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Changes in the Service Evaluations of Automated Buses Over Time: A One-Year, Three-Wave Panel Study in Stockholm

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ABSTRACT

The operation of automated buses (ABs) as a feeder transport service has been advocated as one of the most suitable ways to integrate shared automated vehicles into the current public transportation system. Previous studies based on pilot demonstrations have explored public attitudes and perceptions toward ABs, but most of those studies have relied on cross-sectional data, which cannot capture changes in attitudes over time. To address this gap, a one-year, three-wave panel survey was conducted in Stockholm, Sweden, with a focus on passengers' real-world experiences in relation to an automated bus operating in mixed traffic on public roads. Latent curve analysis was applied to the longitudinal data to examine the evolution of service evaluations. Although the findings indicated that passengers initially rated speed and travel time unsatisfactorily, these evaluations showed steady improvement over time. In contrast, perceptions of safety, comfort, and convenience were positive at the outset but underwent a moderate decline throughout the study period. Current public transport users and tech-savvy individuals were identified as the primary user groups most likely to adopt ABs in the future.

KEYWORDS

automated bus (AB); self-driving bus; driverless bus; technology acceptance; three-wave panel survey; public perceptions and attitudes; Stockholm

Introduction

In recent decades, vehicle automation technology has evolved from an emerging field to a major research topic worldwide. This transformative technology has the potential to substantially change future traffic patterns, and the introduction of automated driving technology is expected to generate social and economic benefits, such as improvements to road safety by mitigating traffic accidents due to human error (Chehri and Mouftah, 2019; Petrović et al., 2020) and improving road capacity, thus enabling more efficient utilization of road infrastructure (Fagnant and Kockelman, 2015; Carrone et al., 2021). Nevertheless, as discussions and research are ongoing, scholars have realized that the

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use of private automated vehicles might not solve the problem of road congestion and may in fact increase the total number of inflow vehicles on the road due to low levels of willingness to share rides. In the worst case, it may cause traffic congestion to increase in the short term before easing in the long term (Alexander-Kearns et al., 2016; Kellett et al. 2019). In addition, recent studies have explored the ecological benefits of automated vehicles, including their potential to reduce greenhouse gas emissions and improve energy efficiency. For instance, Vahidi and Sciarretta (2018) demonstrated that the use of connected and autonomous vehicles can significantly reduce energy consumption and carbon emissions through improved traffic flow and energy-efficient driving strategies. Zhang et al. (2022) studied the optimal eco-driving control of autonomous and electric trucks on highways, with a focus on energy minimization and battery life extension. Lu and Liu (2021) proposed an ecological control strategy for cooperative autonomous vehicles in mixed traffic that took into consideration linear stability, and Lu et al. (2019) presented an energy-efficient adaptive cruise control system for connected and autonomous electric vehicles. Liu et al. (2019) evaluated the potential for reductions in greenhouse gas emissions from autonomous vehicles at the country level. As a sustainable mode of transport, shared automated mobility would help to reduce traffic congestion and contribute to sustainable urban mobility.

Vehicle automation technology can provide potential benefits to the current public transportation system through the implementation of partially or fully automated buses (ABs). However, although these new modes of transport are expected to offer various advantages, the primary barrier to their adoption may not stem from technological limitations but from psychological factors. Public acceptance of ABs will depend on individuals' attitudes towards this new mode of transport. A growing body of literature has investigated the key attitudinal factors influencing this acceptance, such as concerns related to safety and reliability, speed and efficiency, cyber hacking, comfortability and enjoyment (Howard and Dai, 2014; Kyriakidis et al., 2015; Hulse et al., 2018). These behavioral studies suggest that attitudes toward vehicle automation technology are a critical factor in passengers' acceptance of and willingness to use automated transport systems.

