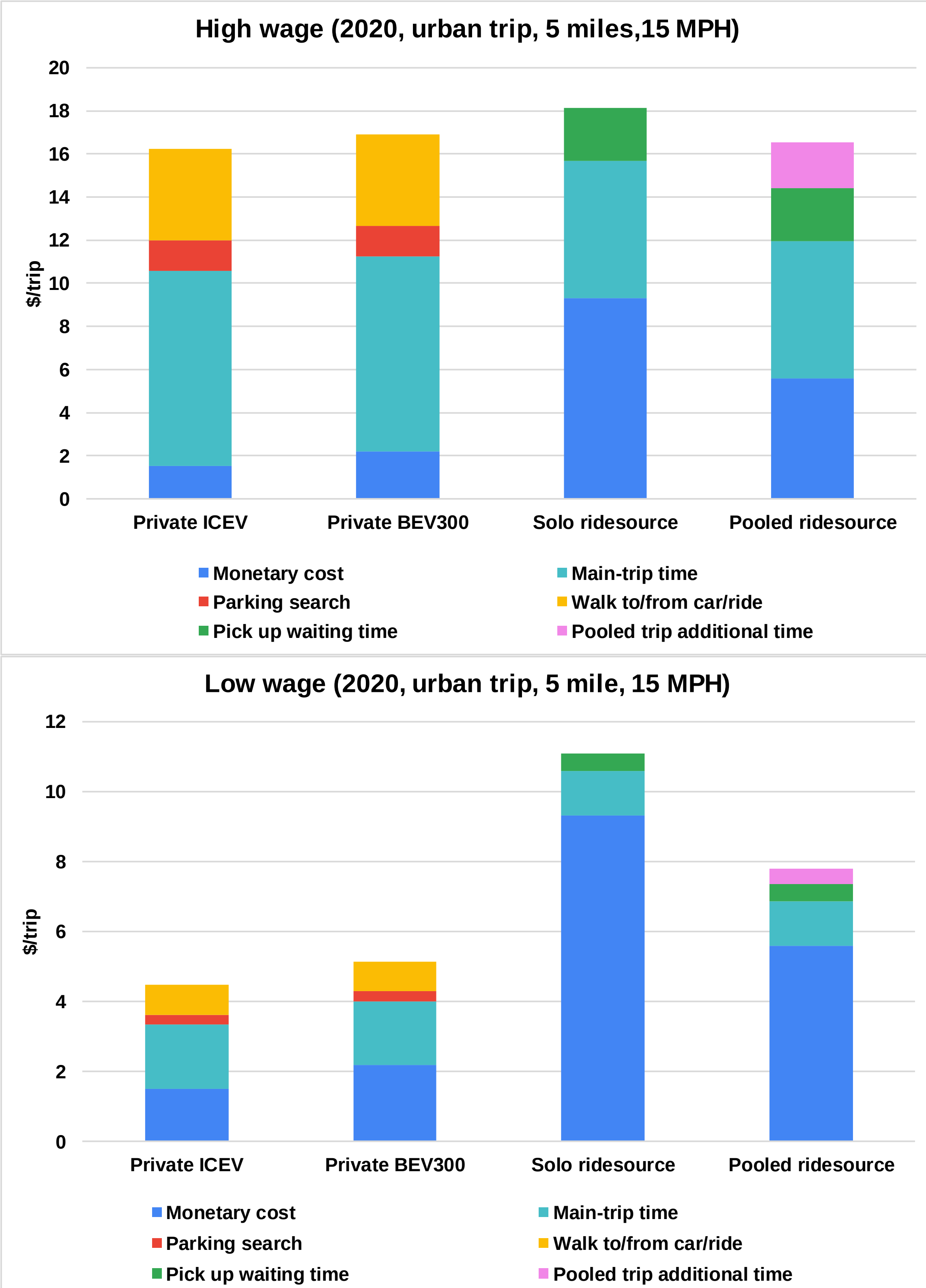


Figure 3. Generalized cost for an urban trip assuming a high (*top figure*) and low (*bottom figure*) wage and value of travel time. (Note: The y-axis scales differ between panels.)

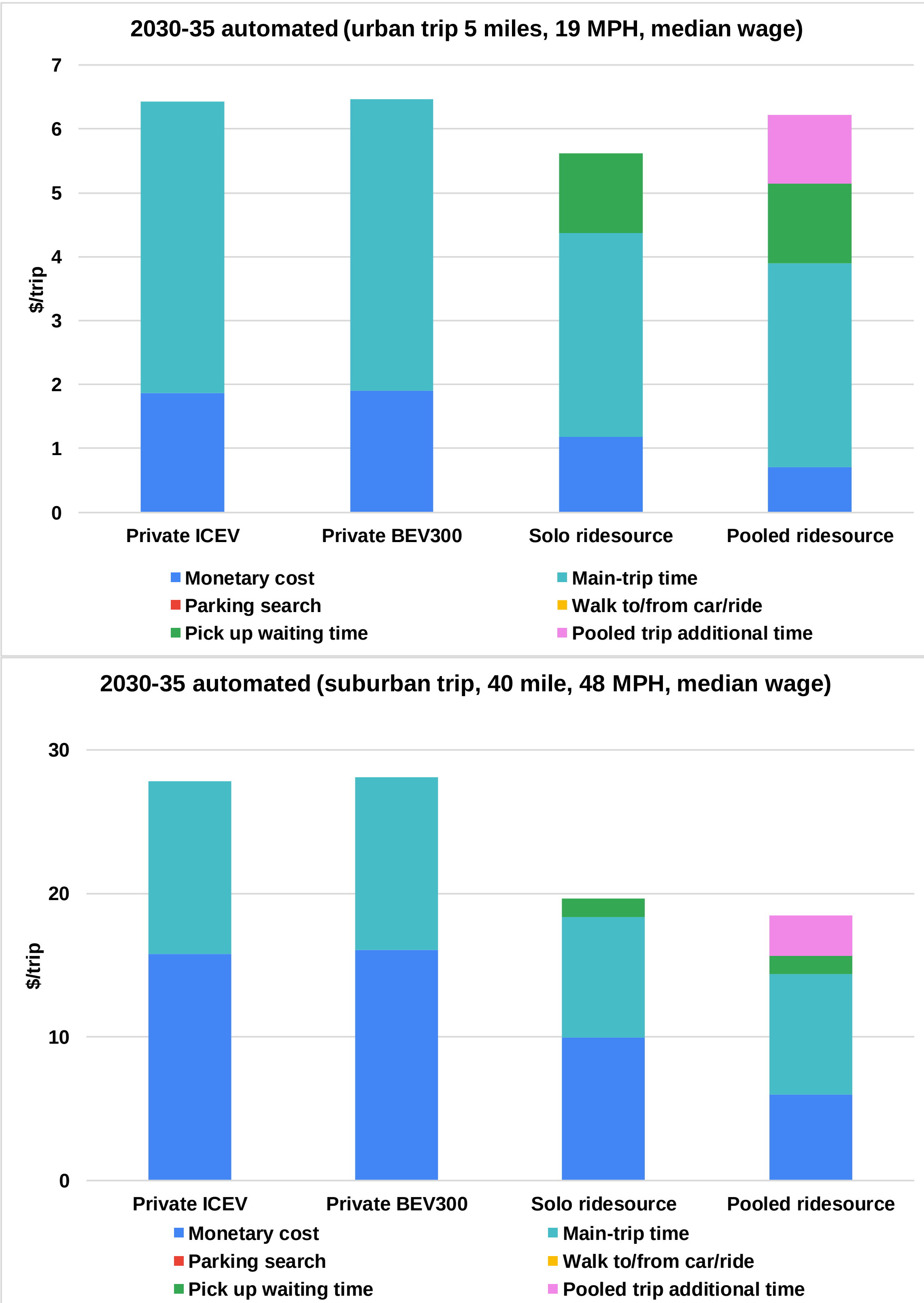


Figure 4. Generalized cost for urban and suburban trips, future scenario (2030-35) with automated, driverless vehicles. (Note: The y-axis scales differ between panels.)

