Modeling travel behavior onboard of privately autonomous vehicle and shared autonomous vehicle

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Abstract: The impact of travel time, travel cost, and multitasking availability on the selection of privately use AV (PAV) and shared AV (SAV) are examined. The main daily trip is only studied, where all trips are within urban areas. A stated preference (SP) survey which includes a discrete choice experiment, was designed and distributed in Budapest, Hungary to collect the preferences of people towards PAV and SAV. As a result, a sample size of 2056 observations was obtained from the survey. A discrete choice modeling approach was applied to the data using a conditional logit (CL) model, where the characteristics of the alternatives are considered. The analysis results show that the value of travel time (VOT) of SAV is lower than AV, and the probability of choosing a transport mode is increased when multitasking is available in a transport mode. Moreover, the impact of travel cost on transport mode choice is higher than the impact of travel time. In conclusion, people are more likely to select SAV over PAV when the multitasking availability is considered as one criterion in the transport mode selection.

Keywords: MULTITASKING, SHARED AUTONOMOUS VEHICLE, TRAVEL BEHAVIOR, VALUE OF TRAVEL TIME

1. Introduction

The continuous advancement in the technology of vehicle manufacturing will lead to having fully automated vehicles in the market in the coming few years [1]. A fully automated vehicle is characterized as no intervention by humans is needed to control the driving, where the machine can drive a car instead of a human driver as in conventional cars. The impacts of Autonomous Vehicles (AVs) on the mobility of people need further studies. Travelers generally assign an indirect money for travel time based on the importance of travel time, for example, traveling for work is more important than traveling for leisure activity [2]. The value of travel time (VOT) is a measure that describes the amount of money a traveler pays in traveling [3]. Some factors that impact VOT negatively are waiting time and crowding, or in other words, those factors increase the VOT [4]. The travelers’ willingness to pay money to overcome the unwanted factors is high because they want to maximize their utility; they can choose better transport modes or shorter routes to minimize the travel time [4]. The VOT is affected by the experience of a traveler onboard of a transport mode, for instance, finding a good environment to multitask during travel decreases the VOT. Moreover, the carried tools onboard also determine the multitasking onboard, such carried tools are internet bundle, and such multitasking is using social media [5-7]. In the conventional transport modes, the travel is divided into three parts, walking time, in-vehicle time, and waiting time [8]. In the AV era, the walking time is minimized and the waiting time is done in the closest street of passenger location where a passenger can track the vehicle and minimize the waiting time. In this study, the in-vehicle time is studied, where AV is used as a transport mode. It is found that the AV will have different characteristics than a conventional car, for example, no human driver, no driving license, higher safety, and door-to-door service [9, 10]. Berlinski et al. [11] define travel-based multitasking as people select a transport mode based on the potential of conducting onboard activities. The attribute multitasking availability is well defined in this paper. Several scholars study the impact of multitasking on travel behavior, such as Varghese and Jana [5] and Ettema and Verschuren [12] who study the impact of onboard activities in conventional transport modes on the VOT. Keseru et al. [13] show that information and communication technology (ICT) are associated with the trip purpose. While Malokin et al. [14] show a change in the mode share based on multitasking and the availability of ICT. Litman [15] shows that travelers are willing to switch to different transport modes in order to find a better environment to multitask (e.g. studying, working, and relaxing) to have a productive travel time. Banerjee and Kanafani [16] find that ICT motivates people to multitask onboard during their travel, which consequently decreases the VOT (i.e. positive impact). Singleton [17] says that transport mode characteristics impact the type of onboard activity.

The focus of this study is two models of AV, the privately-used autonomous vehicle (PAV), and the shared autonomous vehicle (SAV). The in-vehicle time is studied when travelers travel to their main destinations in urban areas. A stated choice experiment considering multitasking availability is scarce in literature, especially, about PAV and SAV, as pointed by [10]. The travelers are asked to choose PAV or SAV based on travel time, travel cost, and multitasking availability. This study adds a new contribution to the literature, where multitasking onboard of autonomous vehicle is modeled using a discrete choice modeling approach. It is obvious from the literature that previous studies focus on the CTMs, while this research studies the PAV, SAV. The contributions of this research are (1) developing a transport choice model for PAV and SAV, and (2) finding the impacts of changes on travel time, travel cost, and multitasking availability on the selection of transport choice.

