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A world of fully autonomous mobility options: On long-distance travel mode choice

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ABSTRACT

What might long-distance travel behaviour look like in a world of fully autonomous mobility options? Within this context, which of the transportation options, including autonomous cars, pilotless planes, driverless trains, and driverless buses would people choose for their long-distance travel? We examine the extent to which people's attitudes towards fully autonomous mobility options, habits, and the level of satisfaction with current travel modes, as well as individual and socioeconomic variables, influence the choice/preference for fully autonomous modes. Data for this study were collected through an online survey (n = 811). A choice model was used to analyse the effects of attitudinal factors and other variables on the probability of choosing four fully autonomous alternatives. The results of the model show that (1) the preferred order of autonomous mobility options is: Autonomous Car (AC), Autonomous Train (AT), Autonomous Flight (AF), and Autonomous Bus (AB), (2) AT was evaluated the safest, most relaxing, and most economical alternative, and (3) both attitudes and habit influence the choice of fully autonomous vehicles. However, sensitivity analyses show that attitudes will have a greater impact on travel behaviour compared to habits. Policy-wise, a demographically differentiated campaign for changing attitudes can be employed.

1. Introduction

The introduction of autonomous transport modes is revolutionizing the transportation sector and bringing about several benefits, mainly towards sustainability. In terms of safety, fully autonomous options have the potential to reduce road accidents and fatalities by eliminating human errors that can impact driving performance (Fagnant and Kockelman, 2015). Therefore, paying meticulous attention to attitudes, especially towards safety, and urban politics is necessary (Cugurullo et al., 2021). Furthermore, in the social context, autonomous mobility can provide a secure means of transportation for elderly and physically impaired people or even children, improving their access to mobility (König and Neumayr, 2017). What is more, autonomous motilities are believed to provide a comfortable trip, allowing passengers to relax, do recreational on-board activities, and even work (Cugurullo and Acheampong, 2023). Overall, familiarity with advanced driver-assisted technologies and a belief that fully autonomous mobility will be useful and user-friendly can increase people's intention to use them (Acheampong et al., 2021).

Another potential benefit of autonomous mobility is related to the environment. Concerns about energy security and climate change have increased the importance of sustainable mobility (Turton, 2005; Bauer et al., 2015). To achieve sustainable transport, high-quality and low-carbon infrastructure is needed (Virag, 2021). Automation in the mobility sector, particularly for long-distance travel, can have a positive impact on the environment in several ways. For example, it can reduce emissions by optimising driving patterns, reduce congestion by optimising route selection, and even reduce light pollution by operating in low-light environments (Fagnant and Kockelman, 2015; Silva et al., 2022). The level of autonomy required to have a positive impact on the environment is still under investigation. However, as per commonly accepted standards, level 5 of automation yields the greatest benefit among all levels (SAE, 2018).

However, research has identified several challenges, including vehicle usage (such as shareability and data privacy) and cost (ownership, software, and hardware), that are considered substantial concerns

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for end-users' acceptance of autonomous technologies (Bezai et al., 2021). Moreover, autonomous mobility options have the potential to change travel behaviour and needs (Kassens-Noor et al., 2020). Hence, considering the different factors that positively or negatively affect behavioural decisions, our aim is to investigate how long-distance travel behaviour might change in a world of fully autonomous mobility options.

Among the various transportation alternatives, special attention has been paid, both in research and industry, to Autonomous Cars (ACs) versus Conventional Cars (CCs) (Fagnant and Kockelman, 2015; Gkartzonikas and Gkritza, 2019; Merfeld et al., 2019). While ACs have received a lot of attention in research and industry (Mehdizadeh et al., 2022a), other transportation alternatives, such as trains, aeroplanes, and buses may be used as fully autonomous in the market and transportation system in the upcoming years. Efforts are being made to fully automate other travel alternatives, such as trains (Fraszczyk and Mulley, 2017), aeroplanes (Rice et al., 2019), and buses (Dong et al., 2019). Therefore, long-distance (e.g., more than 100 km) /intercity travel may be affected by fully autonomous travel alternatives. Exclusive attention to ACs and exclusive analysis of their role in travel demand may lead to bias in predicting future travel behaviour. Hence, we seek to understand how, in a hypothetical world in the future that is full of fully autonomous transportation alternatives, including Autonomous Cars (AC), Autonomous Flights (AF), Autonomous Trains (AT), and Autonomous Buses (AB), people will travel and what factors influence their choice/ preference.

Although there is no explicit definition of long-distance travel, there are thresholds of 50 to 100 km for long-distance/intercity travel (Axhausen et al., 2003; Arbués et al., 2016; Kuhnimhof et al., 2009; Dargay and Clark, 2012). Long-distance travel differs from short-distance travel (in terms of travel characteristics), thus affecting the choice of travel modes. In today's world, long-distance travel for different trip purposes is often made by using alternatives, such as cars, trains, buses, and planes (Dargay and Clark, 2012). Travels longer than 100 km are considered long-distance travel in this study since air travel covers longer distances. Most studies on long-distance travel have focused on factors affecting travelled distance or demand for long-distance travel. Few studies have also investigated how to choose a transport mode for this kind of travel. Geographically, most studies have been conducted in European and American countries, such as the USA (Hess et al., 2018), Canada between Toronto and Montreal (Bhat, 1995), Great Britain (Dargay and Clark, 2012), Italy and Germany (Lundqvist and Mattsson, 2002), Denmark (Fosgerau, 1998), the Netherlands (Daly et al., 2005), Switzerland and Sweden (Zhang et al., 2012), and other countries such as Japan (Yao and Morikawa, 2003) and Indonesia (Aldian and Taylor, 2003). Most studies are based on national household travel surveys, and therefore, most of the explanatory variables of the models are socio-economic and demographic variables. For instance, Limtanakool et al. (2006) reported that women use trains more for long-distance travel than men. Further, they found that older people use cars more often than younger or middle-aged people, and those who are highly educated (with a university degree) tend to use buses more often. On the other hand, Arbués et al. (2016) found that women were less dependent on cars for their long-distance travel. Bhat (1997) also found that higher-income people were more likely to use aeroplanes on long-distance travel.

Psychological variables, such as attitudes, can also be significant in the decision-making process (Ajzen, 1991) for long-distance travel. However, this issue has been less addressed in previous studies due to data limitations. For example, Mokhtarian et al. (2001) reported that attitudinal variables play a crucial role in the analysis of long-distance travel (see also Hess et al., 2018). Since a new choice set (i.e., fully autonomous options) is investigated in this study that people have not yet used, the study of psychological characteristics, including perceptions and attitudes, habits, and people's satisfaction, can be considered relevant and appealing attributes. Therefore, psychological factors along with socio-economic and demographic variables will be analysed in the current study. This study measures a large number of contextually and alternative-specific attributes, such as travel time, cost, safety, and comfort, as attitudinal items. Several studies have recently attempted to examine how AC arrival can alter modal share among conventional vehicles for long-distance travel (e.g., Gurumurthy and Kockelman, 2020). Despite this, no comprehensive study has yet examined people's preferences for choosing from all fully autonomous transportation alternatives for long-distance travel. As an example, based on the American Journey model, Perrine et al. (2020) found that AC arrival in the long-distance travel choice can noticeably reduce the share of air travel. Additionally, LaMondia et al. (2016) found that, for long-distance travel under 500 miles, the AC share would be slightly higher than other vehicles based on Michigan state long-distance travel data. Our contribution to the state-of-the-art field is to analyse the role of attitudes towards the use of various fully autonomous modes, the role of travel mode use (habit) and travel satisfaction with conventional modes on the choice of fully autonomous mobility options in long-distance travel.