Figure 4 shows the long-term driverless vehicle case for a traveler with a mid-level (50 percentile) wage in a short (5-mile) and long (40-miles) trip situation. By removing the cost of the driving, and with a lower cost of time associated with traveling in a vehicle that allows more activities, the solo ridesourcing option becomes cheaper than the private vehicle option. For short trips, shared (pooled) ridesourcing is actually more expensive given the time penalties associated with it.

The point of these studies is not to particularly claim that one mode is cheaper or more expensive than another, nor to predict the actual choices that people will make, since these comparisons are very situational and will vary by person, by trip purpose, by location, and other factors. It is to show the importance of a range of factors in determining trip cost, and how relative cost varies depending on situation and assumptions. This paper continues this process; the following section introduces and discusses additional factors that may affect trip choice, as listed in Table 1 above.

Other Related Studies

There are many studies of mode choice, and many have recently been focused on ridesourcing as a new choice (e.g., Alemi et al, 2017). These are reviewed in Fulton et al, 2020.

Here we focus on recent studies that have included the concept of vehicle automation and how this may affect choices between private and ridesourcing trip options, principally by considering how removing the driver (and driver cost) from the equation may affect the relative monetary and non-monetary costs.

Gkartzonikasa and Gkritza (2019) provide perhaps the most extensive review of choice studies about automated vehicles (AVs), covering about 40 recent studies. Most studies focus on capturing individuals' perceptions of and/or their willingness to pay to use AVs, without comparing this to other mode or vehicle type choices. However, there is little discussion about how studies treat consumer choices between private or ridesourced travel, and between solo or shared ridesourcing, under a regime of autonomous vehicles—both topics of importance in the current paper.

The authors developed a series of hypotheses related to AV perceptions and choice, and found that none could be rejected. These are listed in Table 2.

Table 2. Hypotheses extracted from literature review by Gkartzonikasa and Gkritza (2019).

HI: Level of Awareness have a positive influence on Intention to Use AVs.
H2: Consumer Innovativeness has a positive influence on Intention to Use AVs.
H3: Safety Concerns have a negative influence on Intention to Use AVs.
H4: Trust of Strangers has a positive influence on Intention to Use AVs.
H5: Environmental Concerns have a negative influence on Intention to Use AVs.
H6: Relative Advantage, Compatibility, and Complexity have a positive influence on Intention to Use AVs.
H7: Subjective Norms have a positive influence on Intention to Use AVs.
H8: Self-efficacy has a positive influence on Intention to Use AVs.
H9: Driving-related Sensation Seeking has a positive influence on Intention to Use AVs.

The hypotheses and related findings are generally important and in some cases surprising, such as H4 (trust of strangers), which suggests an expectation that these vehicles will be shared, though the findings would seem to apply to situations with a driver as well. H6, on the relative advantage and comfort (compatibility) of AVs, generally finds that people would like to continue to travel in ways they are used to and comfortable with (compatibility). If they like driving, they may not be inclined toward AVs; if AVs can help solve parking issues that bother them, they may be favorably inclined, etc. Perhaps most significantly, those interested in productivity and enabling technology in vehicles (work stations, Wi-Fi) that could be provided by AVs, were favorably inclined toward them. Other hypotheses were generally confirmed in an intuitive manner—for example, those preferring to drive alone may be less inclined to use AV ride sharing, or even AVs at all.

Some other studies have more directly addressed the impacts of automation on trip choice, or at least the relative cost of trip options. For example, Wadud (2017) estimated the cost of automated vehicle ownership in the UK and compared this to the cost of conventionally driven on-demand services and arrived at a lower per-mile cost than most other reviewed studies. Wadud concluded that commercial operations would benefit most from automation because the driver costs can be eliminated. For private users, it was concluded that households with the highest income would benefit more from automation because of their higher driving distances and higher value of time.

Others have explored the impact of automation on value of time. For example, Mokhtarian (2019) noted that the potential reduction of perceived time cost associated with the use of a fully automated vehicle is caused by the phenomenon of “passengerization,” that changes how people use travel time. The value of travel time might decrease if new on-board vehicle activities are allowed (e.g., business meetings or exercise classes). Fosgerau (2018) found that the potential attractiveness of traveling with AVs is related to the gained productivity of the traveler during the trip since people do not have to drive. He proposed that time cost is an inverse function of productivity.

Haboucha et al (2017) may be the best example to date of a study systematically addressing a range of situations related to private vehicle vs ride-sourced vehicle choices with and without automation, in a stated preference/conjoint manner. They undertook a survey directly on the topic of preferences between future private vehicles (driven), private vehicles (automated), and ridesourced vehicles (automated). Specifically they considered three choices in a stated preference survey:

(1) Continue to commute using a regular car that you have in your possession.
(2) Buy and shift to commuting using a privately-owned autonomous vehicle (PAV).
(3) Shift to using a shared-autonomous vehicle (SAV), from a fleet of on-demand cars for your commute.

Their stated preference survey was undertaken for Israel and North America, and included demographic, attitudinal, driving habits, and choice (conjoint type) questions. The three choices were explored considering 4 main variables:

- Purchase cost of privately owned car
- Annual membership fee for shared system
- Per trip cost of both private and shared vehicles
- Parking cost

The choice set (1–3) did not include shared (pooled) ridesourcing trips, thus all modes were assumed to provide the same in-vehicle trip time. Time searching for parking or waiting for vehicle arrival were neglected.

The study found that there is a pre-disposition toward or against the use of AVs based on perceived characteristics of AVs (safety, environmental impacts), with older respondents being more likely to be concerned. More educated respondents were more favorable to them. Other findings included:

- The more often an individual does errands on the way to work or in the middle of the day, the more likely they are to use a regular car.
- The more an individual uses their car to store or carry items, the less likely the individual is to use an SAV. Related to this, there is no difference between an individual with zero or one child, but additional children in the household increase the likelihood of choosing SAVs.
- Attitudinal variables such as general pro-AV attitude and enjoyment of driving affected choices in expected ways; and concern for the environment correlated with willingness to share.

The survey provides important insights into the choices covered. However, it does not include or consider the following factors that could have a significant or even decisive role in affecting the relevant travel choices:

- Shared rides are not included as a trip choice; including these would allow for exploration of tradeoffs between sharing, time and cost.
- Other non-cost factors are not considered, such as trip time, time spent parking, waiting for SAV arrivals, or extra time from walking.
- Some non-cost attributes are not considered, such as ability to do more types of things in an AV and the value of this (and whether it matters if it is a shared or privately owned AV), or the actual value of using one's own vehicle for storage, the certainty of a ride it provides, or just personal enjoyment or pride that comes from vehicle ownership.

We then investigated literature from the point of view of some of these specific choice factors that have not been well covered in the broader papers, and how some more focused studies have addressed them. This goes beyond the general value of time, which, as discussed above, is far and away the most studied factor. Other factors, shown in the bottom part of Table 1 above, have generally had far less consideration, and few studies have attempted to quantify them with a monetary equivalent value. We review several such factors here.

Travel Comfort is a mode-choice influential factor. While little work has been done for car trips, particularly in terms of car interior design, some studies have looked at crowding and design factors in transit vehicles. Björklund and Swärdh (2015) estimated the willingness to pay for crowding reduction (comfort) when traveling on a bus, metro, tram, or train in Sweden. They found that willingness to pay for crowding reduction increases according to whether the passenger is seated or standing and the number of standing passengers per square-meter. They expressed this as a multiplier of the basic value of time, typically a function of income or wage. This multiplier can reach nearly 3 (i.e., 3 times the basic time cost of traveling) when standing in crowded conditions rather than seated in uncrowded conditions.

Productivity while travelling is another important non-monetary factor. An empirical study performed in California by Malokin et al. (2019) estimated the effect of interest in multitasking (e.g., using a laptop/smart phone for reading, working or emailing while traveling) on mode choice. The authors estimated the value of in- and out- of vehicle travel time turning observations of activities conducted on chosen modes into propensities of doing these activities on that mode. Using only the choosers of a given mode, they estimated a model for whether or not a given activity is engaged in or not, as a function of explanatory variables available for everyone in the sample (both choosers and non-choosers of that given mode). Then the authors used these observed activity-propensities on a chosen mode as explanatory variables in a multinomial logit model to measure the effect of multitasking propensity on mode choice. The authors found that greater perceived productivity of a travel mode adds to its utility.

