Shared autonomous vehicle with pooled service, a modal shift approach

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Abstract

Dependence on private cars has led to numerous problems, where AVs could be a potential solution. Pooled service, however, could be a much bigger step towards sustainable transportation. This paper presents a modal shift analysis emphasizing socio-economic, travel characteristics and their interaction for a sample of private car users in Tehran. A stated preference survey was designed in 2021 exclusively for the research purposes, and 491 valid questionnaires were gathered. One of the main contributions is considering the impact of the number of persons in shared autonomous vehicle with pooled service (SAVWPS). Estimation results of discrete choice model reveal that, high-income respondents, owning a personal car and being a man decrease the likelihood of modal shift to SAVWPS. A negative impact is also observed for travel time, travel cost, waiting time and number of persons in SAVWPS. A significant systematic heterogeneity is observed in the interaction effect of travel time and dissatisfied respondents with internet taxis due to the pandemic. Considering this taste variation, a lower travel time in SAVs could increase the modal shift likelihood among these travelers. The findings could help transportation decision-makers identify the factors affecting modal shift to SAVWPS to achieve a more sustainable transportation system.

Keywords: Modal shift behavior, Pooled service, Ridesharing, Shared autonomous vehicle (SAV), Stated preference.

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1. Introduction

The increasing rate of car ownership and dependency in metropolises have resulted in numerous problems such as traffic congestion, environmental pollution, higher travel time, an increase in the number of accidents, decreased physical activity, and increased rates of obesity, particularly in developing countries [1-4]. Transport sector accounts for 66% of oil consumption and 20% of carbon production and emissions in the European Union [5, 6]. Private cars are the most preferred transportation mode in many countries, particularly developing ones, accounting for over 43% of all trips in Iran [7]. According to the National Highway Traffic Safety Administration (NHSTA), human error accounts for 90% of car accidents in the United States and 92% in Iran [8]. World Health Organization (WHO) reported that road accidents were the third most significant cause of death in Iran in 2019 [9]. Given the challenges associated with the increase in personal car use and the car ownership pattern which is significantly increasing from 175 private car per 1000 capita in 2010, and it is estimated to be 679 in 2030 [10], the government and local authorities are seeking sustainable transportation systems to address the above problems [1].

With the introduction of autonomous vehicles (AVs) and the rapid advancement in these vehicles over the last few years, many studies showed that issues associated with personal cars will be partly reduced, and AVs will play an essential role in the future transportation system [11]. According to previous studies, AVs could reduce air pollution, fuel consumption, human error-related accidents [12, 13]. In the same way, AVs have the capability of changing private car ownership, land use patterns, as well as enhancing network capacity and mobility patterns of vulnerable individuals [14]. Despite these potential advantages, several studies indicate that the high level of comfort and convenience in AVs will increase their use, which is counter to developing a sustainable transportation system. Moreover, the high cost of AVs' ownership makes their establishment challenging, particularly in developing countries [15]. Using shared autonomous vehicles (SAVs) that integrate AV technology with shared mobility services, such as car-sharing, ride-sharing, and ride-sourcing, not only could address these issues but other aspects of the transportation system can also be enhanced [16]. From sharing approach views, car-sharing and ride-sharing are the most common approach. In car-sharing, a user requests a car for their daily needs from an origin to a destination, and it can offer round-trips or one-way services [17-20]. In ride-sharing, on the other hand, users share their travel plans with others, and other people with similar origins and destinations join them to share their trips [21-23].

According to previous findings, SVAs will eventually replace many outdated and costly transportation modes [24, 25]. Potential benefits of SAVs show a 50% reduction in traffic volume [1, 26, 27], a 40-50% reduction in travel costs compared to traditional car request services [28-31], an 80% reduction in accident rates and a 40% reduction in fatal accidents [29, 32], an 80% reduction in fuel consumption and pollutants compared to personal cars [28, 33, 34], and lower need for parking space [35, 36]. Along with all the potential benefits, some studies have evaluated their imperfections and drawbacks, such as security (due to the use of artificial intelligence in car control), safety, interaction with pedestrians, cyclists, and motorcyclists [37], cleanliness (due to public use), and lack of driver to assist passengers in moving their baggage [11, 38].

Considering the acceptance of people and determining their needs are crucial to the successful implementation of any system, this paper aims to determine the explanatory factors such as socio-demographic and travel characteristics of modal shift from private cars to SAVs with pooled service (SAVWPS) among Tehran residents using a discrete choice model. Using stated preference (SP) questionnaire, private car users in Tehran were asked to declare their willingness to shift to SAVWPS based on different experiments, which consist of four three-level attributes, including the number of accompanying persons, travel costs, waiting time, and travel time. After a careful review of the literature, the following research gaps were identified: The majority of previous studies have so far concentrated on AVs, and less attention has been paid to SAVs, particularly SAVWPS, so there is a clear need for more detailed research on SAVWPS. Additionally, most previous studies were conducted in developed countries, and to the best of our knowledge, there is no such study in developing countries. To fill the above research gaps, this paper contributes to the literature by considering the impact of the number of accompanying persons that share their trip on the likelihood of modal shift, which has received less attention in previous studies.

This paper is structured as follows: a review of previous studies on SAVs will be discussed in Section 2; survey design and research method will be presented in Methodology section. Estimation results and discussion will be presented in "Data Analysis" section. Finally, the "Conclusions" section provides the paper’s conclusion, limitations, and recommendations for future studies.