Regarding fully autonomous options, most studies focus on analysing the customers' tendency to purchase or select ACs, and some have examined people's attitudes towards using AC versus CC (Liu and Xu, 2020; Penmetsa et al., 2019; Nastjuk et al., 2020; Gkartzonikas and Gkritza, 2019; Keszey, 2020). Few studies have also exclusively examined perceptions and attitudes of individuals towards using autonomous flight (Rice et al., 2019; Wollert, 2018), autonomous trains (Fraszczyk and Mulley, 2017), and autonomous buses (Dong et al., 2019; Salonen, 2018). Considering the use of AC, previous studies have highlighted the importance of perceptual and attitudinal variables, such as perceived level of safety and security, trust in autonomous driving systems, technology awareness and knowledge, environmental concerns, and travel habits (Panagiotopoulos and Dimitrakopoulos, 2018; Nordhoff et al., 2018; Kyriakidis et al., 2015). Generally, people who believe that ACs are not safe and secure and who have less information regarding their benefits and ease of use are less likely to use this mode (Gkartzonikas and Gkritza, 2019). Dong et al. (2019) showed that men and younger people (18–34) are more inclined to use AB. Fraszczyk and Mulley (2017) showed that perceived safety is one of the most important factors influencing the tendency to use AT. Rice et al. (2019) also showed that educated people, who think AF is exciting and are more familiar with its technology, are more likely to use it.

From a psychological perspective, the choice or preference of using transportation modes can be explained by attitudes, the experience of travel mode use (habit), and satisfaction with different travel modes. According to established behavioural theories, such as the Theory of Planned Behaviour (TPB) and the Theory of Reasoned Action (TRA), attitudes and beliefs about behaviour are considered to be one of the main predictors of travel behaviour (Ajzen, 1991). Attitude reflects a person's positive or negative evaluation of a particular behaviour. Many previous studies have shown that travel mode choice can be a pre-planned process, and attitudes can explain this behaviour (e.g., Kroesen and Chorus, 2020; Ton et al., 2020). In this study, we aim to measure the mode-specific attitudes of each fully autonomous alternative with various items, such as convenience, safety, novelty, data security, and comfort, and analyse their relationship with choice/preference for using fully autonomous modes.

In addition to the attitudinal factor, the rate of use of current/conventional travel modes may also positively affect the decision to use the same mode in fully autonomous performance. This postulation, to some extent, refers to the concept of habit (Gärling and Axhausen, 2003). Although some psychologists argue that attitude as a deliberate and pre-planned process influences travel mode choice, others believe that mode use habit is more strongly correlated to mode use behaviour in the future (Karami et al., 2022; Nordfjærn et al., 2014; Gärling and Axhausen, 2003; Verplanken et al., 1997). For example, people accustomed to using conventional flights may continue to choose AF over other various fully autonomous alternatives for their long-distance travel regardless of unfavourable attitudes (such as poor safety and security) towards AF merely based on their habit. Therefore, another hypothesis of this study is that the habit of using (the rate of using) the current conventional modes of long-distance travel may positively affect the use of fully autonomous versions of the same modes in the future.

In addition to the concept of attitudes and habits, some believe that satisfaction with one of the transportation modes can be positively related to the choice of the same mode in the future (De Vos, 2019; Mokhtarian et al., 2015; St-Louis et al., 2014). Travel satisfaction is known as the cognitive and emotional evaluation experienced during travel (Mao et al., 2016). Lai and Chen (2011) report that people who are more satisfied with certain ways of travelling, are more likely to use the same mode in the future (see also Abou-Zeid and Ben-Akiva, 2012). Therefore, we hypothesise that the degree of satisfaction with conventional long-distance travel options is related to the rate at which the same mode is used in the fully autonomous version.

1.1. *Conceptual model*

Fig. 1 depicts the conceptual model of the study, which shows that mode-specific attitudes, habitual use of conventional modes of transportation, satisfaction levels with current modes, as well as socio-economic and demographic variables, all have an impact on the choice of four fully autonomous transportation alternatives. Attitudes were incorporated into the model through the measurement model by its indicators as latent variables. Other variables, including mode use habit (travel experience), travel satisfaction, and socio-economic and demographic variables, were used as observed variables in the model. Overall, the study aimed to investigate the effects of explanatory variables, including attitudes, travel experience (habit), travel satisfaction, and socio-economic and demographic variables, on the preference for selecting four fully autonomous alternatives.

Attitude, which is regarded as a central component of the TPB, shapes behaviour (Ajzen, 1991). The current study developed specific attitudinal items, referred to as fully autonomous mode-specific attitudes in Fig. 1, to capture the effects of aspects and motivations related to travel modes on people's future behavioural choices. 13 specific attitudes were assessed. According to the literature, Perceived Usefulness (PU) and Perceived Ease of Use (PEU), as the main determinants of Technology Acceptance Model (TAM), are significantly associated with the adoption decision of new technology (Cugurullo and Acheampong, 2023; Karami et al., 2022; Nastjuk et al., 2020). On this basis, we measured respondents' specific attitudes about the convenience, time-saving, transparency, and flexibility of fully autonomous transport modes. In addition, the effects of perceived safety on decision-making processes have been widely tested in previous studies (Xu et al., 2018; Kopplin et al., 2021). Consistent with this, we also evaluated participants' attitudes regarding the safety and protection offered by fully autonomous transport modes. Privacy concerns, which refer to individuals' ability to control and manage their personal information (Belanger et al., 2002), have been reported as an important factor influencing attitudes towards innovations (Cugurullo and Acheampong, 2023; Nasri and Charfeddine, 2012). Therefore, we deemed it essential to include privacy concerns as a factor in shaping attitudes towards each autonomous mode. Additionally, ecological awareness was included in the specific attitudes, following Samadzad et al. (2023). According to motivational theory, the level of individuals' pleasure derived from using a product or service, known as perceived enjoyment, is a significant component that influences their decision-making process (Deci and Ryan, 2013). Thus, respondents' particular attitudes towards the relaxing and fun facets of each autonomous mode were also assessed in this study. Moreover, prestigious and novel facets of the fully autonomous options were captured in the form of attitudes. This is because perceived innovativeness, which refers to "the degree to which consumers believe that a product possesses important attributes of innovation such as newness and uniqueness" (Watchravesringkan et al., 2010), is a crucial component in technology adoption (Fu and Elliott, 2013). Finally, since the adoption of innovation involves costs for potential users (Zainab et al., 2017), we also measured respondents' specific attitudes towards travel costs associated with fully autonomous transport modes.

According to psychological research, previous behaviours may significantly influence current and future behaviours (Aarts et al., 1998; Verplanken and Orbell, 2003). As a result, individuals who have an interest in using specific modes of transportation are more likely to maintain their interest and less likely to switch to other modes (Nordfjærn et al., 2014). Thus, we measured the rate of use (habit) of the conventional/current modes of transportation for long-distance travel.

Generally speaking, satisfaction is considered to be the main factor in customer loyalty and behaviour (Lai and Chen, 2011). Also, customer satisfaction has consistently been recognized as the most significant factor of favourable behavioural intentions in studies based on TPB (Chen, 2008). Thus, we also evaluated the respondents' level of satisfaction with conventional/current transport modes for long-distance travel.

Socio-economic and demographic variables are important factors in explaining the decision-making process (Qu et al., 2021). Mehdizadeh and Shariat-Mohaymany (2020) demonstrated that, besides their direct effects, socio-economic and demographic variables could be indirectly associated with behaviour through attitudinal components as control variables. Therefore, we tested the relationship between socio-economic and demographic variables and mode choice behaviour directly and indirectly. The issue is also important because, if the attitudes are significant in the model, it is possible to determine which segment of the population evaluates them more favourably.

2. Methodology

2.1. *Sample*

In July and August 2020, an online survey was conducted in Iran using the popular social network platform, Telegram. The platform has a high penetration rate among Iranians and is used for news, economic, and social channels, some of which place questionnaire links or advertisements on their channels for a fee. We were also able to enrich our research sample geographically by the millions of members of these channels from all over the country.