Trip Time reliability/uncertainty. All trips involve trip time uncertainty, but this uncertainty rises with some modes relative to others. For example, the arrival time of a ridesourced vehicle varies (whereas an owned vehicle parked outside does not). A pooled ride may have a significant variation in overall trip time, depending on the numbers and locations of other travelers picked up/dropped off during the trip. Besides the additional time, uncertainties about *how much* additional time will be required may affect people's decisions, especially when in a rush. Lam and Small, (2001) measured the value of reliability or time variability. The authors used data on the choice that commuters had to make between two parallel routes, one free but congested and the other with a time-varying toll, on a major highway in southern California (State Route 91). In their model specification they measured travel time as a median value of the distribution of travel time values spent to cover the highway (across different weeks and measured using loop detector data), and time variability (unreliability) as the difference between the median and 90th percentile of the distribution of travel time values. They measured the value of time as about 70% of the weighted average wage of the commuters, and the value of reliability (or cost of time variability) measured from this distribution as an additional cost of about 50% for men and 100% for women.

Safety and Security Perception is another mode choice influencing factor. Safety refers to physical dangers such as accidents, while security, to human-imposed dangers such as assault. Security is especially important for women, though typically neglected in mode choice modeling (Buckley, 2016). Though there is evidence that women prefer driving or for-hire ride services rather than walking, cycling, or public transit (ITF, 2018). Indeed, based on the household travel survey data of different cities around the world, Ng and Acker (2018) found that using for-hire ride services modes has not represented a priority safety concern for most women.

Car pride is different from many other factors since it exists simply as a concept. It may affect the desire to own a car (or be derived from owning a car), and is generally unrelated to particular trips (though it could affect the choice of using one's own car rather than other modes for any particular trip). Several studies of this concept have been undertaken in recent years, nearly all by MIT researchers (e.g., Zhao and Zhao, 2018), and have been more conceptual than quantitative, in the sense that they explore the existence and strength of this factor. In general, the effects of car pride are found to be strong in that they influence car ownership decisions well beyond the basic utility of owning the vehicle. Moody and Zhao (2019) found that, at least for New York and Houston, car pride concepts drive the desire to own a car and car buying actions much more than car ownership generates car pride after the fact. But overall, the research has not yielded value estimates that can be used in a generalized cost analysis.

Car option value and car storage value both seem to be important concepts and potentially important factors influencing travel choices. Car option value, in this case, refers to the value of owning a car, and keeping it nearby, so that trips can be made on demand, any time. While this option value may decline with the advent of ubiquitous ridesourcing, it may still be meaningful and, for some people, an important reason to own a car, apart from other factors that apply to owning a car (such as cheaper per-trip travel than can be achieved by ridesourcing, among others). Storage value is simply the ability to keep things in one's own car and having those things easily available wherever the car is, which most car owners take advantage of, and which cannot be done with a ridesourced or other temporary car use situation. Unfortunately, for car option value and car storage value, we found no literature that attempts to explore their importance or quantify their value.

Driver stress/driving enjoyment: The experience of driving—whether positive or negative—certainly affects travel choices for many people on a daily basis. The wide array of mode choice literature and surveys undertaken about motivations for mode choice, have generated a range of insights into this. However, in our limited search we did not find any studies that attempted to quantify these types of effects as a hedonic cost or benefit. The only study we found that attempted to quantify a relationship was Ditmore and Deming (2017), which reported that vanpooling in one location reduced passengers' stress levels by 20% compared to driving to and from work. A thorough analysis of this type of literature may help establish the importance of the stress/enjoyment factor and quantify it in a manner that helps calibrate generalized cost comparisons. This factor would also need to be related to travel time—perhaps as an adder (for stress) or subtractor (for enjoyment) to the cost per unit time or distance.

Small Sample Study Undertaken to Explore Key Issues

As part of this study, we performed a prototype pilot survey to explore issues around ride sharing and the potential future impact of autonomous vehicles in the Sacramento, California region. This study was framed (hypothetically) to help a team of the region's transportation planners consider whether to launch a shared ridesourcing services pilot program for commuting in the region.

Sample and Method

The project involved convening focus groups and administering a pilot survey (sample size, 37) of professionals (21 to 47 years). This group reflected a convenience sample and one that is relatively likely to have experience with ridesharing and an awareness of automated vehicle concepts. The discussions and surveys were focused on commuting trips.

Three travel modes were considered for this study:

- Solo ridesourcing
- Pooled ridesourcing (door-to-door with stops to pick up and drop off other riders)
- "Express" pooled ridesourcing (short walk to common pickup and drop off point, without any additional stops along the way)

A set of hypothetical trip situations were presented to participants, with trip characteristics varying by:

- Trip time uncertainty (minimum/maximum trip time range)
- Maximum number of other passengers allowed on trip
- Trip cost
- Whether driven or automated vehicle trip

The research was undertaken in two parts, with a qualitative and quantitative (survey) component.

1. Qualitative Research:

Researchers convened a focus group in late April 2019 to understand attitudes and perceptions of young professional millennials (21-37 years of age) that represented a possible target market for shared ridesourcing. The participants confirmed prevalent findings in the literature about mode choices and transportation in general. Trip cost was the generally stated main criteria determining mode choice, and traveling by car was the preferred mode choice for reasons of both autonomy and affordability. Shared ridesourcing was generally deemed costlier than driving, and the metric of comparison used was out-of-pocket expense (gas or gas + parking costs). Participants showed sensitivity to increases in travel time, especially for commute trips, but they did not mind walking and waiting as long as the total trip time remained comparable to the same trip made with a personal vehicle. Unanimously, uncertainty in total trip time, generally displayed as Expected Time of Arrival (ETA) (on mobile apps through which these services are booked) at the time of making a trip request, was rated as a major concern.

2. Quantitative Research:

Using the findings from the focus group, a survey was designed to understand awareness, past behavior, and preferences regarding shared ridesourcing services, taking into account a limited number of attributes. The survey does not attempt to address the wide range of attributes described above in the section “Other Related Studies”, but it does set a framework that could be used in that context. The remainder of this section discusses the survey design, outcomes, data analysis, and interpretation.

Three hypothetical mode choice questions were asked of respondents, with 3 or 4 choices in each, and several attributes of each choice indicated. This was not varied in any manner across respondents; thus, this was not an effort to create a scientifically structured “conjoint” type survey (e.g., paired choices with randomized, orthogonal variation of attribute values). It was conducted simply as a survey of reactions to particular situations. Given the small sample size of 37, no statistically robust findings can be reported, but the results may be interesting and are generally intuitive. These are presented below, by question, with some discussion. In all cases the trip considered was a hypothetical commute trip of 15 miles.

Question 1: Which would you choose: solo vs. pooled vs. express ridesourcing?

As shown in Figure 5, each choice included information on the duration of the wait or walk to the pickup, travel time (fixed or min-max for pooled modes), and the trip cost. The solo trip was nearly double the price of the pooled trip and more than double the price of the express pooled trip, but it was faster with no uncertainty about trip time. Nearly half of the respondents chose the solo option. Of those choosing a pooled or express option, nearly 80% chose express. Given the identical time characteristics of these two options, this result suggests a willingness to walk to save some trip cost.