2. Literature review

This section presents the explanatory factors affecting AV choice. Previous studies have classified the variables affecting the choice of AVs into three categories: 1) socioeconomic characteristics, 2) travel characteristics, and 3) attitudinal factors [11, 14, 24, 39, 40]. It is worth noting that due to the difference in geographical location, culture, income, and consumer innovativeness, contradictory findings have been observed. For example, in terms of socioeconomic characteristics, compared with women in Austin, Asmussen et al. [41] found that men are more likely to buy and use AVs due to their higher income. However, Schoettle and Sivak [42] found a reverse relationship in U.S., U.K., and Australia. In terms of age, Asmussen et al. [41] revealed that older adults (over 64 years old) are more likely to use AVs, but Krueger et al. [43] found that older adults are the least likely respondents to choose and use AVs.

Many studies have shown that high-educated people are more inclined to use/ purchase AVs due to their familiarity with new technologies [42, 44, 45]. However, Zmud and Sener [46] found no significant association between education level and willingness to use AVs. Household income is another factor affecting AVs' acceptability or purchase. Many studies have found that household income is a vital factor in using/purchasing AVs [47-49]. However, some studies have found contradictory results [46, 50, 51].

Although considerable research has examined the determinants behind the choice of AVs, a limited number of papers have addressed this subject in SAVs, especially SAVWPS. Table (1) summarizes previous studies on SAV choice as an emerging transportation mode. According to previous studies, the most critical explanatory factors in choosing SAVs are their operational features, including travel time, waiting time, travel costs, and willingness to share their trip with others [17, 43]. Many studies found that young, men, highly educated, and high-income respondents are more likely to choose SAVs [52, 53]. However, people who occasionally use transit are also less likely to use SAVs [37, 43].

< Table (1) >

Based on the literature, the following topics have received very little attention, which we aim to fill and contribute to the literature by: 1) the majority of studies focus on car-sharing services, and less attention has been paid to SAVWPS; 2) most of the prior studies conducted in developed countries and less attention has been paid to this matter in developing countries; 3) Unlike previous studies, the determinants behind the modal shift behavior have been examined using two utility functions including the factors motivating and prohibiting the modal shift from private cars to SAVWPS.

3. Methodology

In this section, firstly, we introduce the stated choice experiment that has been used to collect the stated preferences of respondents (Section 3-1). Moreover, the questionnaire design (Section 3-2) and Choice experiment design (Section 3-3) will be presented, and finally, analysis of the collected data and variables used in the modeling will be addressed (Section 3-4). The research flowchart is also presented by Fig. 1.

< Figure 1. >

3.1. Choice experiment design

In a conjoint survey, a choice set consisting of hypothetical alternatives based on a combination of different attributes of a service or product, presented to respondents and ask their preference about the alternatives [58]. In this research, a stated preference (SP) survey was exclusively designed and administered for determining travelers' preference for a modal shift from private cars to SAVWPS. To collect the SP data, *Epoll,* as an online survey platform with the capability of designing various questions has been used due to the pandemic situation in Iran.

3.2. Questionnaire and survey design

The questionnaire consisted of 50 questions in three main sections, of which 18 questions were related to SP scenarios. In the beginning, the survey objective, anonymity, and the confidentiality of responses were claimed to respondents. Therefore, respondents were asked to consider their last trip with private car and answer questions on the departure and ending time, in-vehicle time, trip purpose, accident experience during past 5 years, and parking space situation. The logic behind this approach, as also used in most previous studies [43], is that this trip is the most recent trip of the respondents, so fewer invalid or incorrect responses are likely to be given. Also, this would reduce bias in responses to the most frequent trips, which are usually mandatory trips taken on a specific schedule. Thus, we have targeted the last trip (and its characteristics) in order to avoid collecting invalid responses and to collect trips with a variety of purposes. Secondly, due to the absence of SAVs in Tehran, a short video clip along with SAVWPS operation (Fig. 2) have been designed and shown to respondents to better percept this technology's features. As an explanation about the operation of SAVWPS in Figure 1, it should be say that, in section (I), *passenger (A)* registers an SAV request using his/her mobile phone after choosing the origin and destination of his/her trip. The request will be sent to the main server and after some processing in the data center, the best match SAV will be assigned to him/her. In the meanwhile, in section (II), *passenger (B)* also registers an SAV request with a different origin and destination, which the previous processes for *passenger (A)* will be redone. Due to the overlap of the route between *passenger (A)* and *passenger (B),* the main server matches their requests and assigns the same SAV to them. Finally, section (III) presents the optimized route for passengers to be served by the same SAV. After the introduction of SAVWPS, we have asked the respondents to declare their level of familiarity with SAVs ranging from "1= not familiar at all" to "4= very familiar and having comprehensive information". Then, the SP scenarios were presented to respondents to determine their willingness to shift to SAVWPS through a dichotomous (yes/no) variable. Finally, socio-economic along with household characteristics were asked including gender, age, marital status, education, income, driving experience, household size, and car ownership.

Relation (1) proposed by Cochran [59] was used to determine an adequate sample size.

$$n_0 = \frac{pqz^2}{e^2} \quad (1),$$

where, n_0 is the (minimum) adequate sample size, z is the standard error at the considered significance level (1.96 for 5% significance level), e accounts for the acceptable error (5%), p represents the proportion of the population that has the attribute in question (share of using car in daily trips which is 43%), and q represents $1-p$. Based on this relation, the minimum sample size is 377.

< Figure 2. >

3.3. Stated preference section

According to travelers' last trip with private car, we have used stated choice experiment to determine users' preferences about the modal shift. Based on four three-level attributes of SAVs including travel time, travel cost, waiting time, and number of persons inside SAVs, 18 orthogonal scenarios were designed. The levels of considered attributes are presented in Table 2. It should be noted that based on previous studies, we have selected several levels for each attribute and in light of the pilot study results, we have customized the levels in accordance with our context.

< Table (2) >

Considering time limitations and preventing respondents' confusion, a fractional factorial design (FFD) approach was used to design scenarios. Moreover, the choice experiments were divided into three six-scenario blocks and presented to each respondent randomly, and their willingness to shift toward SAVWPS was asked (Table 3). Concerning the randomness of presenting each scenario to respondents, we should mention that the survey platform had the capability of presenting the scenarios equally and randomly. In order to ensure that all three six-scenario blocks scenarios have been sufficiently distributed, we continuously monitor the share of each block. Finally, the distribution of first, second, and third block is 35%, 35%, and 30%, respectively.