Despite some of the drawbacks of online surveys, many studies in the field of transportation have benefited from online surveys (Klöckner et al., 2013; Zavareh et al., 2022; Mehdizadeh et al., 2022b). Maintaining social distance during the Covid-19 outbreak was one of the main advantages of this type of survey compared to a face-to-face one. Besides, according to the information of the Statistics Centre of Iran, it was possible to obtain a sample with characteristics close to the population with a suitable geographical distribution through online surveys. Ultimately, the survey was designed and uploaded to Google Docs and ended after 1000 people participated. It began with an invitation explaining the purpose of the study and the confidentiality of the data and answers. IP addresses of people were not registered for privacy concerns. Even though the survey was designed anonymously, five gift cards were offered to encourage people to participate. Individuals were asked to provide a means of communication, such as an email address or telephone number, in order to participate in the lottery; however, the process was entirely voluntary.

The comparison between the characteristics of the sample and the population was performed based on the latest census data of the Statistics Centre of Iran.[1] The results of this comparison indicate that the characteristics of the sample are mainly consistent with the population (See Table 1). Responses were recorded from 68 different cities in the

[1] https://www.amar.org.ir/english.

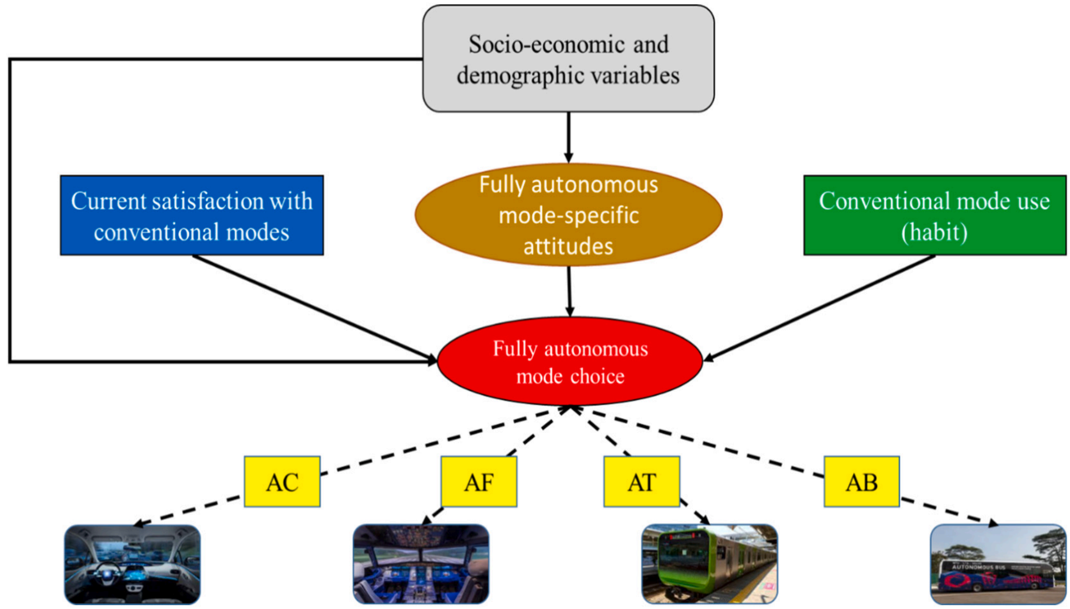


Fig. 1. Conceptual modelling framework of the study.
*Autonomous Car (AC), Autonomous Flight (AF), Autonomous Train (AT), Autonomous Bus (AB).

Table 1
Comparison between sample and census data.

Variable	Sample (n, %)	Census (%)
Gender		
Male	(462) 57	50.67
Female	(349) 43	40.33
Age		
18–24	(146) 18	14.96
25–39	(308) 38	41.47
40–59	(235) 29	30.67
60+	(122) 15	12.90
Education		
High-educated (university degree)	(260) 32	20
Otherwise	(551) 68	80
Household size	3.4	3.3

country. In 2016, the Statistics Centre of Iran reported that men constituted 50.67% of the total population. In this study, 57% of the participants were men. According to the census, about 14.96% of the country's population is aged between 18 and 24, which is close to 18% according to this study's data. The population ratios are nearly the same in other age groups. Likewise, approximately 20% of the population had higher education (university degree), and the average household size was 3.3, wherein the sample of the study is 32% and 3.4, respectively.

Of the 1000 participants in the study, 189 did not have experience with at least one long-distance transportation mode. Due to this limitation, it was not possible to investigate the role of travel mode use (habit) and satisfaction with travel behaviour. As a result, these 189 observations were excluded from the analysis, leaving 811 respondents for the model.

2.2. Questionnaire

The questionnaire used in the present study consisted of several sections, including:

- Socio-economic and demographic variables.
- A hypothetical question about people's preference/choice over fully autonomous transportation modes in long-distance travel (over 100 km).
- An assessment of people's attitudes towards four fully autonomous modes of transportation for long-distance travel.
- Rate of use (habit) of the conventional (current) modes of transportation for long-distance travel.
- Level of general satisfaction with each of the conventional (current) modes of transportation for long-distance travel.

In the first part of the questionnaire, socio-economic and demographic' variables, such as gender, age, education level, household size, and car ownership, were recorded. In the second part, participants first received some explanations and images about the types of fully autonomous modes of long-distance travel, including AC, AT, AF, and AB. Text and images were used to describe these fully autonomous modes of transportation and how to use them. The hypothetical question was then asked, "If in the future all transportation alternatives for long-distance travel become fully autonomous, which of the following fully autonomous modes will you prefer to choose for your long-distance travel (with leisure purpose)?" Respondents were asked to choose one transport mode among four fully autonomous mobility alternatives, including AC, AT, AF, AB.

In the next section, the specific attitudes of each fully autonomous alternative were assessed. According to the recommendations of Ajzen and Fishbein (1977), specific attitudes of each mode were measured (see also Kroesen and Chorus, 2020; Ton et al., 2020). Ajzen and Fishbein (1977) suggested attitudes and behaviour are empirically consistent when they have substantive correspondence. They found a stronger correlation between specific behaviours and specific attitudes. It is therefore recommended that specific attitudes should be used to explain specific behaviours. Thus, some new studies suggest that rather than general attitudes about travel, mode-specific attitudes may be most useful in understanding mode choice (Kroesen et al., 2017; Molin et al., 2016; Ton et al., 2020; Kroesen and Chorus, 2020).

For AC, AT, AF, and AB options, specific attitudes were measured. Each mode was assessed on 13 items (listed below) on a 5-point scale ranging from 1 (totally disagree) to 5 (totally agree).

1. [Travelling by AC/AT/AF/AB] is convenient.
2. [Travelling by AC/AT/AF/AB] is safe.
3. [Travelling by AC/AT/AF/AB] is relaxing.
4. [Travelling by AC/AT/AF/AB] is fun.

5. [Travelling by AC/AT/AF/AB] is time-saving.
6. [Travelling by AC/AT/AF/AB] is data secure.
7. [Travelling by AC/AT/AF/AB] is environmentally friendly.
8. [Travelling by AC/AT/AF/AB] is prestigious.
9. [Travelling by AC/AT/AF/AB] is novel.
10. [Travelling by AC/AT/AF/AB] is protected.
11. [Travelling by AC/AT/AF/AB] is flexible.
12. [Travelling by AC/AT/AF/AB] is transparent.
13. [Travelling by AC/AT/AF/AB] is economic.

In previous studies, such aspects and motivations related to travel modes (both conventional and fully autonomous) were found important by a number of authors.