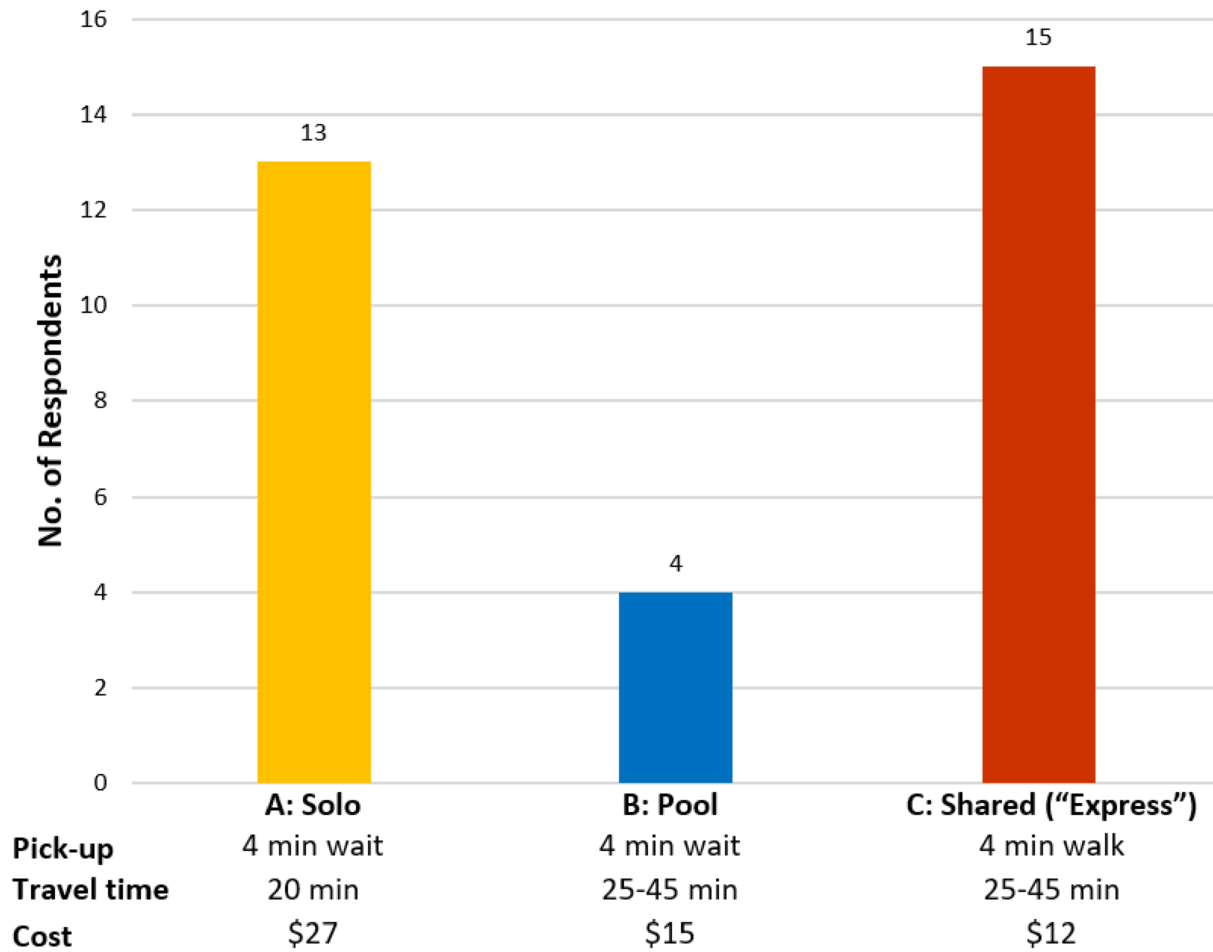


Figure 5. Results of first mode choice question: solo vs. pooled vs. express ridesource.

The respondents were asked their attitudes about trip cost and trip time. Table 3 summarizes the responses, sorted by their choices in the stated preference survey. Not surprisingly, those who chose the solo ride (A) tended to be concerned about time and not too concerned about cost, while those choosing pooled options (B & C) indicated the opposite, in general.

Table 3. Responses of survey participants regarding travel time uncertainty and cost, classified according to which option they chose. (A = solo ride; B = pool ride; C = express ride).

Statement	Options	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree	Count
I don't mind the travel time uncertainty typical of shared ridesourcing.	A: Solo	85%	8%	8%	0%	13
	B: Pool*	0.0%	50%	50%	0%	4
	C: Express*	21%	57%	21%	0%	14
For me, the most important thing is cost savings.	A: Solo	31%	54%	15%	0%	13
	B: Pool	0%	50%	50.0%	0%	4
	C: Express*	0%	37%	43%	21%	14

*Pool: door-to-door with stops to pick up and drop off other riders; Express: pooled ride with short walk to common pickup and drop off point but no additional stops along the way.

Question 2: For a commute, which pooled ride would you choose: $22, $18, $15, or $12, each with increasing uncertainty of duration?

This question included three pooled options (A-C) and one express pooled option (D), each less expensive than the previous, but involving greater time uncertainty (specifically, longer maximum trip time). The express option proved to be the most popular choice (Figure 6). As per Table 4, the respondents' indicated concerns about cost and travel time roughly correlated with their choices (A–D), though it is possible that walking (for express) vs. waiting (for pooled) also played a role in some respondents' choices. This was not explored in the preference questions.

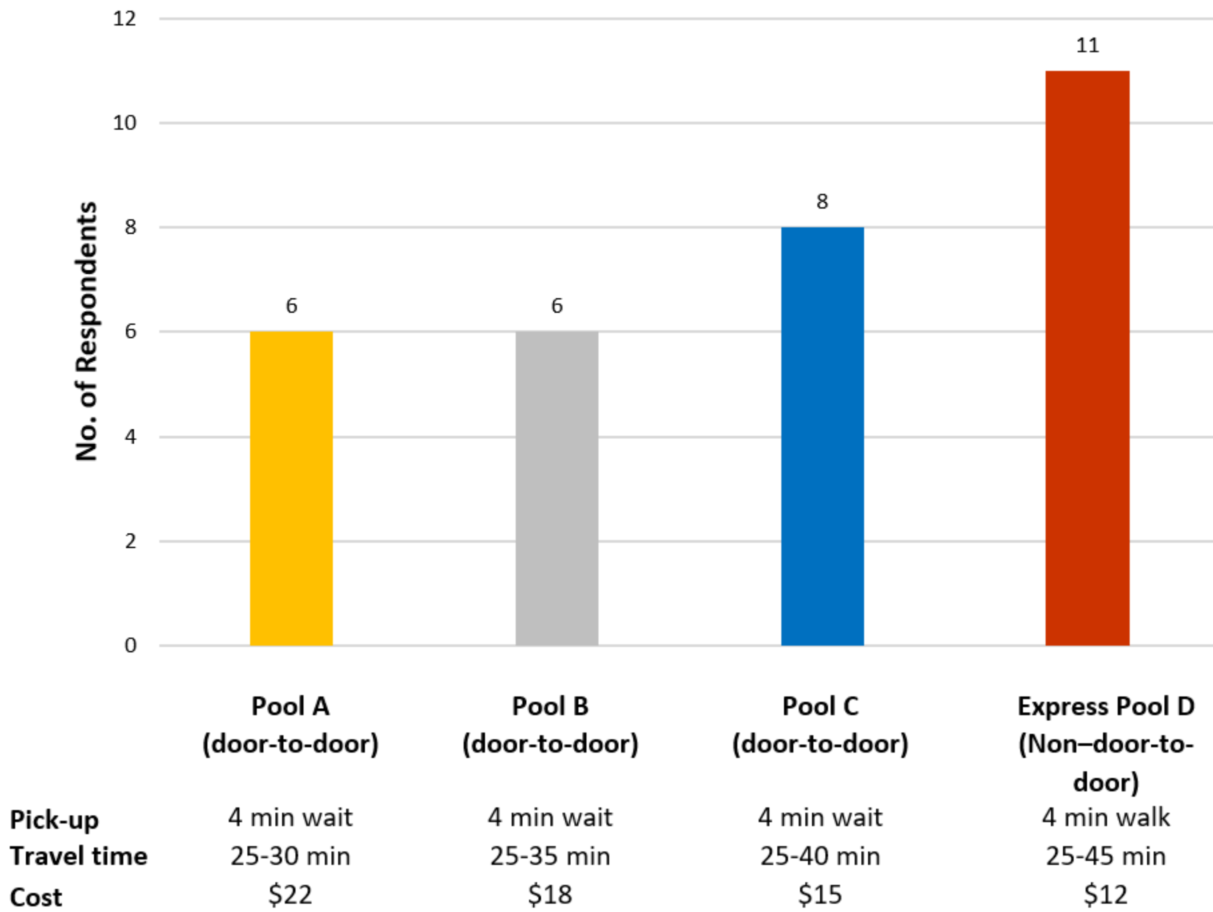


Figure 6. Results of second question on various pooled/shared ride sourcing options