Over the past few years, due to the restrictions arising from laws and regulations, fully autonomous vehicles have not been permitted to operate in a mixed traffic context together with private vehicles, public modes of transport, bicycles, and pedestrians in real on-road environments. Experiments have, therefore, been limited to collecting data on volunteers' reactions in a simulated environment within a test setting. The conditions provided by the specific experimental site (e.g., closed campus) have inevitably led to overestimations of the positive response, biased by real-world conditions. When data are collected from people without actual physical riding experience, using hypothetical scenario-based approaches, it is rather difficult to examine passengers' actual opinions towards ABs, since users are not exposed to a real bus service, and this has left knowledge gaps for further studies. Among the few notable exceptions are several ongoing studies addressing the importance of collecting attitudes and perceptions from respondents who have ridden ABs in a real-life environment rather than a hypothetical environment (e.g., Chen, 2019; Eden et al., 2017; Madigan et al., 2016, 2017; Nordhoff et al., 2018, 2019; Paddeu et al., 2020; Portouli et al., 2017).

The number of AB pilots has increased rapidly over the past decades, and it is expected that with more riding experience and greater knowledge of vehicle automation technology, individuals' attitudes towards this new public transport system will change over time. To facilitate a successful switch from the pilot demonstration stage to the regular use of ABs as a feeder service, it is imperative to continuously monitor the public's perceptions and attitudes towards ABs. In addition, the majority of studies have been based on cross-sectional data, with no data available to explore whether attitudes towards vehicle automation technology tend to change over time. To fill this research gap, we conducted a longitudinal survey. Respondents were asked to report on their behavior, attitudes, and perceptions of AB riding experiences in different waves. Based on these panel data, the present study focuses on the real-world riding experiences of an automated public bus service that is operating in the Barkarby neighborhood of Stockholm, Sweden. Longitudinal analysis was applied to understand the dynamic changes in attitudes over time towards this new mode of public transport.

The remainder of this article is organized as follows. In the next section, the literature relevant to the study is discussed, with a particular focus on the public's perceptions of and attitudes towards ABs. The subsequent section presents the research methodology. Following this, we describe the three-wave panel survey, the data collection process, and the data analysis. We then discuss the results of the research and, finally, give some conclusions, policy implications, and recommendations for future research.

Automated Buses in the EU: State of the Art

Following the development of automated driving technology, shared automated vehicles can offer potential benefits to current public transport systems through the implementation of fully or partially ABs. Based on these technological developments, ABs (also called self-driving or driverless buses, or automated shuttles) have been tested through pilot projects in various European countries, including Austria, Finland, France, Germany, Norway, the Netherlands, the U K, Sweden, and Switzerland (e.g., CityMobile1 and CityMobile2, funded by the EU; Smart Shuttle in Switzerland; EUREF in Germany; WEPods in the Netherlands; SOHJOA in Finland; and Digibus in Austria). This vigorous development has been possible because these projects have removed the main barriers to launching an automated vehicle service on public roads and have allowed ABs to be positioned as an integral part of the automated road transport system.

As this is an innovative technology, the public's perceptions and expectations towards ABs play a crucial role in their introduction. Over recent decades, field experiments have been carried out in order to understand public attitudes and perceptions towards ABs after physically experiencing a ride on such a bus. As summarized in the final report of the CityMobil2 project (2014), people have shown relatively positive attitudes in cities such as Oristano (Italy, July and August 2014), La Rochelle (France, from October 2014 to April 2015), Lausanne (Switzerland, from October 2014 to April 2015), Vantaa (Finland, July and August 2015), Trikala (Greece, from August 2015 to February 2016), Sophia Antipolis (France, from March to May 2016) and San Sebastian (Spain, from April to July 2016), where driverless shuttles served as feeders to public transport.

Madigan et al. (2016) carried out a survey of opinions on automated mobility among 349 respondents who had used an automated shuttle along a popular tourist route in La Rochelle, France, and as a link between a metro station and workplaces/campuses in a district in Lausanne, Switzerland. The study revealed that the most decisive factor affecting the public's attitudes towards fully automated mobility is perceived safety. In another study, Madigan et al. (2017) investigated the opinions of 315 passengers who had used CityMobil2 automated shuttles in the city of Trikala, Greece. These people reported that automated shuttles were useful and easy to use and expressed their willingness to use the automated shuttles again in the future. Likewise, Piao et al. (2016) investigated public attitudes after demonstrations carried out in La Rochelle, France. According to their surveys, public attitudes towards the implementation of ABs in urban areas were positive. About two thirds of people stated that they would consider using ABs if both automated and conventional buses were available on a route. Moreover, passenger security was highlighted as one of most important issues for ABs, especially in relation to nighttime services.