Next, participants were asked: "How often have you generally used a conventional car/train/flight/bus for your long-distance travel (for leisure purposes) (>100 km)? (Please consider the pre-COVID-19 period)." The answer to this question was measured as follows (Podgorski and Kockelman, 2006): 0) Haven't experienced it yet, 1) Once until now, 2) At least once a year, 3) At least once a month, 4) At least once a week, 5) More than four times a week.

Additionally, considering the conditions of the pre-Corona period, it was asked: "How much is your overall satisfaction with using any of the transportation alternatives, including a conventional car/train/flight/bus for your long-distance travel (for leisure purposes) (>100 km)? (Please consider the pre-COVID-19 period)." Respondents were asked to rate their satisfaction on a 5-point scale ranging from 1 (very unsatisfied) to 5 (very satisfied). In previous research, the level of overall satisfaction has been similarly evaluated (Mao et al., 2016).

2.3. Modelling approach

In order to explain the probability of choosing each of the four fully autonomous transportation alternatives, a Hybrid Choice Model (HCM) was used. In the HCM process, the attitudes were included as a latent predictor. Two main parts make up an HCM model: the main choice model and the latent variable model (Ben-Akiva et al., 2002; Walker, 2001; Mehdizadeh and Shariat-Mohaymany, 2020). The latent variable model itself consists of structural parts and a measurement model. According to the recommendations, the HCM model is developed first by identifying the latent variable, then by estimating the whole model at once (Ben-Akiva et al., 2002).

To determine the main factors of the latent variable of the study (i.e., attitudes), the principal component analysis (PCA) was used. This analysis reduces the various items into a smaller number of latent factors. PCA with orthogonal rotation and repetition was used for this purpose. The number of factors was determined using Kaiser and scree plot criteria (Kline, 2015). The KMO value was used to assess the adequacy of the sample for PCA. To test the reliability and validity of the extracted factors, Cronbach's alpha was calculated. For this test, alpha values above 0.7 are acceptable. Additionally, items with factor loadings below 0.4 were removed from the factors.

After determining the number of latent factors, they were entered into the choice model along with other variables. According to the conceptual model shown in Fig. 1, the choice of each of the four fully autonomous alternatives is a function of the direct effects of attitudes, conventional modes use (habit), level of satisfaction, and socio-economic and demographic variables. Therefore, the utility function of these alternatives can be written in the form of Eq. (1):

$$U_{ab} = C_b + \mu_{ab} D_{ab} + \beta_{ab} H_{ab} + \theta_{ab} S_{ab} + \lambda_{bc} \Upsilon_{ac} + \varepsilon_{ab} \tag{1}$$

where,

U_{ab}: the utility that respondent a is related to alternative b.

C_b: the vector of constants specific for $b-1$ modal alternatives.

D_{ab}: a vector of socio-economic and demographic variables related to b-1 modal alternatives (μ_{ab} is the respective coefficients).

H_{ab}: a vector of conventional mode use (habit) variables related to b-1 modal alternatives (β_{ab} is the respective coefficients).

S_{ab} : a vector of satisfaction variables related to b-1 modal alternatives (θ_{ab} is the respective coefficients).

Υ_{ac}: cth latent variable (λ_{bc} is the respective coefficients).

ε_{ab}: error term that is presumed to be identically and independently distributed (IID) extreme value type 1.[2]

Eq. (2) shows how the latent variable (Υ) itself can be expressed:

$$\Upsilon_{ac} = \alpha_c D'_{ac} + \omega_{ac} \tag{2}$$

where,

D'_{ac}: is another vector of socio-economic and demographic variables predicting cth latent variable.

ω_{ac}: is a normally distributed error term with zero mean and standard deviation σ_{wc}, capturing the random element of the latent variable.

In the measurement equation, the indicator of latent variables (Υ_{ac}) is identified by Eq. (3):

$$I_{afc} = \gamma_{fc} + \zeta_c \Upsilon_{ac} + \upsilon_{afc}, \quad f = 1, \dots, F \tag{3}$$

where,

I_{afc}: is the fth indicator for cth latent variable of individual a.

γ_{fc}: is the constant in the measurement equations for indicator $f$of latent variable c.

ζ_c: is the coefficient associating with the latent variable c.

υ_{afc}: shows a normally distributed error term with zero mean and standard deviation σ_{wc}.

γ and ζ: are normalised to zero and one for the first indicator of each latent variable for identification purposes.

The theory of random utility maximization states that in discrete choice part a mode is chosen for individual a based on Eq. (4):

$$y_{ma} = \begin{cases} 1, & if \quad U_m = Max_b(U_{ba}) \\ 0, & otherwise \end{cases} \tag{4}$$

where,

y_{ma}: is the choice indicator, taking the value 1 if mode m is chosen (m has the highest utility among all modes in the choice set) and takes the value of 0, otherwise.

As for the distributions of the latent variable and the indicator, the following equations are used:

$$f_{\Upsilon}\left(\Upsilon_{ac} \middle| D'_{ac}; \alpha_c, \sigma_{wc}\right) = \frac{1}{\sigma_{wc}} \varphi\left(\frac{\Upsilon_{ac} - \left(\alpha_c D'_{ac}\right)}{\sigma_{wc}}\right) \tag{5}$$

$$f_I(I_{ac}|\Upsilon_{ac}; \gamma_c, \zeta_c, \sigma_{\upsilon c}) = \frac{1}{\sigma_{\upsilon fc}} \varphi\left(\frac{I_{ac} - \left(\gamma_{fc} + \zeta_c \Upsilon_{ac}\right)}{\sigma_{\upsilon c}}\right) \tag{6}$$

[2] The stochastic components of random utility models are denoted by adding a term or white noise in order to reflect the degree to which relationships (between independent and dependent variables) are imprecise. Otherwise, models evaluate only deterministic (measured) terms, reducing their accuracy (Hensher et al., 2005; Walker and Ben-Akiva, 2002). Depending on the distributional assumptions about each stochastic variable, HCM models can take different forms. Generally, there are three generalizable assumptions about the vector ε_n: (i) a multinomial logit kernel for the discrete choice sub-model as the most likely candidate for research is obtained by the vector $\varepsilon_{n,}$ in which the error term is presumed to be identically and independently distributed (IID) extreme value type 1 (known as Gumbel distribution); (ii) the multinomial probit kernel for the discrete choice sub-model is formed by the vector ε_n which has normal distribution with a mean vector of zeros; (iii) the mixed logit kernel is derived from ε_n which is a mixture between normally distributed and Gumbel distributed vectors (Vij and Walker, 2016). Logit kernels simplify the computation process (Walker and Ben-Akiva, 2002) since they are closed-form functions, which is why we chose them.

where,

φ: is the standard normal distribution function.

Meanwhile, the choice probability can be specified by Eq. (7):

$$P_{ab} = \int_{\omega} P_{abc}(\Upsilon_{ac}(\omega_{xc}))f_{\Upsilon}(\omega_{ac})f_I(\Upsilon_{ac}(\omega_{ac}))f(\omega)d\omega \quad (7)$$

A full information approach using PythonBiogeme (Bierlaire, 2016) is used for estimation purposes. In terms of estimation, the sequential method (not joint estimation of latent dimensions with the choice model) may produce biased estimates. As a result of this method, estimators may have a greater statistical significance than their real contributions to the model due to an underestimation of their standard deviations (Raveau et al., 2010). Therefore, a joint estimation (full information) approach was used (Raveau et al., 2010; Bierlaire, 2016).

3. Results

3.1. Descriptive statistics

As illustrated in Fig. 2, 48% ($N = 390$) of respondents preferred AC as an autonomous option for the future. With a share of 21.95% ($N = 178$) and 19.73% ($N = 160$), respectively, AT and AF are the next two preferred options for long-distance travel after AC. The last preferred autonomous option for transportation is AB, with a share of 10.23% ($N = 83$).