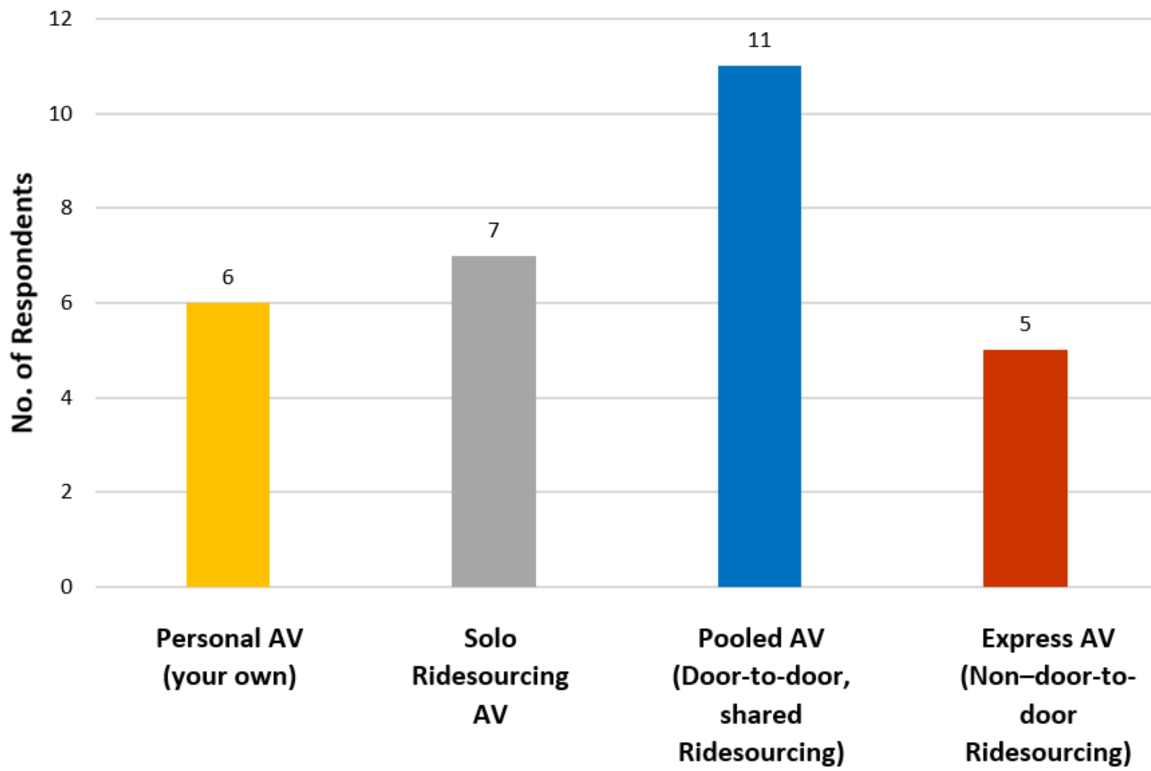
Table 4. Responses of survey participants related to pooled ridesourcing options.

Response	**Type of Pooling Preference**				**Total**
	A **$22** **25–30 min** **(n = 6)**	**B** **$18** **25–35 min** **(n = 6)**	**C** **$15** **25–40 min** **(n = 8)**	**D** **$12** **25–45 min** **(n = 11)**	**N = 31**
Don’t mind about uncertainty	**0 (0%)**	**1 (17%)**	**2 (33%)**	**3 (50%)**	**6**
Mind about uncertainty	**6 (24%)**	**5 (20%)**	**6 (24%)**	**8 (32%)**	**25**
Cost is the most important saving	**0 (0%)**	**2 (15%)**	**4 (31%)**	**7 (54%)**	**13**
Cost is not the most important saving	**6 (33%)**	**4 (22%)**	**4 (22%)**	**4 (22%)**	**18**

Question 3: Which type of AV would you prefer: (A) individually owned vs. (B) solo ridesourced vs. (C) pooled ridesourced vs. (D) express ridesourced?

For this question, the cost was highest for owning an AV, based on an estimate of the total cost of ownership divided by a per-trip cost. The lower cost of the ridesourced options (B-D) is based on amortization of vehicle costs over many more trips, because of these vehicles would be used much more intensively. In any case, this question allowed an exploration of the preference of owning/driving in one's own AV vs. other lower-cost options. The solo ridesourced AV trip was 40% cheaper and took the same amount of time to reach the destination, though it had a 4-minute wait time, so it required 20% more time. The shared options had much higher maximum trip times but were cheaper. Here the pooled AV option was a clear favorite, despite the risk of long trip times. The difference in the number of respondents who chose a pooled ride at $4 vs. an express ride at $3 (11 vs. 5 respondents) suggested that the $1 difference was not enough to make the latter appealing and casts doubt on the idea that walking was preferred to waiting for the same amount of time. About 20% of respondents chose to own an AV—a small share which, may relate to the relatively high cost compared to the solo ridesourcing option.

Table 5 summarizes responses to questions about using shared and personally owned AVs, with those responses categorized according to Question 3. Those choosing solo ridesourcing AV trips indicated the least interest in owning their own AV in the future, while more than half who chose an express AV trip indicated they would like to own an AV. These responses are somewhat counterintuitive and are deserving of further investigation in future studies.



Pick-up	0 min wait	4 min wait	4 min wait	4 min walk
Travel time	20 min	20 min	25-45 min	25-45 min
Cost	$12	$7	$4	$3

Figure 7. Results of third question on AV ride sourcing options

Table 5. Responses of survey participants related to AV ridesourcing options.

Statement	Options	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree	Count
I could make good use of the time while riding in an AV.	Personal	0%	17%	50%	33%	6
	Solo	14%	14%	43%	29%	7
	Pool	0%	0%	56%	46%	11
	Express	0%	0%	80%	20%	5
Because the cost is so low, I would expect to use shared AVs.	Personal	17%	50%	33%	0%	6
	Solo	0%	14%	57%	29%	7
	Pool	9%	55%	18%	18%	11
	Express	0%	20%	60%	20%	5
With widely available, inexpensive shared AV services, we might own fewer household vehicles.	Personal	17%	33%	50%	0%	6
	Solo	43%	29%	29%	0%	7
	Pool	9%	55%	36%	0%	11
	Express	0%	80%	20%	0%	5
Considering all factors, I would expect to own my own AV.	Personal	0%	17%	50%	33%	6
	Solo	57%	29%	0%	14%	7
	Pool	9%	46%	46%	0%	11
	Express	20%	20%	60%	0%	5

Note: Chi-squared tests indicated that most responses are not significant at the 90% level.

Overall, despite the small sample (and associated insignificant chi-squared tests), the survey provides some qualitative insights and suggests strategies for additional survey work in the future. It generally supports the findings of others cited in our literature review regarding the importance of different factors and how these factors may be valued differently by people in different situations or with differing background attitudes. However, the survey does not provide statistically robust results that can be added to generalized cost models at this point. A more detailed and larger sample survey would certainly help in this regard. The following section considers some additional factors that could be included and makes an initial attempt to estimate values of these factors.

An Exploration of Using Time Value to Address Additional Non-Monetary Costs

Table 1 above listed a range of factors that may influence how people choose to travel, particularly in terms of private vehicle vs. ridesourced vehicle, taking into account solo vs. shared trips and the potential future impacts of automation. The last row of that table presents several factors that appear difficult to quantify using either monetary or time cost approaches. Some of these were also discussed in the literature review. Here we consider one approach to value these, by estimating the time each might require during a typical trip, week, month, or year and assigning this to a trip-based cost per mile metric.

There are many issues with this approach, the main one being whether time costs that are not directly related to trips can be thought of on a per-trip or per-mile basis. There are other ways in which these may impact choices, such as general tendencies to travel one way or another, but these are had to put into a generalized cost framework. Our main goal here is to identify an order-of-magnitude importance for some activities in a generalized cost framework, to see if they seem likely to play a major role in trip choice making, and are worthy of further research such as through stated preference surveys.

Based on the literature, some of these non-monetary factors matter only at certain times and/or only to some travelers. For example: driving can be a source of stress for many individuals and might influence their decisions to ride hail; 2) hesitancy to use unexplored technology might influence people not to travel with an autonomous vehicle; 3) lack of privacy in sharing a ride with strangers might influence travelers to solo ridehail or drive; 5) not having the possibility to leave personal belongings in the vehicle might influence travelers to use their personal car and not to ride hail; 6) social status and "car pride" might influence people to continue with car ownership.