Nordhoff et al. (2018) presented the results of a questionnaire study among individuals who had physically experienced automated shuttles on an office campus in Berlin-Schöneberg. Their study indicated that the respondents felt positively towards automated shuttles in both urban and rural areas. The authors reported that elderly people expressed higher intentions to use the automated shuttles but found the shuttle less effective than their existing mode of travel. In addition, speed and efficiency would need to be improved for this to become viable on a wide scale. Wicki and Bernauer (2018) investigated public attitudes towards an AB service in Switzerland and found that passengers showed a relatively high level of trust in the system's safety and reliability. During trials of driverless shuttles in Finland, Salonen (2018) investigated public opinions of ABs, and showed that users assessed the perceptions of traffic safety as better in an AB than in a conventional bus with a driver, although the majority of respondents reported that the sense of in-vehicle security in the AB was worse than for a conventional bus.

In a Norwegian project called Smartfeeder, Roche-Cerasi (2019) investigated individuals' opinions on the usefulness of automated shuttles. Their results indicated that one-fourth of the respondents thought there was a need for driverless shuttles running between residential areas and public transit. Individuals who stated that it was unlikely that the implementation of automated shuttles would make them use public transit more often were also more concerned with safety and security issues. Through a face-to-face survey following trials of driverless buses in Spain, Rosell and Allen (2020) examined passenger satisfaction and the behavioral intentions after passengers had experienced a driverless vehicle trip. Their study confirmed that perceptions of safety affect the user's reuse intention and satisfaction. In addition, female users were reluctant to ride on ABs alone. A study by Hilgarter and Granig (2020) involved a survey in Austria that was conducted to assess public perceptions of automated shuttles after respondents had experienced an actual ride. This study reported that the predominantly positive public attitude towards automated vehicles highlighted the enormous potential of automated vehicle use. Mouratidis and Cobeña Serrano (2021) investigated the use of autonomous shuttle buses running along a regular public transport line in a residential area of Oslo, Norway; based on survey and interview data from two independent studies, the results suggested that the intention to use ABs was mostly positive both before and

after people had taken the bus. Most passengers felt safe while traveling by autonomous bus.

In a more recent study, Nordhoff et al. (2021) used a structural equation modeling approach to explore the acceptance of driverless shuttles in mixed-traffic environments and found that perceived safety and convenience were key factors influencing users' intentions to adopt these technologies. Similarly, Molinillo et al. (2024) examined users' willingness to travel on autonomous buses and found that experience played a moderating role in shaping user attitudes, with increased ride experience leading to more favorable views. Furthermore, Quinones et al. (2024) investigated factors determining the intention to use and recommend the use of public autonomous shuttles and emphasized the importance of real-world trial experiences in shaping perceptions.

Although many pilot projects have begun to investigate public attitudes towards ABs, most previous studies have been based on cross-sectional data, meaning that an understanding of the temporal changes in public opinion towards this new mode of public transportation is lacking, and leaving knowledge gaps for further studies. Among the few notable exceptions is work by Chee et al. (2021), who drew attention to the longitudinal changes in users' valuation of an AB trial in Stockholm-Kista. In their study, the authors evaluated the longitudinal changes in users' perceptions of the new public transport service with increasing ride experience. The results implied that the users' intention to adopt vehicle automation technology was initially influenced by safety and travel time, whereas ride comfort became a primary determinant with increasing rider experience. However, these findings were based on a demonstration trial in which the AB service operated only along a straight line 800 m long, without validation in a mixed traffic environment on public roads. The current study, based on a three-wave panel survey conducted in the Barkarby neighborhood of Stockholm, Sweden, aims to fill this research gap and to understand the change in the public's dynamic attitudes towards a regularly scheduled AB service.

Research Design and Data Sources

Study Area

A survey was carried out in Stockholm-Barkarby, Sweden. Barkarbystaden is a sustainable and smart city project parcel, with approximately 40,000 inhabitants, in western Stockholm (Barkarby, 2020). As a new regional center under development in Järfälla, Barkarbystaden is planned to become one of the largest housing development projects in Northern Europe. Our choice of Barkarbystaden as our research location was predicated on its distinction as one of Europe's first real-world deployments of ABs, operating along Stockholm's Barkarby route. The Swedish government has strategically selected Barkarbystaden, one of the main areas of expansion in the Stockholm region, as the deployment site for its pioneering AB initiative, a decision that has provided an ideal testbed for the study of early adoption patterns in a rapidly growing urban hub. Passengers in Barkarbystaden have substantially greater exposure to and familiarity with autonomous vehicles compared to other regions, making them uniquely qualified as study participants.