< Table (3) >

3.4. Featuring the selected sample

The designed survey was distributed online in Tehran for two months due to the pandemic from August 2021. Through different social media platforms (Telegram, Instagram, Twitter, Facebook, etc.), we have asked administrators of popular channels and groups to place the questionnaire. Using some incentives, we have motivated the members of channels and groups to respond to our survey. Considering the research objectives, private car users were only eligible to respond to the questionnaire. Before the main survey, 30 questionnaires were filled out as a pilot to check the clearness of the questions. After removing the incomplete and invalid responses, 491 valid questionnaires were used for modelling purposes. Descriptive analysis of individuals' sociodemographic characteristics (Table 4) shows that 306 (66.56%) respondents were men, while the remaining 164 (33.40%) were women. Approximately half (51.52%) of responses were gathered from persons aged 25 to 34. Due to the fact that this survey was conducted online, our sample is partly limited to respondents who are younger, especially those who have a social media account. In order to reduce the possibility of sampling bias, we have distributed our survey to a variety of groups and channels in order to improve its visibility among respondents. Regarding marital status, 327 respondents (66.59 %) were single, while 164 (33.4%) were married. According to the respondents' educational level, 240 (48.87%) have a master's degree. According to the respondent's car ownership level, 240 (48.87%) persons own at most a car. Regarding the number of driving licenses in the household, 175 (35.63%) responses belong to households with at most one driving license, and 186 (37.88%) respondents have 0 to 5 years of driving experience. Finally, the majority of respondents, 203 (41.34%), stated they are middle-income.

<Table (4) >

Stated modal shift behavior of respondents is shown based on their socioeconomic characteristics, familiarity with SAVs, and travel-related attributes (Figure 3). As it can be seen, female have a higher tendency to modal shift which it might be due to their lower income and car ownership level compared with men. Regarding the accident experience, it can be concluded that there is no significant difference between the related cohorts. It is due to the fact that respondents who did not experience any accidents are more confident about their driving skills while people with any experience in accidents are concerned of SAVs' safety. Increasing the mobility is one the potential advantages of SAVs which enhance the mobility of people who do not have a driving license, people with disabilities and elderlies. Hence, considering the driving license status, we can see that respondents without driving license are more inclined to shift to SAVs. Regarding age, it can be seen that people aged less than 24 years are the most inclined group among different age categories to shift to SAVs due to their higher technology awareness. While, people aged more than 45 are the least inclined to modal shift to SAVs. Due to the high car dependency and ownership in Iran, as a developing county, we can see that as the car ownership increases, people are also less likely to shift to SAVs. Furthermore, a similar behavior is also found about income levels which shows that high-income respondents have a lower tendency to shift to SAVs and consist on using their private cars. As an interesting finding, increasing the familiarity with SAVs is accompany with higher likelihood of modal shift to SAVs. It is due to the fact that respondents who have more information about SAVs’ operation could better trust in SAVs. Considering the travel-related attributes (i.e. travel time, travel cost, waiting time, and number of person), as each of these factors increases, the likelihood of modal shift to SAVs decreases. In addition, we explore how travel-related attributes influence the modal shift preferences of individuals based on their socioeconomic characteristics, specifically income levels. By comparing the shifting behavior of low-income and high-income respondents (Figure 4), we shed light on the modal shift preference of a specific respondents. Regarding waiting time, respondents generally exhibit reluctance to shift to SAVs as waiting time increases. However, low-income individuals appear less sensitive to this factor, maintaining a consistent preference for SAVs even with extended waiting times. As high-income participants have a higher value of time (VOT), their modal shift preference to SAVs significantly reduces as SAVs' travel time increases. In contrast, low-income individuals remain less sensitive to travel time variations. The importance of travel cost is pronounced among low-income respondents. As SAV travel costs rise, their modal shift preference decreases significantly. In contrast, higher-income individuals prioritize comfort and privacy over cost considerations. Furthermore, as the number of people sharing SAV rides increases, high-income individuals exhibit a substantial decline in modal shift preference, while lower-income respondents are less affected by this factor.

< Figure 3. >

< Figure 4. >

4. Estimation result

Considering the research objectives, we have determined the most substantial explanatory factors in shifting and not shifting from private cars to SAVWPS. The dependent variable is the likelihood of modal shift from private cars to SAVs. Independent variables include socio-demographic characteristics (such as age, gender, marital status, household car ownership, and driving license) and travel characteristics (such as departure time, travel time, waiting time, travel costs, and number of accompanying person in SAV). The examined factors which are investigated the explanatory factors of modal shift behavior among private car users in Tehran are presented in Table 5.