2. Literature Review

The rapid advancement of the vehicle manufacturing industry due to the advanced technology will emerge fully autonomous vehicles (AVs) [18]. The people’s acceptability to AV which a machine takes the role of driving instead of a human driver is a challenge that will change the travel behavior of people [17, 18]. Travelers are willing to change a transport mode based on the importance of in-vehicle time for them, for example, traveling of high value includes onboard activities, minimum travel time, and minimum travel cost [19]. Travelers pay money to remove the unwanted travel time by changing a transport mode, route, time of conducting activities [2]. The saved time from using faster transport mode or using shorter route is considered an opportunity for other activities (positive utility) [20, 21].

The qualitative improvements on the transportation system (e.g., safety, service, comfort, and conveniences) is more attractive than infrastructure actions (i.e., less costly with varied positive impacts), as stated by Litman [15]. He demonstrates that VOT is improved when qualitative measures are enhanced and not only when travel time is reduced. The advancement of technology that enables people to carry and use ICT and the changes in the design of new vehicles as well as the future promising technology AV, all participate in enhancing the qualitative measures of transportation system. The utilization of the travel time by involving travelers in onboard activities makes the perceived travel time smaller than actual, as stated by Belenky [4], Cirillo and Axhausen [22] find that having a pleasant journey affect the preferences of people, such as the authors find that people do not mind choosing longer travel...
distance if they experience pleasant journey. It is found that travelers try to enhance their perceived travel time by conducting onboard activities during their travel [23]. Xumei et al. [24] finds that the VOT of work trips is larger than the VOT of leisure trips while the waiting time has the largest VOT. Based on the characteristics of AV and SAV, travelers will have less stress than conventional cars because the task of driving is removed, and the provided service is door to door [21, 25, 26].

The VOT is estimated based on the random utility theory, where a discrete choice modeling approach is applied [22]. Several studies are conducted on conventional transport modes using a discrete choice modeling approach where VOT is estimated and the travel behavior is assessed, while studies on the AV are limited. The study of Simoni et al. [28] shows AV will have lower VOT than conventional cars. Others show the factors that impact using AVs, such as Gurumurthy and Kockelman [29] say the long travel commuters are more willing to use AVs, Lavieri and Bhat [30] show that using SAV is influenced by companion's type and the number of picked up passenger along the travel (i.e., additional time), and the group of people impacts using AV. The high-income group has smaller VOT when they use AVs, as stated by Bozorg and Ali [31]. Steck et al. [6] show that the commuters can reduce their VOT when AV and SAV are used. Steck et al. [6] show that AV is more attractive than SAV. Kolarova et al. [32] find that the VOT of AV is less than conventional cars, and the VOT of SAV is higher than conventional cars. Studies such as [17, 33] show that multitasking can reduce the VOT and when drivers get rid of their tedious driving task. The reduction in VOT is high when travelers involve in multitasking in long distances as stated by Singleton [17]. The VOT is affected by trip purpose as also multitasking is influenced by the trip purpose [32].

The acceptability of people to ridesharing determines the use of SAV. Bansal et al. [34] find that the acceptability of people to the SAV depends on the level of fear regarding the system failure which is considered the strongest reason to not use SAV. Burghout et al. [35] show that people can use SAVs if the average waiting time in ridesharing is acceptable to them. Krueger et al. [36] show that waiting time determines the use of SAVs, in addition to the cost and travel-time factors. Stoiber et al. [37] choose experiments that SAVs are more likely to be used in pooled mode where multiple riders can join through a trip and the travel time can be used more efficiently through SAVs compared to regular cars. Lavieri and Bhat [30] finds that people are likely to use SAVs with strangers on commute trips, and the waiting time is a negative impact on the use of SAVs during picking up and dropping passengers off.

In this research, the travelers’ behavior onboard of PAV and SAV is discussed using discrete choice modeling. A new definition for multitasking is proposed where a traveler chooses a transport mode based on multitasking availability, travel time, and travel cost.