Fig. 3 illustrates the level of conventional mode usage for long-distance travel, as well as the level of satisfaction with these modes. In Fig. 3a, cars are reported to be used more than other alternatives, followed by planes, buses, and trains. Fig. 3b shows that air travel is more satisfying than competing long-distance alternatives. Fig. 3b shows that air travel is more satisfying than competing long-distance alternatives. Buses also rank lowest in terms of satisfaction.

3.2. Principal attitudinal components

The radar chart of Fig. 4 presents the average score per attitude item per full-autonomous mode for the entire sample. In terms of convenience, prestige, time-saving, and novelty, the fully autonomous flight was rated as the best mode among fully autonomous options by sample participants. However, AF would also be the least economical, least secure, least protected, and least safe option for transportation. In terms of safety, security, relaxation, protection, environmental friendliness, and economics, the fully autonomous train is rated as the best option. In terms of system transparency and flexibility during travel and fun, AC scored highest among the sample. In addition, the fully autonomous buses were not ranked as the highest value out of the 13 items.

The PCA reveals four attitudinal components towards the use of AC, AT, AF, and AB (Table 2). The PCA results of this study are consistent with previous studies that measured mode-specific attitudes based on

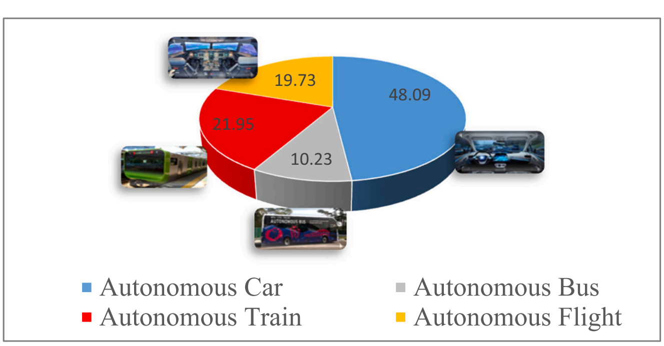
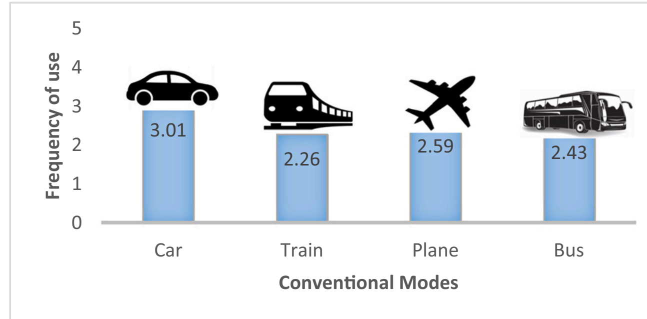
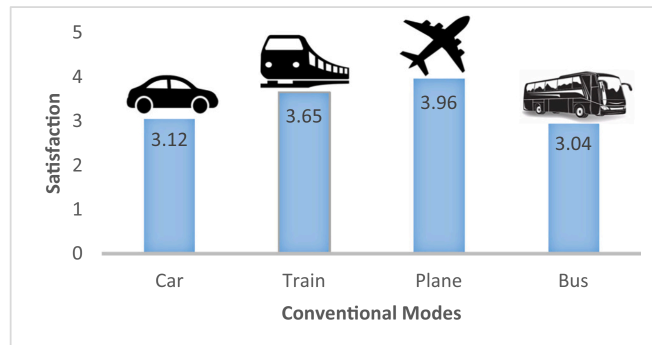


Fig. 2. Share of different preferred fully autonomous mobility options ($n = 811$).



a) Conventional mode use



b) Satisfaction with different conventional modes

Fig. 3. Self-reported mode use and satisfaction with conventional long-distance mobility options ($n = 811$).

travel modes. An explanation for this result can be the fact that attitudinal statements are formulated around certain modes, and PCA can also be revolved around modes. In this case, the KMO value was 0.83, which is acceptable. Moreover, only items with a factor loading greater than 0.4 were considered members of a principal component. The eigenvalue diagram was used to determine the principal components and to interpret the results. Four main components were identified based on the fractures and the eigenvalue diagram. A total of 57.81% of the variance is explained by the final four components. The first principal extracted component explained 20.25% of the total variance and had a desirable Alpha of 0.92. There are nine items in this factor that describe the attitude towards AC use. As a result, we can refer to this factor as the attitude towards using AC. There are seven items in the second factor, which explains 13.24% of the variance. An acceptable internal correlation coefficient of 0.78 is achieved by this factor, which has a nature of attitude towards AT use. A third factor explaining 12.77% of the variance consists of six questions regarding attitudes towards the use of AF. This factor has an internal correlation coefficient of 0.71. A fourth factor explaining 11.55% of the variance includes four items related to an attitude towards using AB. This factor has an internal correlation coefficient of 0.78. These four latent factors were then entered into the HCM model.

3.3. Model estimation

The results of the HCM model estimation are shown in Table 3. The results of this table include three sections: discrete choice, latent variable, and measurement model. The utility function was defined for all four fully autonomous alternatives in the choice model. Several mode-specific variables, such as attitudes, rates of using conventional modes (habits), satisfaction, as well as socio-economic and demographic variables, were tested as direct predictors. Variables that were statistically significant in the 95% confidence interval ($p-$ $value < 0.05$) were retained in the model, and the rest of the variables were discarded from

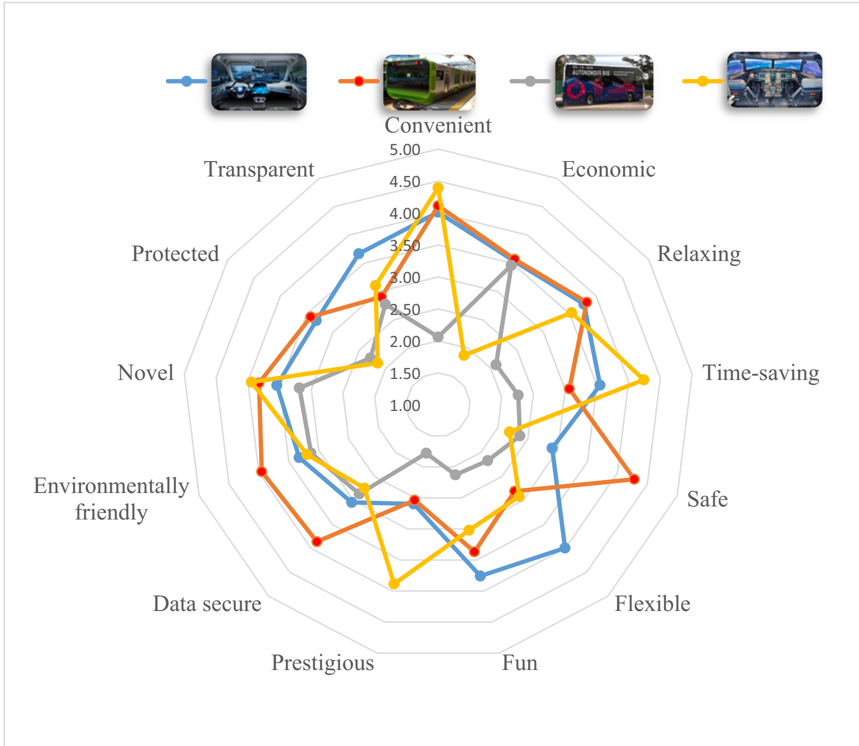


Fig. 4. Average score per attitude item per full-autonomous mode for the entire sample.

Table 2
Principal component analysis on attitudinal items related to the different fully autonomous modes.