< Table (5) >

4.1. Discussion

After calibration of about 200 binary logit models in Nlogit, Table 6 presents the estimated parameters for the best fit model along with significance level, t-test and marginal effect. The t-values show that most estimated coefficients are significant at 95% confidence level. The interaction variables have also been used to investigate the systematic heterogeneity among respondents. Also, to facilitate the successful policymaking and implementation of SAVs, the factors contributing to the modal shift behavior have been estimated separately in two utility functions. The positive and significant coefficient of passenger variable (β: 0.264, p-value: 0.006) indicates the higher likelihood of no modal shift. In other words, if a respondent is a driver, she (he) will be less likely to persist in using her (his) private car and shift to SAVs. One of the reasons for this matter is that drivers can experience a more productive trip by doing other activities than driving, which is in line with previous studies [60]. The negative and significant coefficient for users without car ownership (β: - 0.407, p-value: 0.000) indicates the lower likelihood of no modal shift to SAVs. It can be concluded that the lack of private car ownership will increase the likelihood of modal shift to SAVs. It is due to the fact that in accordance with the findings of Dicianno et al. [14] and Yuen et al. [53], SAVs will increase the mobility of individuals who do not own a private car, elderlies, people aged under 18, and disabled which increase the likelihood of choosing AVs and SAVs. Given the high level of car ownership and dependency in Iran, the estimated parameter for INCNPS_1 (β: 0.194, p-value: 0.000) indicates that by increasing the income, even if respondents share their trip with another person in SAVs, their willingness to persist in the current travel mode is increased and the likelihood of modal shift to SAVs is reduced, which is aligned with the findings of Bansal and Kockelman [47], Kyriakidis et al. [48], and Howard and Dai [49]. Regarding gender, female respondents (β: - 0.272, p-value: 0.001) are less likely to do not modal shift. Considering the lower level of income and car ownership among women compared with men, they are more inclined to modal shift to SAVs, which is in line with Yuen et al.[53] and Aboutorabi Kashani et al. [61] findings. The positive and significant coefficient of the interactive variable (INC_3TTM) indicates the systematic heterogeneity among middle-income persons in perceiving the impact of private car travel time. It can be concluded that by reducing private car travel time among people with average income (β: 0.743, p-value: 0.026), the likelihood of modal shift to SAVs decreases and this income group are more sensitive to private car travel time. Increasing household car ownership level among respondents who use private parking (β: 0.200, p-value: 0.060) is positively associated with the probability of keeping on using private cars and decreases the likelihood of modal shift to SAVs. High level of car ownership and presence of free parking in Tehran has led to a high dependency upon private cars and a reduction in the willingness to use public transportation [62]. Hence, as an implication for policy and practice, it is recommended to implement some travel demand management policies such as parking management and congestion pricing to reduce private car desirability. Considering the potential benefits of SAVs in reducing accidents due to human errors, respondents who experienced more than two accidents during 5 past years (β: 0.417, p-value: 0.067) are more likely to shift to SAVs. This significant finding is in accordance with Singh [63] results. A two-minute waiting time for SAVs (β: - 0.279, p-value: 0.000) is negatively associated with modal shift to SAVs, which is in line with Lokhandwala and Cai [21] findings. The positive and significant impact of TTSMCOV (β: 17.189, p-value: 0.015) indicates that as the travel time in SAVs decreases, the likelihood of modal shift to SAVs will increase among respondents who are less likely to use internet taxis due to pandemic situation. Hence, reducing SAVs' travel time is recommended by implementing policies such as using dedicated lanes at least during pandemics, which will increase the likelihood of sharing attitudes among these groups. The positive and significant coefficient of PHD_TTSM reveals the systematic heterogeneity among respondents (β: 7.598, p-value: 0.072), showing that respondents with a Ph.D. degree are more sensitive to travel time in SAVs. In other words, these persons are more likely to modal shift from private cars to SAVs if the travel time in SAVs decreases by implementing such recommended policies in previous lines. Finally, the negative and significant estimated parameter for (TCSSSIN_3) shows that middle-income individuals (β: - 0.139, p-value: 0.000) are more sensitive to SAVs' travel cost. It can be concluded that as the travel cost by SAVs increases, the likelihood of modal shift among middle-income respondents will decrease.

< Table (6) >

4.2. Implications for policy and practice

Several implications for policy and practice are presented in this section within the context of some variables, with the aim of increasing the likelihood of modal shift to SAVs.

Concerning the significant effect of NACDR_2 variable, it should be mentioned that it is essential for authorities to build trust among their potential users. It is, therefore, imperative to ensure the safety of this technology. As a result of continuous monitoring of SAVs, constant checks to prevent potential defects, and the presence of cameras and operators inside the vehicle, people's concerns are reduced and trust is formed. Moreover, it is recommended to report the potential benefits of SAVs such as reduction in the number of accidents in all possible media channels, such as social media and mass media. Based on the positive and significant effect of TTSMCOV, it is recommended to use enhanced air conditioning systems in SAVs, regular disinfection, and establishing dedicated lanes, at least, during pandemics to decrease SAVs' travel time, which will increase the likelihood of sharing attitudes among these groups.

Concerning the impact of *TCSSIN_3* and *PhD_TTSM*, it is recommended that service providers suggest passengers with the option of selecting the preferred number of people to share the trip at various levels of travel cost to better adjust with their income and value of time. Due to the negative impact of PASSEN on willingness to shift to SAVs, it can be suggested to increase the awareness of individuals about the potential benefits of SAVs such as the possibility of having more productive and effective trip through conducting other activities rather than driving in SAVs. Considering the positive effect of *CarOwn0* and *NCAR_FP* on the willingness to shift to SAVs, it is recommended to implement travel demand management (TDM) policies [64] to decrease dependence on private cars and encourage car users to use SAVs, such as increasing taxation and related costs of households' additional cars as well as congestion pricing and parking management.

5. Conclusions and future suggesting for further studies

As an emerging sustainable transportation system, shared autonomous vehicles (SAVs) have significant potential advantages such as increasing travel convenience, reducing accidents and death rates and reducing pollutant emissions [65, 66]. Besides their numerous benefits, there are many concerns about using this technology. Hence, understanding potential user’s motivations and preferences for using these vehicles will be critical to their successful implementation, especially in developing countries due to the capital investment limitation and high level of car ownership and dependency [67]. After reviewing the literature, it was found that there is a further need to examine the factors affecting the modal shift behavior to SAVs with pooled services (SAVWPS), particularly in developing countries because to the best of authors’ knowledge, this study is the first study about SAVWPS in Iran and previous studies have paid less attention to this topic. This paper aims to examine the effect of socioeconomic and travel characteristics on modal shift behavior of private car users in Tehran using discrete choice model.