### 3. Methodology

The section presents the methodological approach of this study. Travelers choose a transport mode based on their preferences, where each traveler seeks to maximize his/her utility. The travel time is considered unproductive time (i.e., negative utility) based on the random utility theory while conducting activities is considered productive (i.e., positive utility) [38]. The reduction in the travel negative utility is obtained when travelers experience pleasant journeys or conduct onboard activities during their travel. The possibility to conduct onboard activities is influenced by several factors such as transport mode. Moreover, the perceived travel time is affected by the environment onboard of transport mode, where the perceived travel time is improved when travelers experience pleasant journey. This section will present the methods that are used in analyzing the impacts of conducting onboard activities in PAV and SAV, where the changes in the travel time and travel cost are also examined. A stated choice experiment survey is conducted where other factors are collected, such as sociodemographic, economic, and trip variables. The stated choice experiment includes two alternatives (AV and SAV), travel time, travel cost, and multitasking availability. The power of the stated choice experiment method is its efficiency to obtain responses from respondents based on their preferences, associated with characteristics of transport modes [27]. The aim of the analysis is to develop mode choice models for AV, and SAV.

Fig. 1 shows the structure of the survey and the used methods. The discrete choice experiment includes travel time, travel cost, and multitasking availability. Multitasking availability means a traveler has the possibility to conduct one or more of the following activities: reading, writing, talking, listening, using social media, eating-drinking, while multitasking unavailability means doing other activities such as thinking, window gazing, and sleeping that do not need contact with ICT and passengers (e.g., talking). Three levels of each travel time and travel costs are used, and two levels for multitasking are used. The alternatives are PAV and SAV. Some descriptive statistics are presented to characterize the sample. Moreover, other variables are used and examined to see their impacts on the transport mode choice, such as gender, income, age, education, job, car ownership, trip purpose, and transport mode. Finally, the VOT is calculated which describes the importance of traveling using monetary values per hour.

![Fig. 1 The methodological approach](image)

A stated preference (SP) survey is distributed in Budapest, Hungary, during the period from March to April 2020. The respondents are asked to report their existing conditions and their preferences towards PAV and SAV considering normal conditions away from the impact of COVID-19.

In the random utility theory, every person is a rational decision-maker, where each individual seeks a decision to maximize his/her utility [38]. The probability of a traveler to select one alternative out of certain outcomes is given in Equation 1:

$$P(s_j/S) = \text{Pr}(U_j > U_k) \quad \forall s, K \in S$$

where $P(s_j/S)$ is the probability of a person to choose outcome $(s_j)$ from a choice set $(S)$, $U_j$ is the utility of choosing the outcome $(s_j)$ from the choice set $S$, where the earned utility is larger than the utility of all other outcomes $(K)$ in the choice set $S$ [38]. The utility that a person has when he conducts daily activities contains a deterministic and a stochastic part, as shown in Equation 2:

$$U_j = D_j + \epsilon_j$$

where $D$ is the deterministic part while the $\epsilon$ stands for the stochastic part. The deterministic part is defined as the average perceived utility of individuals when they choose an outcome [38]. The random part is defined as the unknown deviation of a person’s utility from the mean value. The random part is used to capture the uncertainty in the choice modeling [38]. The conditional logit (CL) model which is one of the random utility models is selected.

In CL, all persons are given different situations before they choose an outcome Moreover, the same persons are used in choosing an outcome per situation is taken into account by CL.
Moreover, the characteristics of outcomes are taken into account rather than the characteristics of individuals [39]. Let \( Z_{ij} \) be the characteristics of outcome \( j \), and \( \alpha \) is the vector parameter of choosing the outcome \( j \), the probability that a person \( i \) will choose outcome \( j \) is given in Equation 3.

\[
P_{ij} = \exp(Z_{ij}^\alpha) / \sum_{k=1}^{J} \exp(Z_{ik}^\alpha)
\]

From Equation (3), the likelihood function is calculated.

4. Results and discussion

The results of the survey include 2056 observation, where each observation represent an outcome with its characteristics. For example, each person is subjected to two observations to choose one of them (i.e., 2056×2=4102 answers). The characteristics of the collected sample are presented in Table 1 and Table 2. \( \text{Грешка! Невалидна препратка на показалец към себе си.} \)

Table 2.

Table 1 presents descriptive statistics of the sample, such as age, job, income, and gender groups.