In October 2018, the world's first regular scheduled AB, Line 549, was put into operation. Three electrically powered EZ10 vehicles (EasyMile) served this route, each of which could carry up to 11 passengers per vehicle at a time, operating during peak hours (06:30–09:00 and 12:30–19:00 on weekdays, and 11:30–19:00 on Saturdays). The length of this bus route was 2.5 km, and it had four stops, connecting two newly built residential areas, Herrestaskolan and Stora Torget (See Figure 1). With a maximum speed of 15 km/h, it took each bus 11 minutes to complete the whole route. The service could be accessed via the local transport administration, Stockholm Public Transport (SL), and by buying tickets.

Theoretical Framework

This study was guided by a theoretical framework in which established models of technology acceptance and adoption were integrated in order to examine the factors influencing the public's attitudes and behaviors towards AB services. The Technology Acceptance Model (TAM) and the Theory of Planned Behavior (TPB) provided a basis for understanding the antecedents of technology acceptance, with an emphasis on perceived usefulness, perceived ease of use, subjective norms, and attitudes towards the use of new technology (Davis, 1989; Ajzen, 1991). In order to extend these frameworks within the context of AB services, this study focuses on key factors including perceived functional attributes (e.g., travel time, speed, and frequency), perceived safety, user experience expectations (e.g., convenience and onboard comfort), and the degree of user interaction with the AB service. These factors were hypothesized to shape attitudes towards the technology and to influence the acceptance and intention to use.

Moták et al. (2017) and Kaye et al. (2020) highlight that public perceptions of new technology, individual openness to technological innovation, and familiarity with underlying technology significantly influence adoption behaviors. In this study, socio-demographic characteristics (e.g., gender, age, education), technological savviness, and travel behavior attributes serve as moderators in an exploration of the variations in the acceptance of AB services. The inclusion of these moderators allows for a deeper investigation of individual and contextual differences that may affect perceptions and behaviors.

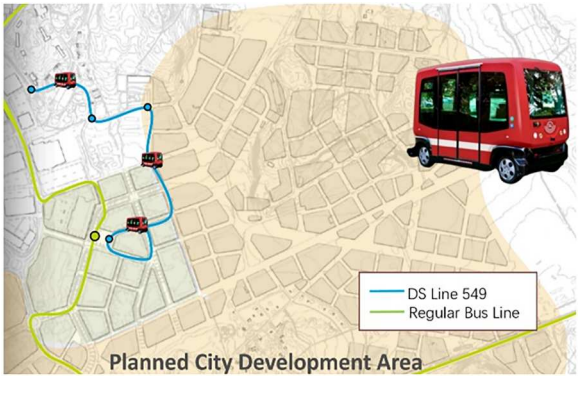


Figure 1: Operational route for the Barkarbystaden driverless shuttle, Line 549
Source: https://www.drivesweden.net/

Data

Data Collection. Three waves of a panel survey were conducted in March, September, and December 2019. An online survey company identified inhabitants and workers in the research area as respondents who might have had the opportunity to interact with or use the ABs. In each wave, respondents were asked a series of questions, based on a five-point Likert scale, related to public attitudes and perceptions of the ABs, including the functional service characteristics (e.g., travel time, speed, frequency, etc.), evaluations and expectations of user experience performance (e.g., convenience and onboard comfort) and perceived safety. The questionnaire also included items regarding the degree of interaction between the respondents and the ABs: respondents were asked whether they had seen the ABs themselves and were required to report the cumulative time representing their use of the AB service and their riding time during the last week before the interview. Lastly, the study also assessed respondents' socio-demographics and personality, along with travel behaviors. In this study, travel behavior refers to accessibility to private mobility (i.e., car ownership) and the weekly use frequency of this mode of transport as a first-/last-mile solution connecting to the nearby transit hub.