Items	Component			
Travelling by [AC/AT/AF/AB] is …	Attitude towards fully autonomous …			
	Car (AC)	Train (AT)	Flight (AF)	Bus (AB)
Convenient	0.85	–	0.61	–
Data secure	0.67	–	–	–
Economic	0.74	0.71	–	0.83
Environmentally friendly	0.61	0.54	–	0.55
Flexible	0.87	–	–	–
Fun	0.70	0.59	0.54	0.66
Novel	0.52	–	0.49	0.46
Prestigious	–	–	0.78	–
Protected	–	0.67	–	–
Relaxing	0.81	0.64	–	–
Safe	0.80	0.78	0.42	–
Time-saving	–	–	0.50	–
Transparent	–	0.51	–	–

Note: - Cronbach's alpha and explained variance for attitude towards AC/AT/AF/AB are (0.92 and 20.253%)/(0.78 and 13.243%)/(0.71 and 12.773%)/ (0.78 and 11.550%), respectively.
- Items that are loaded below 0.40 are removed from the relevant factor.

the model. The choices include four options: AC, AT, AF, and AB. The choice model has an acceptable goodness of fit (likelihood ratio index) of 0.39.

Three of the four attitudinal factors were statistically significant, but attitudes towards AB were not. In addition, three variables of using the conventional mode of transportation were found to be significant in the model. Only two variables of travel satisfaction, flight satisfaction and bus satisfaction, were significant. Among the socio-economic and demographic variables, the gender variable in two utility functions, the elderly variable (over 60 years) in two utility functions, the young variable (under 25 years old) in one utility function, the variable of having two or more owned cars in one utility function, and the variable of high-educated individuals (with university degree) were found to be statistically significant in three utility functions.

Several socio-economic and demographic variables were found to predict attitudes in the latent variable model. For instance, households with four or more members had a favourable attitude towards using AT. The measurement model also showed statistical significance for parameters related to attitude items.

Using pseudo-elasticity methods, we evaluated how the variables estimated in the model affected the share of change in each fully autonomous transport alternative. Since socio-economic and demographic variables are dummy variables in the model, we calculated the mean of share differences among fully autonomous alternatives, since elasticity is not interpretable (Hensher et al., 2005). The AC option, for instance, is 1.5% higher for men than for women (see Fig. 5).

In addition, since the psychological variables were measured on a 5-point Likert scale, the share of transportation alternatives was calculated by adding one unit to each. On the basis of the model's significant psychological variables, Table 4 shows the share of alternatives in the estimated model and the different scenarios. For example, by improving attitudes towards AC, AT, and AF by one point, the share of these modes would increase by 3.5%, 1.5%, and 4.5%, respectively.

4. Analysis of the results and discussion

According to the results, the following findings can be interpreted.

Firstly, the research model shows that among the various fully autonomous mobility alternatives for long-distance travel, the AC has the largest share, with 51%. Following AC, AT, AF, and AB are preferred by people. While planes, buses, and trains are the conventional means of transportation most frequently used in the sample after the car. Consequently, long-distance transport is expected to undergo a modal shift as it becomes fully autonomous.

The preference for train between current and autonomous versions would be worth discussing, as AT was shown to have gained more

Table 3
Estimation results of the hybrid choice model.

Variable	Modal group	Estimate (*t*-test)
Discrete choice part		
Constant	Full-autonomous Car (AC)	3.24 (3.45)
	Full-autonomous Train (AT)	−1.28 (−2.97)
	Full-autonomous Flight (AF)	−0.86 (−2.78)
	Full-autonomous Bus (AB)	–
Socio-economic and demographic		
Male	Full-autonomous Car (AC)	0.37 (2.92)
	Full-autonomous Train (AT)	−0.50 (−2.73)
	Full-autonomous Flight (AF)	–
	Full-autonomous Bus (AB)	–
Age 18–24	Full-autonomous Car (AC)	0.41 (3.15)
	Full-autonomous Train (AT)	–
	Full-autonomous Flight (AF)	–
	Full-autonomous Bus (AB)	–
Age 60+	Full-autonomous Car (AC)	−0.38 (−2.82)
	Full-autonomous Train (AT)	–
	Full-autonomous Flight (AF)	−0.52 (−2.56)
	Full-autonomous Bus (AB)	–
Highly-educated (university degree)	Full-autonomous Car (AC)	–
	Full-autonomous Train (AT)	0.33 (2.61)
	Full-autonomous Flight (AF)	0.64 (3.18)
	Full-autonomous Bus (AB)	−0.12 (−2.90)
Car ownership 2+	Full-autonomous Car (AC)	0.21 (3.43)
	Full-autonomous Train (AT)	–
	Full-autonomous Flight (AF)	–
	Full-autonomous Bus (AB)	–
Attitudes		
Attitudes towards AC	Full-autonomous Car (AC)	1.31 (2.64)
Attitudes towards AT	Full-autonomous Train (AT)	0.93 (2.64)
Attitudes towards AF	Full-autonomous Flight (AF)	1.62 (3.61)
Attitudes towards AB	Full-autonomous Bus (AB)	–
Conventional mode use (habit)		
Conventional car use	Full-autonomous Car (AC)	0.94 (3.18)
Conventional train use	Full-autonomous Train (AT)	0.66 (4.76)
Conventional flight use	Full-autonomous Flight (AF)	–
Conventional bus use	Full-autonomous Bus (AB)	−0.14 (−2.84)
Satisfaction with		
Conventional car	Full-autonomous Car (AC)	–
Conventional train	Full-autonomous Train (AT)	–
Conventional flight	Full-autonomous Flight (AF)	0.27 (2.96)
Conventional bus	Full-autonomous Bus (AB)	0.11 (2.43)

Latent variable part	Attitudes towards AC	Attitudes towards AT	Attitudes towards AF	Attitudes towards AB
Male	0.21 (3.48)	−0.94 (−3.34)	–	–
Age 18–24	0.78 (3.48)	–	–	–
Age 25–39	–	–	–	–
Age 40–59	–	–	–	–
Age 60+	–	–	–	–
Highly educated (university degree)	–	–	0.76 (4.02)	–
Household size 4+	–	0.29 (4.53)	–	–
Car ownership 2+	–	–	–	–
Random term	0.31 (5.65)	0.61 (6.89)	0.49 (9.33)	–

Measurement model	Indicator	γ	ζ	σ
Attitudes towards AC	$I_{2\text{-}AC}$	0.58 (4.75)	2.39 (10.11)	−0.46 (−11.24)
	$I_{3\text{-}AC}$	0.78 (6.90)	2.04 (7.32)	−0.95 (−13.53)
	$I_{4\text{-}AC}$	−0.24 (4.34)	1.94 (7.39)	−0.37 (−12.21)
	$I_{5\text{-}AC}$	0.97 (9.78)	1.78 (5.55)	−0.11 (−7.40)
	$I_{6\text{-}AC}$	0.66 (6.75)	1.94 (5.99)	0.21 (4.44)
	$I_{7\text{-}AC}$	−1.03 (−8.71)	2.01 (13.43)	−0.88 (−16.34)
	$I_{8\text{-}AC}$	0.65 (4.47)	1.12 (6.06)	−0.73 (−4.67)
Attitudes towards AT	$I_{2\text{-}AT}$	0.41 (9.33)	1.31 (7.56)	0.42 (11.23)
	$I_{3\text{-}AT}$	0.21 (5.27)	1.13 (9.05)	−0.85 (−12.45)
	$I_{4\text{-}AT}$	1.12 (7.44)	1.05 (15.59)	10.22 (−6.38)

(*continued on next page*)

Table 3 (*continued*)

Measurement model	Indicator	γ	ζ	σ
	$I_{5\text{-}AT}$	0.45 (6.96)	1.15 (9.78)	−0.65 (−10.43)
	$I_{6\text{-}AT}$	0.32 (8.06)	1.25 (14.38)	−0.97 (−7.65)
Attitudes towards AF	$I_{2\text{-}AF}$	−0.21 (−3.28)	0.96 (4.23)	0.12 (3.43)
	$I_{3\text{-}AF}$	−0.15 (−6.38)	0.78 (7.97)	0.26 (2.54)
	$I_{4\text{-}AF}$	−0.34 (−3.17)	0.90 (4.57)	0.29 (5.62)
Attitudes towards AB	$I_{2\text{-}AB}$	−0.14 (−4.74)	1.02 (6.45)	0.35 (4.76)
	$I_{3\text{-}AB}$	0.31 (3.46)	0.76 (4.76)	−0.13 (−2.97)
Number of observations	811			
Final log likelihood	−681.16			
Rho-square for the model	0.39			

Note 1. Only statistically significant variables at CI 95% are retained in the final HCM.
Note 2. T-statistics are shown in parentheses.
Note 3. Due to inconsistencies, a few indicators were removed from the measurement model.