To value some of these factors influencing mode choice, we generate rough estimates by assuming that various activities take a given amount of time. We do this using a sample 10-mile trip and considering how often these activities must be undertake (percentage of trips). We also consider how long these activities may take and relate this to the trip distance and time.

Below we show the calculations and estimations for each of the factors considered.

Value of being able to store things in the vehicle vs. loading/unloading

This would apply to leaving things in a car over multiple trips vs. having to put in/remove items each trip, such as in a commercial ridesourced trip. One example of a necessary and cumbersome object would be a child's car seat. Beyond the time to put things in and take them out of a vehicle, there are questions about where they would be stored in the interim, between multiple trips, and other "hassle factors." There could also be the benefit of not forgetting things, having them easily available whenever needed, etc. Here, for simplicity, we simply assume the following: if it takes at least 2 minutes each to load and to unload things like car seats for every trip, and it's an unwelcome hassle, this might be valued at our default time value of $15/hour (though we also acknowledge that the time cost could be higher, depending on the perceived "hassle factor" above a normal time cost). At 4 minutes or 1/15 of an hour, that's a $1 time cost; applied against a 10 mile trip, that's **$0.10 per mile or $1.00 for a 10 mile trip.**

Cost of an uncertain ride

A "certain" ride means there is a car in a known location, and the traveler has access to drive it or ride in it. In contrast, the uncertainty of a ridesourced trip, in terms of the time of departure or arrival, may be associated with a cost. If one expects to travel in a ridesourced vehicle with an estimated pick-up time in 5 minutes, there is likely a hedonic (or possibly monetary) cost associated with the vehicle being late, and psychologically this hedonic cost applies even to the possibility that it might be late. This could relate to stress, frustration, or just fear of being late to an important event, such as a meeting or a departing flight. The value or cost of this lateness could be higher than the normal value of time and could increase with each passing minute. Or, the traveler may need to add "buffer time" to the trip, which would reduce stress but add "wasted" time, beyond what is used just in transit. Thus, the cost factors for this could be complex and are deserving of detailed study, which is beyond the scope here.

Here we hypothesize a simple function. Each additional minute might cost an additional amount equal to double the usual time cost of waiting ($15 per actual minute late and $15 for stress, etc.). If the original time cost is $15/hour, this would represent $30/hour for each minute late or 1/60 of that per minute, i.e., $0.50. If we further hypothesize that each time a vehicle is late, it is late by an average of 4 minutes, and that this occurs every fourth trip, it would mean an average of $0.50 penalty applied across all ridesourced trips, or about **$0.05 per mile, and $0.50** for a 10-mile trip.

Waiting time at refueling/cleaning events and maintenance/repair events

Owners/drivers of a car, whether privately or commercially used, must regularly undertake refueling events and (less frequently) maintenance, repair, and cleaning events. There is a time cost to these events, whether simply sitting and waiting or actively participating (such as some types of cleaning and self-serve fueling). Here we simply hypothesize an amount of time per year and allocate this per trip and per mile.

For simplicity, we treat refueling and cleaning together, as some refueling stops also involve cleaning (vacuuming and/or washing the car at the refueling location). We assume refueling stops take 7 minutes and cleaning 15, occurring once every 4 refuelings (about one refueling per week and one cleaning per month). This can be stated as an overall average of 10 minutes per week, with perhaps 30 trips made in a week so occurs for 1/30th of trips. The net effect is an average of $0.01/mile or $0.10 for a 10-mile trip.

We treat maintenance/repair events as special "take the car in" events, involving either waiting for the car to be maintained/repaired or via a drop off/pickup set of events, either way taking 30 minutes per event. These events can take much longer, though anything much longer than

30 minutes probably often triggers the drop off/pickup strategy in many cases (an empirical question beyond the scope here). Including various repairs, scheduled maintenance, tire rotation or swap out, oil changes, etc., we are assuming there are four of these events per year (also warranting further empirical investigation). We assume a normal value of time and 30 minutes per event and therefore 30 minutes per quarter. At around 3 trips per day, there are 100 trips per quarter, so one event per 100 trips. The overall effect is about $0.008/mile or $0.08 for a 10-mile trip.

Parking searching and walking to/from vehicle

These two types of time cost have been investigated in a number of studies (e.g., Inci, E., JV. Ommeren, M. Kobus. 2017) and were covered in detail in Fulton et al (2020), but they are included here for comparative purposes. We assume about $20/hour here, 33% higher than basic travel time cost, as per literature-based estimates in the Fulton et al. (2020). report. We also assume an average parking search time of 5 minutes, once per trip and walking time of 2 minutes, twice per trip. The result is an average $0.167 per mile or $1.67 for a 10-mile trip.

General driving stress

This topic is quite complex and situations and attitudes are variable. Some enjoy driving and thus a time cost might be lower than we assume as an average. However, others find driving stressful, especially if under time stress and/or if traffic is congested or hazardous. Here we assume a stressful trip occurs every tenth trip for the entire trip, just to get an idea of what occasional driving stress would cost. Clearly if it occurred every trip, all the time, it would be ten times higher. We assume a stress related time cost of $30/hour, double the usual time cost. However, since we already include the base driving time cost of $15 per hour, we use another $15/hour as an “add on” here to account for stress. The result is an average stress-related cost of $0.05 per mile or $0.50 for a 10-mile trip.

Public recharging search time for EVs

For electric vehicles, there is a wide range of recharging behaviors and patterns, and concerns about “range anxiety” or “charging anxiety” – not having enough battery power to reach a destination or get home where a recharger is available (in most cases). There is ample evidence that most EV owners become well acquainted with recharging options in their areas and do not experience “charging anxiety” very often, but it does happen (Autovista Group, 2020). Here we assume a cost if on one-tenth of trips a traveler was running low on charge, could not make it to the usual charger, and had to look for a charger near his/her present location. The cost can be measured by the time spent looking for an available charger and getting to it, an average of 5 minutes per event. The time cost, $30/hour, is assumed to be double the usual time cost, accounting for the stress; this is the same time value as for driving in stressful conditions and waiting beyond an estimated pick-up time for a ridesourced vehicle. The result is a $0.025 cost per mile or $0.25 cost for a 10-mile trip.

Main-trip travel time

Finally, we include the most basic time-related cost, the time associated with “main trip” travel. This is the point-to-point car trip, which we covered in detail in Fulton et al (2019) and is a fundamental aspect of time value of travel. We have three situations that we include here: the main trip as a driver, which we assume at the standard time rate of $15/hour. We assume a reduction of 33% as a passenger in a ridesourced trip, since the person can do many things other than drive, both for fun or productivity (most likely use their phone). Finally, we assume a 50% reduction compared to driving when one travels as a passenger in an automated vehicle that is specially designed for passengers and has design features like workstations, large screen monitors, etc. to enable activities. These estimates are consistent with our assumptions in the previous paper (Fulton et al, 2019).

Results of comparisons

The results of these hypothetical cost examples are shown in Table 6, which indicates how long they last, how often they occur, the time value assigned to them, and ultimately their cost per trip and cost per mile for a 10 mile trip, if the costs were allocated in that way. Again, it is not clear that travelers think of such hedonic costs in this manner, especially ones that do not occur on every trip. But the table allows for some comparisons and indicates which factors seem more likely to play a significant role in affecting trip choices.

A couple of observations can be made based on the cost per trip or per mile (which are always proportional). The main-trip value of time, driver time cost, is by far the most important (highest time cost) factor in the Table 6, at $0.50 per mile. Clearly, eliminating this cost, e.g., via ridesourcing or vehicle automation, can have a strong influence on travel choice—though even as a passenger there is a time cost, which in our recent work we assume to be at least 50% of the driver time cost. But even at $0.25 (driver cost over passenger cost), driving a vehicle creates a significant time cost.

Second, the time costs associated with waiting for a ridesourced vehicle to arrive and with parking one’s own vehicle and walking to/from that vehicle can also be significant, at least with the assumptions used here. These all land in the range of $0.10 to $0.20 per mile. They also rise in relative cost for short trips, since they don’t (necessarily) change with trip length. Conversely, on long trips, they may become insignificant compared to main-trip driving time cost.