The rationale for the questions related to the underlying theoretical framework guiding the study was as follows. Questions on functional service characteristics, safety, and user experience were rooted in established theories of technology adoption, with an emphasis on how perceived utility and safety influence public acceptance. Respondents were asked to answer a series of questions, based on a five-point Likert-scale, that were related to public attitudes and perceptions of driverless shuttles, including the functional service characteristics (e.g., travel time, speed, frequency etc.), evaluations and expectations of user experience performance (e.g., convenience and onboard comfort), and perceived safety. By examining respondents' frequency of interaction and use of ABs, the study sought to understand how direct experience modifies public attitudes, a key element of the TAM and TPB extensions for transportation technologies.

Sample Description. After nine months of the survey, the numbers of completed responses were 511 in the first wave, 445 in the second wave and 584 in the third wave. A total of 363 people completed all three waves, and their responses were linked and evaluated as panel data, with each individual having a unique, continuous ID across the three different waves. Of the 363 respondents, 131 had taken the driverless shuttle at least once, and 232 people had no experience with the AB service at all. Although differentiating between users and non-users of driverless shuttles offers valuable insights, it is essential to recognize that attitudes toward emerging technologies are also shaped by indirect experiences, including media exposure and societal narratives. An approach in which all respondents are modeled collectively provides a comprehensive perspective on public sentiment, encompassing the perceptions of those without direct use experience, a group that represents the majority during the early stages of deployment. This enables a wide range of attitudes to be captured, thereby offering insights into potential barriers to adopting and informing policy measures aimed at enhancing public knowledge and acceptance. As presented in Table 1, males and females were

Table 1: Socioeconomic characteristics of the respondents

Variable	Classification	All Respondents (N=363, %)
Gender	Male	50%
	Female	50%
Age	Young (15- to 24-years-old)	4%
	Adult (25- to 44-years-old)	59%
	Middle-aged (45- to 64-years-old)	24%
	Elderly (≥65-years-old)	12%
Education	Higher than/equal to bachelor's degree	45%
	Lower than bachelor's degree	55%
Employment Status	Employed	79%
	Unemployed	1%
	Student	7%
	Pensioner	12%
Annual Income Level	Low-income (<30,000€)	12%
	Middle-income (30,000–69,000€)	42%
	High-income (≥69,000€)	25%
	Do not want to specify	21%
Car Owner	Yes	76%
	No	24%
Lives near the Automated Bus Line	Yes	94%
	No	6%
Tech-savvy (self-perception)	Yes	89%
	No	11%
Familiar with Autonomous Driving Technology	Yes	21%
	No	79%

Note: A self-assessment of "tech-savvy" reflects the respondent's confidence in their ability to understand and engage with new technologies, with an emphasis on their perceived level of comfort, familiarity, and capability in using technological solutions. This is distinct from "attitude towards new technology" as presented in Table 2, which measures respondents' evaluations, perceptions, and emotional responses specifically towards the automated bus service and its associated features, such as safety, convenience, and overall usefulness.

equally distributed among the respondents. The uppermost age span among the sample was the adult group (25- to 44-years-old) with a share of 59 percent, while the middle-aged group (45- to 64-years-old) made up 24 percent of the sample. With regard to education level, highly educated people were slightly predominant, as respondents with a bachelor's degree or higher made up 45 percent of the sample. In terms of employment status, 80 percent of respondents were employed, and people with upper and middle incomes represented the largest income classes. In addition, 76 percent of respondents owned at least one car per household. The questionnaire was distributed in Barkarby, Stockholm, and 9 percent of the respondents stated they lived along the AB line.

Individual preferences for innovative technology were investigated by asking about technological savviness and familiarity with the technology behind the automated bus. Although 89 percent of respondents rated themselves as tech-savvy people, only a quarter were aware of the technology that allowed the AB to run on the road without a human driver. Thus, the public's knowledge and awareness of vehicle automation technology could be improved. To understand respondents' attitudes towards the new technology, four questions were designed. As shown in Table 2, all items were measured using a seven-point Likert scale (ranging from completely disagree to completely agree). The results indicate a relatively high level of technological openness, with a mean score of 4.84 (SD = 1.73), indicating that respondents expressed openness to new technology. In addition, respondents agreed on the importance of staying informed about technological developments (mean = 4.84, SD = 1.73). The enthusiasm for new

Table 2: Descriptive statistics for attitude towards technology

Response Statement (N=363)	Mean Value	Standard Deviation
It is important for me to follow technological developments.	4.84	1.73
I am always among the first to try to use new technology products.	3.58	1.69
I am excited about the possibilities of new technology.	3.83	1.85
I know more than others about the latest technology products.	3.44	1.83

technology was also measured, and the findings revealed that respondents had a strong curiosity and desire for innovative technology (mean = 3.58, SD = 1.69). Finally, respondents expressed confidence in their knowledge of the latest technology products (mean = 3.44, SD = 1.83). In general, people willing to embrace this change had a positive attitude towards technology.