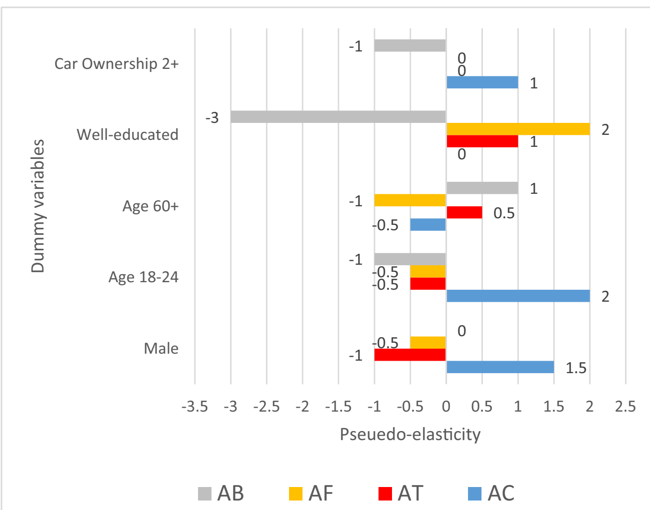


Fig. 5. Share differences between categories of dummy variables in the model (the values have been rounded).

Table 4
Predicting changes in the alternatives.

#	Scenario	Share of alternative (%)			
		AC	AT	AF	AB
0	Do Nothing[a]	51%	21%	20%	8%
1	One-point increase in attitudes towards AC	54.5%	20%	19%	6.5%
2	One-point increase in attitudes towards AT	51%	22.5%	19.5%	7%
3	One-point increase in attitudes towards AF	50%	19.5%	24.5%	6%
4	One-point increase in Conventional Car Use	53%	20.5%	19.5%	7%
5	One-point increase in Conventional Train Use	50.5%	22.5%	20%	7%
6	One-point increase in Conventional Bus Use	52%	21.5%	20%	6.5%
7	One-point increase in Satisfaction with Conventional Flight	51%	21%	22%	6%
8	One-point increase in Satisfaction with Conventional Bus	50.5%	21%	19%	9.5%

[a] The share of alternatives (market shares) are based on estimated HCM.

preference over AF and AB. This modal shift might be explained by the respondents' perspective, both in terms of climate change making people worry nowadays (Bouman et al., 2020) and the perceived safety of fully autonomous air travel. As the largest growth rates of CO_2 emissions are observed in the transportation sector (IEA, 2009), air travel can have the greatest impact on the environment (Khardi, 2014). So, instead of short-haul flights, fully autonomous versions of High-Speed Rail (HSR) can potentially become one of the most dominant options for long-distance travel in the future. The HSR has gained attention as a viable and sustainable alternative to air travel, especially when it comes to mitigating the environmental effects of short-haul domestic flights. (Avogadro et al., 2021; Rajendran and Popfinger, 2022). In comparison to long- and medium-haul flights, short-haul flights have lower load factors and carry less cargo, causing the energy-intense take-off and climb phase to be dispersed over a shorter flight distance, therein lies the problem (Baumeister, 2019). In many developed countries, widespread acceptance of HSR has been established as an alternative way to deal with environmental issues in the transportation sector (European Commission, 2001; FRA, 2009), and some countries go further and deem HSR as a major competitor of airlines in the future.

Secondly, the findings indicate that the effect of psychological variables on the share of fully autonomous transportation alternatives is greater than socio-economic and demographic variables. Among the psychological variables, the results indicate that both attitudes about fully autonomous modes according to the TPB and habit can affect the choice of a fully autonomous mode for long-distance travel. There are various debates in the literature regarding how to decide on transport modes. Some believe that habit plays a major role in travel decisions (Nordfjærn et al., 2014; Gärling and Axhausen, 2003; Verplanken et al., 1997), while others (Kroesen et al., 2017; Molin et al., 2016; Kroesen and Chorus, 2020; Ton et al., 2020) have sought to determine the relationship between attitude and travel decisions, arguing that, according to the TPB, attitudes can play a crucial role in shaping the future's choices. Both concepts played a significant role in our study, but attitudes impacted people's preferences for fully autonomous modes more than mode use habits. The sensitivity analysis of the variables shows that increasing one unit of attitudes compared to the habits of using modes will have a greater impact on the share of using fully autonomous modes.

Third, those who have positive attitudes towards AC, AT, and AF are more likely to use AC, AT, and AF, respectively. By strengthening the attitude, especially about the safety and security of each mode, a greater likelihood can be achieved. In general, to address concerns and improve people's attitudes and beliefs, some items should receive higher priority in behavioural campaigns. Although AC received the highest attitude scores for flexibility, fun, and system transparency, they were less desirable than AF and AT in other aspects, such as prestige and convenience. AT is perceived as providing the highest levels of safety, security, and convenience. As a result, it is expected that fully autonomous trains will be able to compete with fully autonomous cars in fully autonomous ground transportation. By relying on these types of attitudes, policymakers can shift a large portion of AC's share to AT. Another point that should be driven here is that attitudes towards AB were not significantly associated with mode choice. Among the various fully autonomous alternatives, ABs appear to be undervalued. The attitude item "travelling by vehicle is time-saving and economical" was evaluated on the basis of level-of-service attributes. In terms of travel time, AF, AC, AT, and AB alternatives were considered the most economical. Moreover, AT, AC, and AB modes were evaluated at almost the same level when it came to travel costs, while the AF mode was assessed as the most expensive.

Additionally, our research model allows us to understand the three attitude components of AC, AT, and AF, among which segments of the sample are more or less perceived. Using AC is viewed favourably by men and youngsters (ages 18–24). Those with more than four members in their household and those who are female are more favourable to AT. Furthermore, people with university degrees are more likely to be positive about using AF. By better planning on target communities, policymakers can conduct effective attitude campaigns for behaviour change.

Fourth, according to the study hypothesis, the habit of using current/conventional travel modes impacts use of those modes in fully autonomous versions. However, the study's results differ slightly from previous studies on travel habits and behaviour. In contrast to previous studies that showed habit could have a positive effect on the use of certain modes (Gärling and Axhausen, 2003; Verplanken et al., 1997), this study shows habit can have a negative impact as well. AC and AT are more likely to be used by those who use cars and trains more often. However, those who are frequent users of intercity buses are less likely to use AB. According to the analysis, this result could be attributed to the fact that the use of fully autonomous buses may reduce the number of old passengers and encourage them to use other fully autonomous options. A special focus should be placed on this issue by manufacturers of ABs and policymakers in the transportation sector. A cautious approach should be taken when it comes to bringing some collective fully autonomous options to the market, such as buses and aeroplanes. It may still be necessary to use operators for such travel options.

As for the travel satisfaction variables, the level of satisfaction with air travel and bus travel positively influences the use of these modes in fully autonomous versions. Nevertheless, trip satisfaction for car and train trips did not affect the use of AC and AT. As a result of these findings, maintaining high levels of satisfaction among current passengers of public transportation modes, such as planes and buses, can also increase the likelihood of using these modes in fully autonomous versions.