Based on a questionnaire designed exclusively for the purpose of this research, 2946 valid observations (491 valid questionnaires) gathered during August–September, 2021. The survey consisted of three main sections including: respondents' last trip characteristics with private car, stated preference scenarios, and demographic characteristics. Respondents’ modal shift likelihood was studied based on four three-level attributes of stated preference scenarios including travel time, travel costs, waiting time, and number of people who share their trip inside SAVs.

Findings indicate the significant influence of different socioeconomic and travel characteristics as well as their interactions on shifting trips from private cars to SAVWPS. In terms of socioeconomic characteristics, the lack of car ownership and being female are positively associated with the likelihood of modal shift to SAVWPS. Concerning respondents' income, a systematic heterogeneity has been observed that shows by increasing the income, the likelihood of modal shift decreases among individuals who share their travel with another person. Furthermore, middle-income individuals are more sensitive to travel cost of SAVWPS, and as the travel cost increases, the likelihood of modal shift among these individuals will decrease. Regarding travel characteristics in SAVWPS, travel time, travel costs, waiting time, and the number of passenger inside SAVWPS significantly affect the modal shift behavior individually or as an interaction variable with other factors. The findings suggested a reduction in the likelihood of modal shift to SAVWPS when each variable was increased. Furthermore, by reducing SAVWPS' travel time, the probability of modal shift reduces among persons who hold a PhD degree, and who are less likely to use internet taxis due to pandemic situation. Based on the sensitivity analysis using marginal effect, it was concluded that reduction in private car travel time among middle-income persons has the most negative impact on modal shift to SAVWPS. However, reducing SAVWPS' travel time has the most positive impact on modal shift among individuals who are dissatisfied with internet taxis due to COVID-19. As a result, the probability of modal shift from private cars to SAVWPS will increase through the increasing travel cost and travel time of private cars and allowing SAVWPS to be used in dedicated lanes.

There are limitations in this study, as well. We have asked respondents' willingness to shift to SAVWPS based on a binary scale (due to the complete lack of SAVs in Iran), where a Likert scale could be a more precise identification of their willingness to shift to SAVWPS. This research was conducted during the pandemic, a post pandemic survey could be another suggestion for further studies to investigate respondents' preferences when ridesharing would be more probable. Systematic heterogeneity of respondents has been investigated in this paper (for example effect of SAV's travel cost and income, education and travel time in SAVs). Random heterogeneity using mixed logit model could also be another topic for identifying and extracting the source of random heterogeneity.

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Data available on request due to privacy/ethical restrictions.