<table>
<thead>
<tr>
<th>Age</th>
<th>%</th>
<th>Job</th>
<th>%</th>
<th>Income</th>
<th>%</th>
<th>Gender</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-24</td>
<td>18.44%</td>
<td>Workers</td>
<td>50.00%</td>
<td>High</td>
<td>34.43%</td>
<td>Male</td>
<td>64.75%</td>
</tr>
<tr>
<td>25-54</td>
<td>75.41%</td>
<td>Student</td>
<td>40.16%</td>
<td>Middle</td>
<td>26.64%</td>
<td>Female</td>
<td>35.25%</td>
</tr>
<tr>
<td>55-65</td>
<td>4.51%</td>
<td>Unemployed</td>
<td>6.15%</td>
<td>Low</td>
<td>38.93%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;65</td>
<td>1.64%</td>
<td>Retired</td>
<td>3.69%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Trip Characteristics variables, transport mode, and trip purpose

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>%</th>
<th>Trip purpose</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bike</td>
<td>5.74%</td>
<td>Education</td>
<td>41.39%</td>
</tr>
<tr>
<td>Car as driver</td>
<td>21.31%</td>
<td>Work</td>
<td>43.85%</td>
</tr>
<tr>
<td>Cas as passenger</td>
<td>5.74%</td>
<td>Leisure and others</td>
<td>6.56%</td>
</tr>
<tr>
<td>Public transport</td>
<td>53.69%</td>
<td>Shopping</td>
<td>4.10%</td>
</tr>
<tr>
<td>Taxi</td>
<td>3.69%</td>
<td>Home</td>
<td>4.10%</td>
</tr>
<tr>
<td>Walking</td>
<td>9.84%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 presents the estimates of the model, where CL is applied. The results show the marginal utilities of travel time and travel cost are negative (-0.0161, and -0.0027, respectively), which means traveling is disutility (i.e., negative utility) where travelers pay money instead of gaining money from travel. Multitasking availability increases the probability of choosing a transport mode by 0.25 points more than the probability of choosing a transport mode without multitasking availability. All variables are significant at confidence interval 95% except travel time which is significant at confidence level 90%. The result of the model shows that the model without considering the variables; travelers are more likely to choose SAV over PAV, as shown in the PAV-β0. Moreover, the VOT is 358 Ft/hr.

Table 3. Conditional logit-model estimates

Table 4 present the predictive margins across multitasking options. The model demonstrates that the predictive probability (i.e., margin) of using SAV when multitasking is available is 58.1% while it is 52.13% when multitasking is unavailable. Similarly, the predictive margin of using PAV when multitasking is available onboard is 47.84%, while it is 41.85% when multitasking is unavailable. Thus, having multitasking onboard of PAV and SAV impacts the choice of travelers.

Table 4. Predictive margins across multitasking

Table 5 present the predictive margins across travel time. In this table, three values are used to estimate the margins, bottom value, middle value, and upper value. In the case of SAV, the probability of choosing SAV is decreased when travel time is increased. For example, at the travel time of 20 minutes; the margin of SAV is 56.9%. While at the travel time of 25 minutes; the margin of SAV is 55.2%. Moreover, the margin of SAV is examined, when a change in the travel time of PAV is occurred rather than SAV. It is found that the margin of SAV is increased when the travel time in PAV (i.e., the opponent alternative) is increased. For example, the margin of SAV is 53.5% when the travel time in PAV is 20 minutes, and the margin of SAV is 55.3% when the travel time in PAV is 25 minutes. In the case of PAV, the probability of choosing PAV is decreased when travel time is increased. For example, at the travel time of 20 minutes; the margin of PAV is 46.5%. While at the travel time of 25 minutes; the margin of PAV is 44.7%. Moreover, the margin of PAV is examined when in the travel time of SAV a change is occurred rather than PAV. It is found that the margin of PAV is increased when the travel time in SAV (i.e., the opponent alternative) is increased. For example, the margin of PAV is 43.1% when the travel time in SAV is 20 minutes, and the margin of PAV is 44.7% when the travel time in SAV is 25 minutes. It is found that the change on the margins in the case of PAV is higher than SAV, for example, changing the travel time from 20 minutes to 25 minutes the margin of PAV is increased by 1.9% in the case of SAV, for the same travel time interval. Fig. 2 illustrates the probability of choosing PAV and SAV when travel time is varied. It is shown that travelers are more willing to use SAV over PAV.