Last, among the socio-economic and demographic variables, gender, age, education, and car ownership directly affected the choice of fully autonomous mobility options for long-distance trips. It was 1% more likely for females to use AT than for males, while males were more likely to use AC. These results are somewhat consistent with previous studies on long-distance travel by conventional vehicles. Limtanakool et al. (2006) found that women use trains more frequently than men. Two age groups, young adults (24 to 28) and older adults (over 60), had a direct influence on mobility choices. In comparison with other age groups, young people are more likely to choose AC (2% more likely), whereas older people are less likely to choose AC and AF. Contrary to this result, Limtanakool et al. (2006) found that older people use the conventional car more on long-distance travel. Despite Dong et al. (2019) showing men and younger people use more ABs, this study found these variables did not affect AB use. Higher educated individuals are more likely to use AF and AT and less likely to use AB. This finding is in line with Rice et al. (2019), which showed that educated people are more inclined to use AF, while Limtanakool et al. (2006) showed that educated people are more likely to use buses on long-distance travel.

5. Summary and conclusions.

The development of mobility transition in the transportation sector should be aimed to address major global sustainability challenges including climate change, paucity of resources, current economic climate, and the challenges of such. It is therefore more likely that a transition to fully autonomous mobility options will take place in the future to address such issues. Besides policies and economic conditions, socioeconomic and psychological factors can influence modal shifts. Using survey data and a hypothetical scenario, we explored travellers' preferences for long-distance travel among different fully autonomous mobility options. The effects of socio-economic and demographic variables and psychological variables, including attitudes, habits, and travel satisfaction, were investigated on the choice of a fully autonomous mode. In light of the study's findings, our conclusions are as follows.

- In accordance with prevailing preferences, the preferred order of autonomous mobility options for long-distance travel is as follows: autonomous cars, autonomous trains, autonomous flights, and autonomous buses.
- The choice of fully autonomous modes is influenced by both attitudes towards them and the frequency of use (habit) of conventional vehicles, with attitudes having a greater impact on travel behaviour compared to habits.
- The habit of using conventional travel modes can positively and negatively influence the use of those modes in fully autonomous versions. Specifically, those who frequently use cars and trains are more likely to use autonomous cars and autonomous trains, respectively. On the other hand, people who frequently use intercity buses are less likely to use autonomous buses.
- Higher levels of satisfaction with air travel and bus travel are positively associated with the likelihood of using these modes in fully autonomous versions.
- Among the socio-economic and demographic variables, gender, age, education, and car ownership were found to directly influence the choice of fully autonomous mobility options for long-distance trips.

At this point, regarding the discussion on the mobility transition, the following policies can be formulated.

- Due to the inclusion of multiple autonomous travel options, the current study highlighted plausible modal shifts in long-distance travel. Compared to the current modal shares among different conventional options, we expect a modal shift may occur in a fully autonomous mobility world for long-distance travel. A shift from air travel to railway travel in an autonomous version is expected. We anticipate that national policies may be required to induce such modal shifts. The implementation of policies aimed at improving railway systems' integration, in addition to attitudinal change campaigns, could facilitate such shifts.
- People's attitudes can play a significant role in the share of various fully autonomous modes. For some modes among the different attitude items, subjective beliefs were rated extremely positive or very negatively. In terms of time savings, convenience, prestige, and innovation, the autonomous flight was rated higher than other fully autonomous options. Autonomous flight was considered one of the least economic and unsafe modes of transportation at the same time. However, autonomous trains were considered to be the safest, most secure, relaxing, and economically efficient option. The autonomous car was also regarded as the most transparent, fun, and flexible mode of transportation. As mode-specific attitudes affect the likelihood of people choosing these three options, namely autonomous cars, autonomous trains, and autonomous flights, policymakers can change consumers' perceptions of different modes by focusing on each of them. In the case of fully autonomous flights, deploying operators can significantly reduce passengers' concerns about their safety and security. Consequently, the process of converting some transport modes, such as aeroplanes, to fully autonomous performance should be undertaken with caution.
- The study's findings suggest that attitudes towards the usefulness of autonomous buses play no role in their use. The results also showed that those who are currently frequent users of buses might no longer want to use autonomous buses in a world of fully autonomous

alternatives. Conventional bus users are more likely to switch to other autonomous options for long-distance travel. Among these individuals, 1% switch from autonomous buses to autonomous cars, and 0.05% switch to autonomous trains, according to sensitivity analysis. Policymakers should give special consideration to the competitiveness of autonomous buses compared to other fully autonomous modes. In most attitudinal items, autonomous buses received the lowest scores. Advertising and training programs should therefore focus on activating beliefs about the usefulness and safety of autonomous buses.
- The use of fully autonomous modes is not viewed as beneficial by some population groups. Even though attitudes towards autonomous cars were more strongly perceived among men and younger people, better planning for women and older people may lead to positive attitudes. To improve attitudes towards autonomous trains, behaviour change campaigns can also focus more on men and nuclear families.

This study had some limitations that should be taken into account when generalizing its findings:

- The study sample consisted of individuals who had never used fully autonomous options for long-distance travel, and the research question regarding their preference for fully autonomous modes was hypothetical. Although respondents were given accurate and detailed information about each fully autonomous alternative in the online survey, both textually and visually, it is possible that their attitudes or preferences towards these modes may change once they have actual experience with fully autonomic modes.
- Preferences for all travel options could have been captured on a Likert-scale or by asking respondents to rank or report the frequency of use within a specific period. However, we used a forced-choice format in our survey, as we believed that measuring each fully autonomous mode preference, frequency of use, or rank could have some limitations. Unlike attitudes, behavioural measures such as mode choice should be measured more carefully to avoid misleading results. It is unrealistic to expect people to report detailed behavioural choices regarding each fully autonomous option since they are not yet available. Therefore, we asked respondents about their dominant choice among different modal options to obtain a more reliable result regarding the dominant preferred mode.
- Participants were required to be 18 years of age or older to take part in the survey. As fully autonomous modes may become a reality within the next 20 years, future studies should also include participants from the younger generation (under 18). In addition, it should be noted that the current study's participants had experience with each of the conventional modes of long-distance travel at least once. Thus, individuals who have never used certain modes of transport, such as aeroplanes or trains, may behave differently if they were fully autonomous.
- The study participants came from a society with a lower level of knowledge about fully autonomous modes compared to those in developed nations. Therefore, it is important to interpret and generalize the study's results with caution.
- In addition, the study was limited to leisure travel of more than 100 km. People's preferences and choices for different transportation options are influenced by various factors, such as travel distances and trip purposes. As a preliminary study, we did not focus on trip purposes and distances, and future research could address this issue. Additionally, we did not quantitatively measure travel times or costs. Instead, we used attitudinal items to capture trip characteristics such as travel time, cost, convenience, and flexibility.

Future studies could build upon this research by examining mode preferences based on various trip characteristics, including the purpose of the trip. Furthermore, researchers could investigate mode preferences at different distance thresholds to gain a more comprehensive understanding of how distance influences the selection of autonomous transport modes. This would provide valuable insights into the circumstances in which fully autonomous modes are most appealing and the potential for their integration into the transportation system. By addressing these research gaps, we can better understand the factors driving the adoption of fully autonomous modes and develop policies and strategies that support their successful implementation.

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CRediT authorship contribution statement

Ali Karami: Data curation, Writing – original draft, Visualization, Methodology, Investigation. **Hossein Karami:** Conceptualization, Methodology, Investigation, Software. **Milad Mehdizadeh:** Writing – original draft, Writing – review & editing, Methodology, Formal analysis, Visualization, Supervision, Project administration.

Declaration of competing interest

The authors have no conflict of interest to report.

Data availability

The authors do not have permission to share data.

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