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Figures and Tables

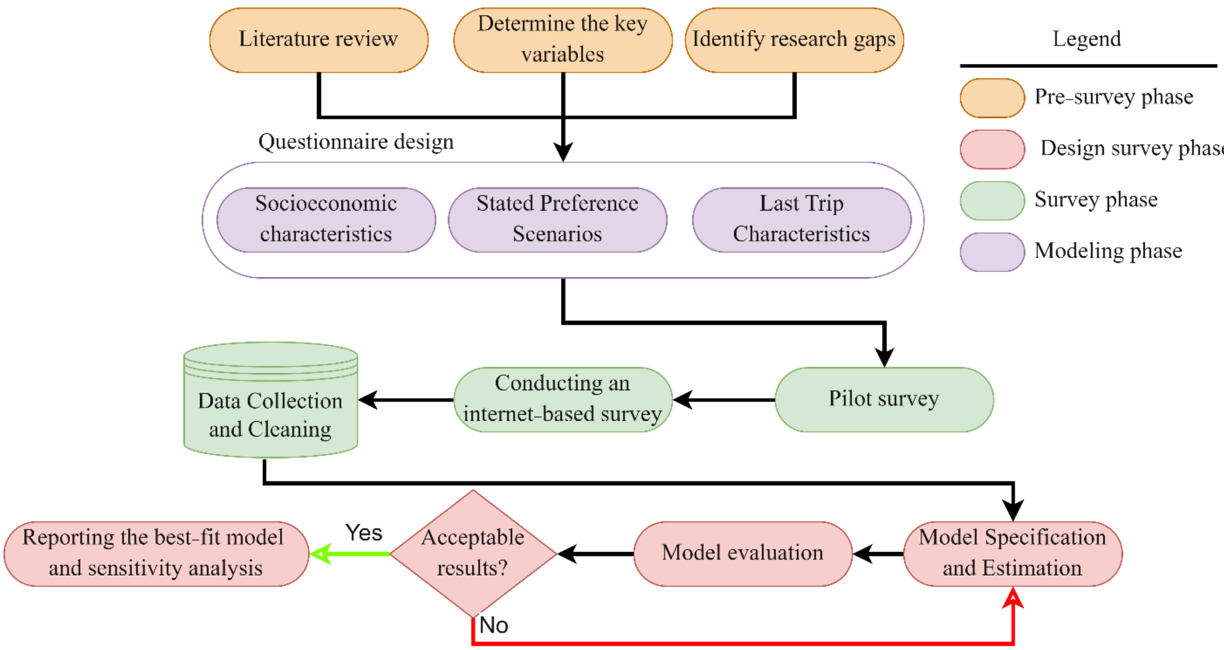

Figure 1. The research flowchart

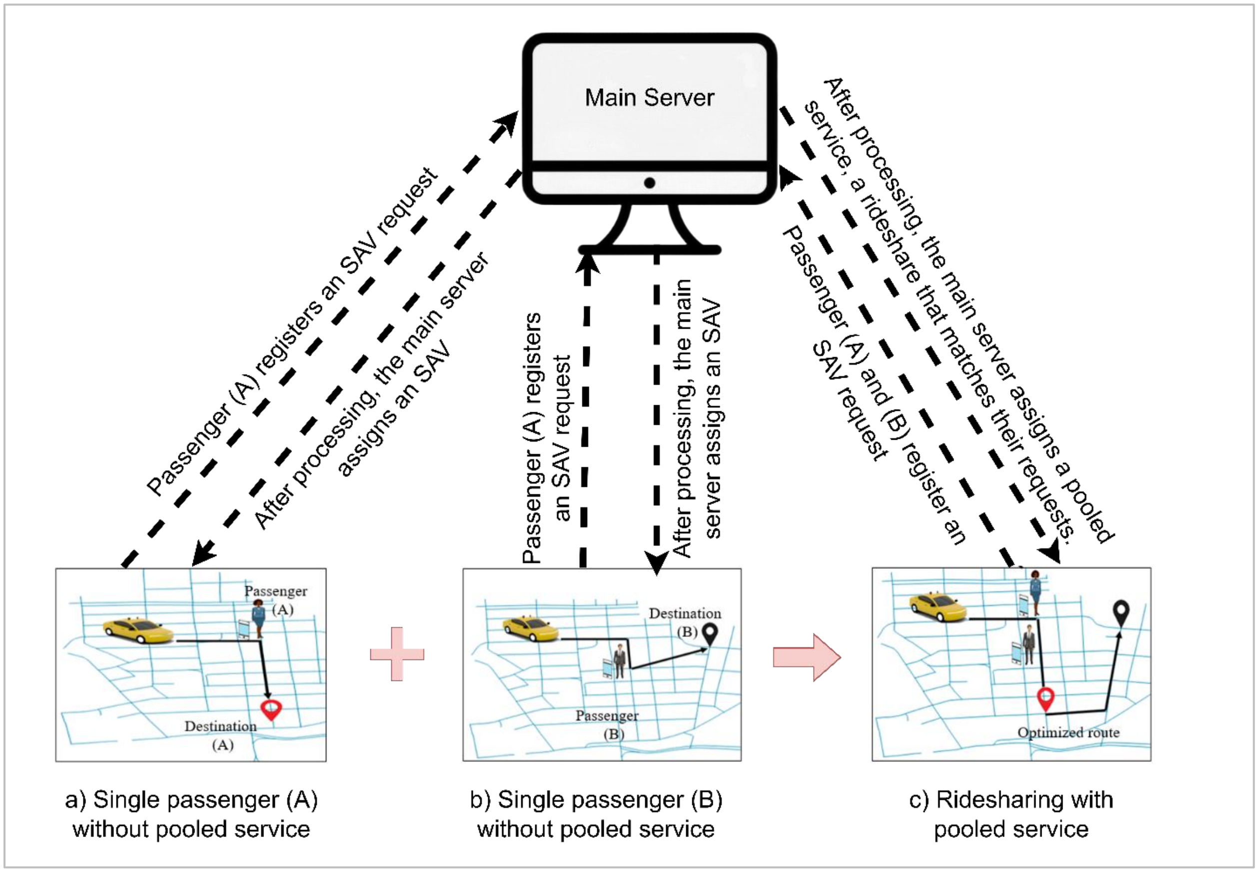

Figure 2. An example of pooled service operation

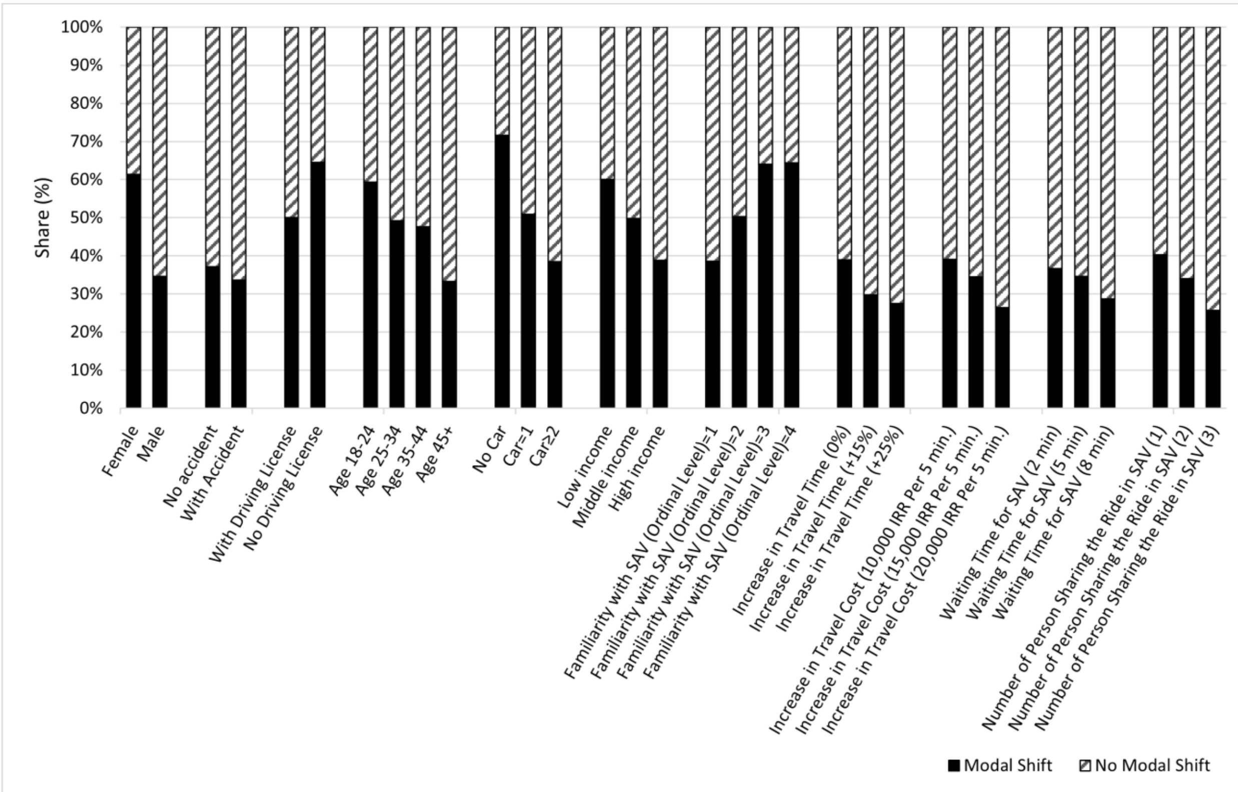

Figure 3. Some socioeconomic and SAVs travel-related attributes considered in the research scenarios