Table 5. Predictive margins across travel time

\( *** p<0.01, ** p<0.05, * p<0.1 \)
Table 6 present the predictive margins across travel costs. Three values are used to estimate the margins, bottom value, middle value, and upper value. In the case of SAV, the probability of choosing SAV is decreased when travel cost is increased. For example, at the travel cost of 175 Ft; the margin of SAV is 61.9%. While at travel cost 250 Ft; the margin of SAV is 55.5%. Moreover, the margin of SAV is examined when a change in the travel cost of PAV is occurred rather than SAV. It is found that the margin of SAV is increased when the travel cost of AV (i.e., the opponent alternative) is increased. For example, the margin of SAV is 44.8% when the travel cost of PAV is 175 Ft, and the margin of SAV is 55.5% when the travel cost of PAV is 250 Ft. In the case of PAV, the probability of choosing PAV is decreased when travel cost is increased. For example, at the travel cost of 175 Ft; the margin of PAV is 51.2%. While at travel cost 175 Ft; the margin of PAV is 44.5%. Moreover, the margin of PAV is examined when a change in the travel cost of SAV is occurred rather than PAV. It is found that the margin of PAV is increased when the travel cost of SAV (i.e., the opponent alternative) is increased. For example, the margin of PAV is 38.1% when the travel cost of SAV is 175 Ft, and the margin of PAV is 47.3% when the travel cost of SAV is 250 Ft.

![Fig. 2 Prediction margin based on the changes in travel time](image1)

**Table 6. Predictive margins across travel cost**

| Delta method | At alt. (x) at travel time (i) | Margin | Std. Error | z | P>|z| |
|--------------|-------------------------------|--------|------------|---|-------------|
| SAV          | SAV @ 175 Ft                  | 0.619  | 0.019      | 32.11 | 0.0***      |
|              | SAV @ 250 Ft                  | 0.553  | 0.016      | 35.62 | 0.0***      |
|              | SAV @ 300 Ft                  | 0.485  | 0.021      | 23.54 | 0.0***      |
|              | PAV @ 175 Ft                  | 0.488  | 0.02       | 24.02 | 0.0***      |
|              | PAV @ 250 Ft                  | 0.555  | 0.015      | 35.85 | 0.0***      |
|              | PAV @ 300 Ft                  | 0.621  | 0.019      | 31.91 | 0.0***      |
| PAV          | SAV @ 175 Ft                  | 0.381  | 0.019      | 19.75 | 0.0***      |
|              | SAV @ 250 Ft                  | 0.447  | 0.016      | 28.78 | 0.0***      |
|              | SAV @ 300 Ft                  | 0.515  | 0.021      | 24.98 | 0.0***      |
|              | PAV @ 175 Ft                  | 0.512  | 0.02       | 25.25 | 0.0***      |
|              | PAV @ 250 Ft                  | 0.445  | 0.015      | 28.7  | 0.0***      |
|              | PAV @ 300 Ft                  | 0.379  | 0.019      | 19.45 | 0.0***      |

*** p<0.01, ** p<0.05, * p<0.1

Fig. 3 illustrates the probability of choosing PAV and SAV when travel cost is varied.

As a result, it is found that the change in the travel cost impacts the margins more than the changes in the travel time, and multitasking availability increases the probability of choosing a transport mode. However, in almost all situations, travelers demonstrate choosing SAV over PV based on the three attributes: time, cost, and multitasking.

It is worth mentioning that the sociodemographic, economic and trip characteristics show insignificant results at a confidence level of 95%. Therefore, they are removed from the model.

![Fig. 3 Prediction margin based on the changes in travel cost](image2)

### 5. Conclusion

The travel behavior of people towards two types of automated vehicles is discussed through a discrete choice modeling approach. An SP survey is conducted where a discrete choice experiment (DCE) is designed. Two alternatives (PAV and SAV) are included in the DCE, where CL is used to study the behavior of travelers toward these two alternatives considering the characteristics of each alternative. The included characteristics are called attributes, and they are travel time, travel cost, and multitasking availability. The SP is distributed in Hungary, and the collected observations are analyzed. The results of the analysis show that the availability of multitasking on board increases the opportunity to use a transport mode (i.e., travel-based multitasking). In conclusion, people are more willing to use SAV over PAV considering travel time, travel cost, and multitasking availability when they travel to their main destination within the urban area. Moreover, the travel time influences the use of PAV and SAV, while more influence is obtained when travel cost is changed.

### 6. Acknowledgment

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