All of the other factors are assumed to occur only on some trips, with some occurring fairly rarely, such as vehicle maintenance/repair, assumed to occur only once in 100 trips. This tends to depress the per-trip and per-mile cost of these factors. Those that appear most important are loading/unloading, driving stress, and additional/uncertain waiting time for ridesourced vehicles. With our assumptions, all of these trigger an average cost in the range of $0.05 to $0.10 per mile.

Finally, the group of factors with the lowest average per-mile impact are refueling and cleaning, maintenance/repair, and EV recharging anxiety.

Again, one could change specific assumptions in this table and derive quite different results, and we've attempted to create something like average conditions and frequencies. On trips where specific time-consuming factors are actually present, such as refueling or charging search efforts, they can add significant time cost to the trip.

Table 6. Estimated costs per trip given hypothetical situations and valuations, for selected travel choice factors.

Activity	Time per event (mins)	$ / hour valuation	$ / event	Events / trip	$ / trip	$ / mile for a 10-mile trip	Notes
Loading/ unloading	2	15	0.50	2	1.00	0.10	Avg. 2 minutes twice per trip
Ridesourcing "normal" waiting time for vehicle arrival	6	15	1.50	1	1.50	0.15	Normal value of time, typical expected wait time
Uncertain ride arrival time	4	30	2.00	0.25	0.50	0.05	Avg. 4 minutes unexpected wait time, 1/4 of trips
Refueling/ cleaning time	10	15	2.50	0.04	0.10	0.01	Assumes one refueling per 30 trips
Waiting time at maintenance/ repair events	30	15	7.50	0.01	0.08	0.01	4 times per year, once per 100 trips
Parking/searching	5	20	1.67	1	1.67	0.17	5 mins for parking search and parking, once per trip
Walking to/from car	2	20	0.67	2	1.33	0.13	2 minutes twice per trip (short walks, one could be driveway)
Driving stress	20	15	5.00	0.1	0.50	0.05	Additional time cost due to stressful driving, assumed adds $15/hour to basic time cost, 1/10 of trips
Public recharging search time, anxiety	5	30	2.50	0.1	0.25	0.03	Search time at higher per-hour cost, 1/10 of EV trips

Activity	Time per event (mins)	$ / hour valuation	$ / event	Events / trip	$ / trip	$ / mile for a 10-mile trip	Notes
Main trip driving time	20	15	5.00	1	5.00	0.50	10 mile, 20 minute trip; general travel time cost
Main trip passenger time (own vehicle or ridesourced trip)	20	10	3.33	1	3.33	0.33	Assumed 2/3 time cost of driving
Main trip passenger time, automated vehicle	20	7.5	2.50	1	2.50	0.25	Assumed 1/2 cost of driving, specially designed vehicle

Another important aspect of the table is that not all types of costs occur for the same types of trips. Notably some only occur to one's own vehicle, or when one is the driver. Other costs only occur for ride-sourcing trips. Charging anxiety would only occur when driving an EV (and presumably not when being a passenger in a ridesourced EV—unless the driver clearly shares his own anxiety and passes it on to the passenger).

Figure 8 gives a very approximate sense of how different costs affect the generalized cost for different travel choices. We also add in the base monetary cost of these vehicle/trip types, based on our previous work (Compostela et al, 2020 and Fulton et al, 2020). The results indicate that while all these factors affect the overall cost, few of them have a major effect on the relative cost of the different choices. Driving time, parking search time, walking time, and ride-arrival waiting time are the most significant and can change the relative cost position of different options. But adding many of the smaller costs together, such as for privately owned/driven vehicles, can make these options significantly more costly than they would otherwise be.

In particular, the various time costs associated with owning/driving one's own vehicle make this option more expensive than some other options (e.g., automated private and ridesourced options) despite its relatively low monetary cost. Automating privately owned vehicles would eliminate many of these costs and becomes the lowest cost option overall (Figure 8).

Once again, we stress that these are hypothetical situations and rough cost estimates, so the results should be considered accordingly. The results do provide a rough sense of how various factors might influence relative costs of trip choices.

In addition, the results will vary considerably for individuals with specific (and relatively different) values for the variables in question, and for trips where some of the factors play a bigger role than assumed here. A good example is a trip, or a series of trips, where there would be a significant time component and hassle factor for loading and unloading a vehicle, rather than leaving things in the vehicle over many trips. This could quite easily push people toward using their own vehicle rather than doing repeated ride-sourcing trips. Traffic congestion (making trips longer and adding driving stress) and frequent repair events (not to mention breakdowns) might push people toward more ridesourcing.

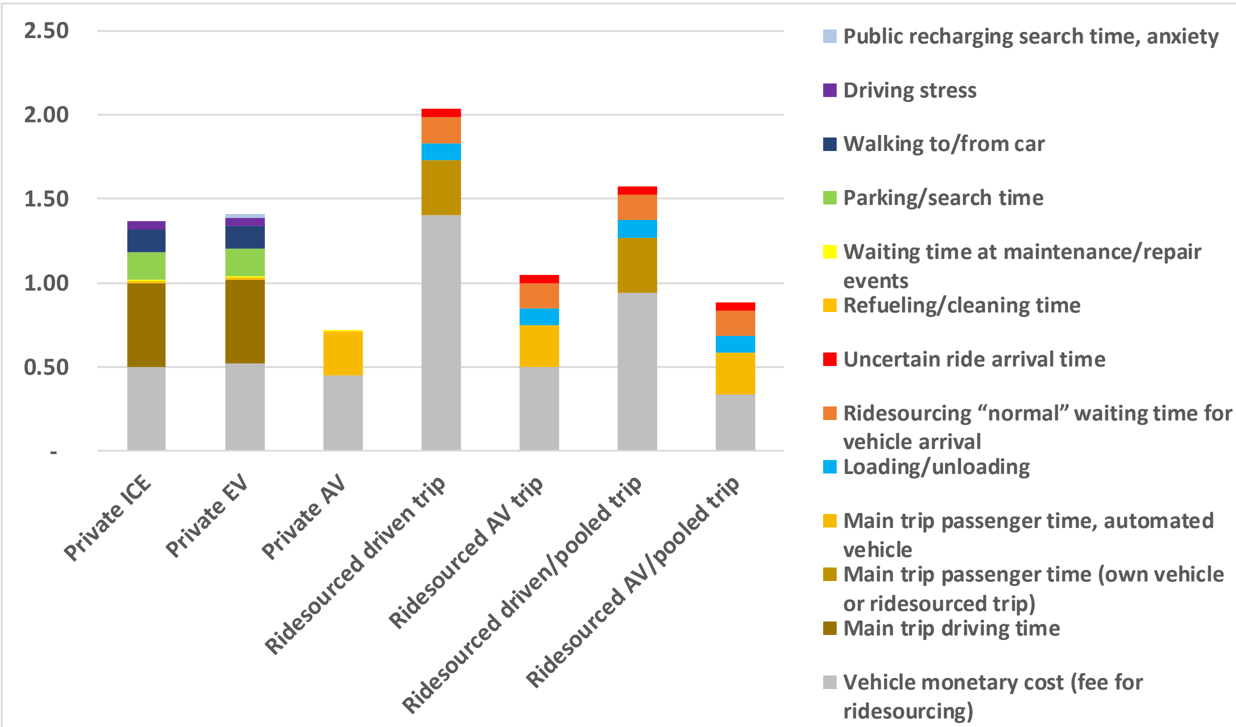


Figure 8. Travel time costs of a range of factors for various vehicle/trip types

Conclusions

This report has reviewed our own and others' recent work on monetary and non-monetary costs of travel, associated with "3 revolutions" type factors (especially ridesourcing and automated vehicles). We have used this review to develop a fuller set of cost factors affecting trip choices, and provided some estimates of the values of these factors using a range of approaches and drawing from the literature. We have added to existing estimates of the generalized (monetary and hedonic) identified needed future efforts to better quantify a range of trip choice factors. The report covers own-vehicle trips and ridesourcing trips, and it considers pooling as well as future vehicle automation.