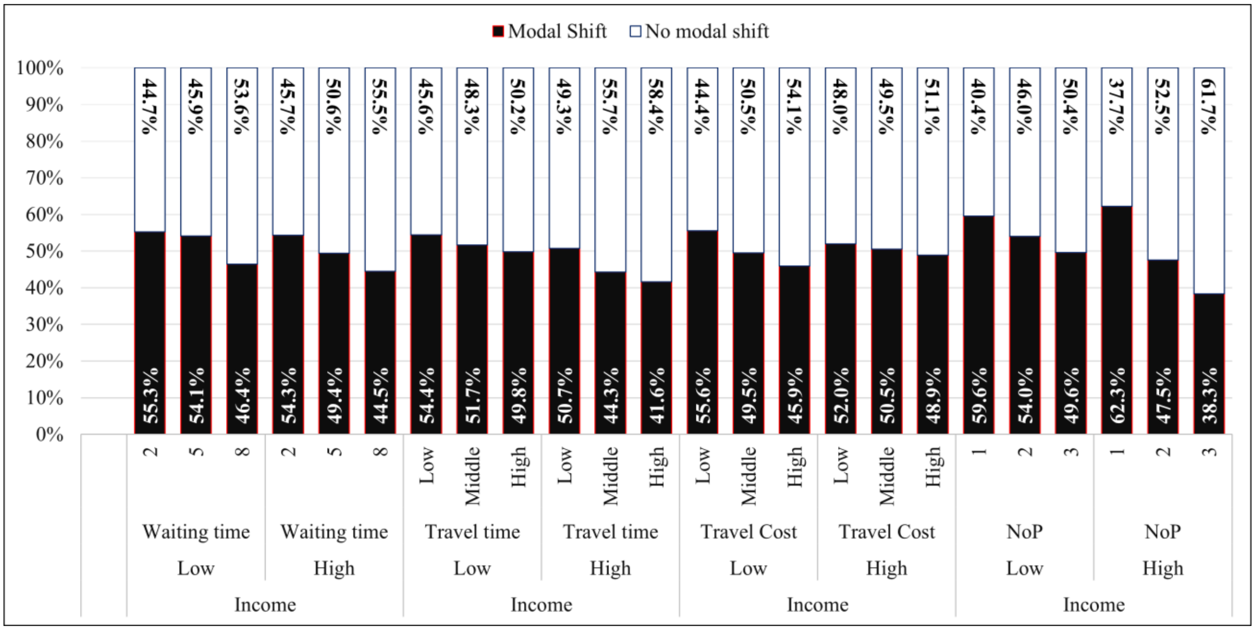

Figure 4. Comparing the modal shift preference of low-income and high-income participants based on four main travel-related attributes

611 **Table (1) - A brief review of a selection of researches on users' willingness to choose/use SAVs**

Authors	Variables	Key Findings
Maeng and Cho [54]	Autonomous driving level, pickup and delivery service, liability for accidents, waiting time after booking, monthly household income, fuel cost per month, gender, age, education.	• Negative effect of waiting time on the likelihood of choosing SAVs. • Negative influence of service fee (per hour) on the likelihood of choosing SAVs. • Derive different findings based on the interactive effect of socioeconomic characteristics and other variables.
Tian et al. [55]	Travel cost, waiting time, car availability, using laptop, household size education level, gender, age, and income.	• Higher willingness of individuals to purchase privately owned AVs rather than using SAVs. • More inclination of respondents to do other activities while using SAVs. • Higher willingness of younger respondents to use SAV.
Wang et al. [56]	Travel distance, travel time, waiting time, travel cost, gender, income, education, age.	• Higher willingness of respondents from Dalian to shift from private car to SAV. • Critical role of travel time, waiting time, and travel costs. • Higher willingness of high-educated and high-income respondents from Pakistan to use SAV.
Winter et al. [18]	Travel time, waiting time, travel cost, parking cost, travel time to station, finding a park, gender, income, education, age.	• Higher interest of car- and transit-users in using SAVs. • Higher impact of travel time, high-education, and being young on use of SAVs.
Menon et al. [57]	Gender, income, daily travel time, household size, household car ownership, and number of accidents.	• Positive effect of high-education, accident experience, and men single-car owners on using SAV.
Krueger et al. [43]	Travel time, waiting time, travel costs, travel time, gender, age, and weekly income.	• Younger individuals as the most likely users of SAVs. • The vital impact of travel time, waiting time, and travel cost on choosing SAVs.