The paper first presented specific generalized cost estimates derived from literature and previous analysis, that cover the main monetary cost categories and several time-related categories. We then presented a number of other factors affecting travel choices, that are difficult to quantify for a number of reasons. We presented some literature related to these, and how they could be quantified via conjoint-style analysis. Next, we presented a conjoin type survey approach and some findings from our own pilot survey. Finally, we made an initial effort to quantify some additional factors, by converting them into time costs, which may or may not be a reasonable way to value various types of factors. We find that most of these factors do not have a big impact on relative costs of trip types, suggesting that our approach, at least as an initial attempt, does not support the hypothesis that these factors are "game changers". Though we acknowledge that they could be very important for some travelers, and in some situations.

This work would logically be extended by developing better estimates of all the new types of costs considered, perhaps via conducting highly targeted stated preference surveys, and using conjoint style hypothetical choice sets including the types of cost variables presented here. It is clearly still "early days" in the study of the wide range of non-monetary factors influencing travel choices.

References

Alemi, F., G. Circella, S. Handy, P. Mokhtarian (2017), What influences travelers to use Uber? Exploring the factors affecting the adoption of on demand ride services. TRB 96th annual meeting. January 7-12, 2017, Washington DC. https://trid.trb.org/view/1439233

Autovista Group (2020), EV charging anxiety is the new range anxiety, 28 January, 2020. https://autovistagroup.com/news-and-insights/ev-charging-anxiety-new-range-anxiety

Björklund, G. and J. Swärdh (2015), Valuing in-vehicle comfort and crowding reduction in public transport No 2016:2, Working papers in Transport Economics from CTS - Centre for Transport Studies Stockholm (KTH and VTI).
https://econpapers.repec.org/paper/hhsctswps/2016_5f002.htm

Bruzelius, N.A. (1981), Microeconomic theory and generalised cost. Transportation 10, 233–245. https://doi.org/10.1007/BF00148460.
https://link.springer.com/article/10.1007/BF00148460

Buckley, Nathaniel Garcelon, (2016), Sexual Harassment on Public Transit and the Influence of Perceptions of Safety on Travel Behavior, Presented to the Faculty of the Graduate School of the University of Texas at Austin in Partial Fulfillment of the Requirements for the Degree of Master of Science in Community and Regional Planning The University of Texas at Austin, May 2016, https://repositories.lib.utexas.edu/bitstream/handle/2152/41496/BUCKLEY-MASTERSREPORT-2016.pdf?sequence=1

Compostela et al (2020), Near- (2020) and long-term (2030–2035) costs of automated, electrified, and shared mobility in the United States, Transport Policy, Volume 85, January 2020, Pages 54-66, https://www.sciencedirect.com/science/article/pii/S0967070X18309119.

Ditmore, Crissy and Deming, Devon (2017), Comparative Analysis of Vanpool and Single Occupant Commuters' Self-reported Stress Level Before and After the Commute, ICoMaaS, Tampere 28.-29.11.2017, Conference Proceedings 1st International Conference of Mobility as a Service.

Fosgerau M. (2018), Automation and the Value of Time for Passenger Transportation. In: International Transport Forum-Organisation for Economic Co-operation and Development - Zero Value of Time Roundtable, 25-26 September, 2018. Paris, France: International Transport Forum; 2018. https://www.itf-oecd.org/sites/default/files/docs/automation-value-of-time-passenger-transportation-fosgerau.pdf

Fulton, Lewis et al (2020), Generalized Costs of Travel by Solo and Pooled Ridesourcing vs. Privately Owned Vehicles, and Policy Implications, https://escholarship.org/uc/item/6vz5q4mc Fulton, Lew, PhD Brown, Austin, PhD Compostella, Junia, UC Davis, Publication Date 2020-02-01 DOI 10.7922/G2WD3XTK.

Gkartzonikasa, C. and G Gkritza (2019), What have we learned? A review of stated preference and choice studies on autonomous vehicles, Transportation Research Part C 98 pp323–337.

Haboucha, Chana J., Ishaq, Robert, Shiftan, Yoram, (2017), User preferences regarding autonomous vehicles, Transportation Research Part C 78 37–49.

Inci, E., JV. Ommeren, M. Kobus (2017), The external cruising costs of parking. Journal of Economic Geography. Vol 17, Issue 6, pp. 1301-1323. https://academic.oup.com/joeg/articleabstract/ 17/6/1301/3077167?redirectedFrom=fulltext

ITF (2018),Women's Safety and Security A Public Transport Priority, ITF, Paris, https://www.itf-oecd.org/sites/default/files/docs/womens-safety-security_0.pdf

Koopmans, Carl. et al (2013), Measuring generalised transport costs as an indicator of accessibility changes over time, Transport Policy, Volume 29, pp 154-159. https://www.sciencedirect.com/science/article/abs/pii/S0967070X13000875

Lam T.C., Small K.A. (2001), The value of time and reliability: measurement from a value pricing experiment, Transportation Research Part E: Logistics and Transportation Review, 37 (2) pp. 231-251

Littman, Todd (2016), Transportation Cost and Benefit Analysis Techniques, Estimates and Implications, Second Edition Update, Victoria Transport Policy Institute, https://www.vtpi.org/tca/

Malokin A, Circella G, Mokhtarian PL. (2019), How Do Activities Conducted While Commuting Influence Mode Choice? Using Revealed Preference Models to Inform Public Transportation Advantage and Autonomous Vehicle Scenarios. *Transp Res Part A Policy Pract*.124:82–114. http://doi.org/10.1016/j.tra.2018.12.015

Mangan, M. (2018), The Value of vanpooling as a strategic, cost-effective, and sustainable transportation option. Institute of Transportation Engineers. ITE Journal. Vol. 88, Issue 2, pp. 36-39

Mokhtarian PL. (2018), The Times They Are A-Changin': What Do the Expanding Uses of Travel Time Portend for Policy, Planning, and Life? *Transp Res Rec J Transp Res Board*. 2672(47):1–11. http://doi.org/10.1177/0361198118798602

Moody, Joanna and Jinhua Zhao (2019), Car pride and its bidirectional relations with car ownership: Case studies in New York City and Houston. Transportation Research Part A: Planning and Policy, 124: 334-353. https://doi.org/10.1016/j.tra.2019.04.005

NG, Wei-Shiuen and Acker, Ashley (2018), Understanding Urban Travel Behaviour by Gender for Efficient and Equitable Transport Policies, International Transport Forum Discussion Papers 2018/01, OECD Publishing, Paris, https://ideas.repec.org/p/oec/itfaab/2018-01-en.html

Wadud Z. (2017), Fully Automated Vehicles: A Cost of Ownership Analysis to Inform Early Adoption. *Transp Res Part A Policy Pract*. 101:163–76. http://doi.org/10.1016/j.tra.2017.05.005

Zhao, Z., Zhao, J., (2018). Car pride and its behavioral implications: an initial exploration in Shanghai. Transportation. https://doi.org/10.1007/s11116-018-9917-0

Data Management

Products of Research

UC Davis/STEPS developed a cost model of the choices travelers make between a range of vehicle trips, including with their own vehicles, use of new mobility services (e.g., Uber), and the use of pooled trips of that type. This model considers the cost impacts of combustion, electric, or automated/electric vehicles in the near and longer term. This work reveals wide variations in trip cost under different assumptions. However, there are also many non-monetary ("hedonic") factors, such as travel time, parking time/inconvenience, willingness to drive or be in an automated vehicle, willingness to travel with strangers, and other factors. These factors have major policy implications since they will affect travel choices and thus the net effect on societal impacts such as congestion, interaction with transit, and pollution. This project undertook focus group and a small-scale survey to explore such factors with the public, and how they perceive a range of issues associated with making various types of trips. The results were compiled and analyzed without expecting strong statistical significance, but provided some directional findings and a survey template that can be used by other researchers.

Data Format and Content

There are two resulting files: a spreadsheet with all survey results (n=78) and all identifiers removed, and the survey instrument in a PDF file, which can be used to compare to all responses.

Data Access and Sharing

The survey results and instrument files are available on the Dryad data repository website at https://doi.org/10.25338/B8Q04H

Reuse and Redistribution

The data is accessible to the public and open for reuse and redistribution with appropriate citation:

> Fulton, Lewis; Kothawala, Alimurtaza; Compostella, Junia (2020), Estimating the costs of new mobility travel options: monetary and non-monetary factors, v5, UC Davis, Dataset, https://doi.org/10.25338/B8Q04H