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Table (2) – Levels of attributes SAVs in this research

Attributes	levels		
	1	**2**	**3**
Travel time change (%)	0	+ 15%	+ 25%
Travel cost (IRR per 5 min)	10,000	15,000	20,000
Waiting time (min)	2	5	8
Number of persons in SAV	1	2	3

Table (3) - An example scenario of the stated preference survey

Travel Time (minutes)	Travel Cost (Iranian Rial)	Waiting Time (minutes)	Number of person in SAV	Would you like to modal shift to SAV?	
				Yes	No
1.15×TT	TT/5×20,000	8	2	☐	☐
1.25×TT	TT/5×20,000	5	1	☐	☐
1.25×TT	TT/5×10,000	5	3	☐	☐
1.15×TT	TT/5×15,000	8	3	☐	☐
TT	TT/5×15,000	2	2	☐	☐
TT	TT/5×10,000	2	1	☐	☐

Note: TT stands for travel time

Table (4) - Descriptive analysis results of socio-economic characteristics of the research sample

Variable	Response Category	Frequency		Mean (S.D.)
		Absolute	Relative (%)	
Gender	0: Female	38.00	185	0.62 (0.48)
	1: Male	62.00	306	
Age	0: 18-24	119	24.24	1.09 (0.88)
	1: 25-34	255	51.93	
	2: 35-44	71	14.46	
	3: 45-64	43	8.76	
	4: +64	3	0.61	
Marriage Status	0: Single	327	66.60	0.33 (0.472)
	1: Married	164	33.40	
Education	0: At most diploma	48	9.78	1.57 (0.79)
	1: Bachelor	158	32.18	
	2: Master	240	48.88	
	3: PhD	45	9.16	
Number of cars in household	0	10	2.04	1.65 (0.77)
	1	230	46.84	
	2	173	35.23	
	+3	78	15.89	
Number of driving license in household	0	29	5.91	2.09 (1.14)
	1	146	29.74	
	2	135	27.49	
	3	115	23.42	
	+4	66	13.44	
Driving experience	0: 0-5	186	37.88	1.07 (1.06)
	1: 6-10	154	31.36	
	2: 11-15	80	16.30	
	3: +16	71	14.46	
Income	0: Very low	27	5.50	2.06 (0.93)
	1: Low	98	19.96	
	2: Medium	203	41.34	
	3: High	145	29.53	
	4: Very high	18	3.67	

Table (5) – Definition and descriptive analysis of model variables

Variable type	Symbol	Definition	Min.	Max.	Mean/ Percent
Dummy	PASSEN	If the respondent was a passenger in a car: 1; otherwise: 0	0	1	29.93%
	CarOwn0	Not owning a private car: 1; otherwise: 0	0	1	5.70%
	NPS_1	Sharing the trip with one another passenger: 1; otherwise: 0	0	1	33.33%
	FEMALE	Female: 1; otherwise: 0	0	1	37.67%
	INC_3	Having a middle income: 1; otherwise: 0	0	1	41.34%
	FP	Having a private parking at home: 1; otherwise: 0	0	1	77.18%
	NACR0	Experiencing no accident in past 5 years as a driver: 1; otherwise: 0	0	1	68.83%
	DREXP1	Having 0-5 years of driving experience:1; otherwise: 0	0	1	37.88%
	NACDR_2	Experiencing more than two accidents in past 5 years as a driver: 1; otherwise: 0	0	1	12.83%
	WTSS_2	Two minutes waiting time for SAV: 1; otherwise: 0	0	1	33.33%
	COVID	Dissatisfy with internet taxis due to COVID: 1; otherwise: 0	0	1	4.48%
Continuous	TTM	$\frac{1}{private\ car\ travel\ time\ (minute)}$	0.005	0.200	0.02
	HHCAR	Household car ownership	0	4	1.68
	TTSM	$\frac{1}{SAV\ travel\ time\ (minute)}$	0.004	0.200	0.01
	INC	Income level (1: very low; …; 5: very high)	1	5	3.05
	TCSS	SAV travel cost (IRR)	120,000	756,000	199,070
	PHD	Holding a PhD degree:1; otherwise: 0	0	1	9.16%

Table (6) - Estimation result and marginal effect of model shift to SAV

Variables	Coef.	t-statistic	M.E.[1]
Utility of the alternative: shift to SAV			
Constant	0.140*	1.83	-
Experiencing more than two accidents in past 5 years as a driver	0.417***	3.52	0.099
Two minutes waiting time for SAV	-0.279***	-3.49	-0.067
$\frac{\text{Dissatisfy with internet taxis due to COVID}}{\text{Travel time of SAV}}$	17.189**	2.42	4.098
SAV travel cost × Bing a middle-income	-0.013***	4.18	-0.003
$\frac{\text{Holding a PhD}}{\text{Travel time of SAV}}$	7.598*	1.80	1.811
Utility of the alternative: Not shift to SAV			
Being a passenger in a private car	0.264***	2.74	0.063
Not owning any private cars	-0.407***	-3.48	-0.097
Income × Sharing a ride with one another passenger	0.194***	7.80	0.047
Being a female	-0.272***	-3.17	-0.065
$\frac{\text{Being a middle} - \text{income}}{\text{Private car travel time}}$	0.743**	2.22	0.177
Car ownership × having private parking	0.200*	1.88	0.047
Model statistics			
Number of observations	2946		
Log-likelihood at zero (LL(0))	-2042.01		
Log-likelihood at market share (LL(C))	-2041.00		
Log-likelihood at convergence (LL(β))	-1970.36		

*Note: ***, **, *: confidence level at 99%, 95% and 90%.*
[1] M.E.: Marginal Effect

Biography

Mahsa Aboutorabi Kashani graduated from Islami Azad University in civil engineering in 2018, and earned an MSc degree in Transportation Planning from Tarbiat Modares University in 2022. Her research interests are discrete choice modeling, behavioral models in transportation, and travel demand management.

Amir Reza Mamdoohi earned his PhD from Sharif University of Technology with an excellent degree in 2005 and started his career as a faculty member in the Institute for Management and Planning Studies and after four years at Trabiat Modares University where his collaboration resulted in the establishment of Transportation Planning Course at the Masters and PhD degree. He has (co)supervised more than 20 PhD and 130 MS theses, published (in English or Farsi) more than 205 refereed journal papers and more than 125 refereed conference papers. His international collaboration has resulted in signing memorandum of understanding with TU Wien (Austria), TU Berlin (Germany) and IST (Portugal) and action plans including joint international workshops, seminars, theses co-advisorship, projects and papers. He has (co)lead more than 25 industrial or research projects.

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