Methodology

Latent Growth Curve Model

Two of the objectives of this study were to understand the longitudinal changes in people's evaluations of the AB service and to explore the influences of socio-demographic, individual characteristics and travel attributes on these evaluations. Traditional analytical methods predict longitudinal change by using parameters that are common across cases; in other words, they smooth a repeated measure to obtain a mean latent trajectory that cannot be directly observed for the entire population. However, underlying individual time trajectories cannot be captured by a simple regressive model. For this reason, a different approach to analyze longitudinal change was required in this study, and as an alternative, the latent growth curve model (LGCM) was applied. This model captures the inter-individual variability in intra-individual patterns of change over time (Bollen and Curran, 2006); moreover, LGCM can deal with various complex issues in a flexible way, including discretely scaled repeated measures, unequally spaced time points and the inclusion of time-varying covariates (TVCs; Curran et al., 2010).

Unconditional Model. The LCGM is a powerful model for estimating the average trend in intra-individual growth patterns across a population and is structured into two levels. The first level of the model is defined as a "within-person" regression model and requires longitudinal data where individual trajectory y_{it} at time point (waves) t for individual i.

$$y_{it} = \alpha_i + \lambda_t \beta_i + \varepsilon_{it} \tag{1}$$

y_{it} is described by the intercept between the individual trajectory α_i, the slope of the individual trajectory β_i, and the trend variable λ_t. y_{it} ($t = 1,\ 2,\ 3$) represents repeated measures of the target variables at three interview time points. In this study, y_{it} refers to functional attributes, safety attribute, general comfort and convenience on board, respectively. The trend variable λ_t captures the time interval between the different

waves of the panel survey. In addition, a disturbance term ε_{it} is attached to the end of the equation based on the assumption that $E(\varepsilon_{it}) = 0$ for all t and i.

The second level is defined as a "between-person" model, in which the intercept and slope are assumed to be constant for a given individual but to vary among the population. Thus,

$$\alpha_i = \mu_\alpha + \zeta_{\alpha i} \tag{2}$$

$$\beta_i = \mu_\beta + \zeta_{\beta i} \tag{3}$$

where the intercept and slope are composed of the fixed components μ_α, μ_β and the random components $\zeta_{\alpha i}$, $\zeta_{\beta i}$. The mean intercept μ_α and mean slope μ_β describe the central tendencies of the intra-individual patterns for all cases in the sample. $\mu_\alpha = E(\alpha_i)$, $\mu_\beta = E(\beta_i)$. The disturbance terms $\zeta_{\alpha i}$ and $\zeta_{\beta i}$ represent the inter-individual deviation from the central tendencies, where $E(\zeta_{\alpha i}) = 0$, $E(\zeta_{\beta i}) = 0$ are assumed for all individuals. In addition to the assumptions for the means [i.e., $E(\varepsilon_{it}) = 0$, $E(\zeta_{\alpha i}) = 0$, $E(\zeta_{\beta i}) = 0$], the correlations between the trajectory parameters (i.e., α_i, β_i) and the disturbance term ε_{it} are deemed to be zero.

Conditional Model. In order to examine the influences of socio-demographic, individual characteristics and travel attributes on the longitudinal changes in people's evaluations of the new bus service, moderators were used, which were divided into time-invariant covariates (TICs) and TVCs. TICs are moderators that do not change over time and only influence random intercepts and random slopes. The use of these quantities makes it possible to predict which individuals will have a relatively high initial value and which will have a relatively steep growth rate in the sample. Socio-demographic variables including gender, age, education level, employment status, car ownerships were represented as TICs influencing the inter-individual differences. In addition, travel attributes and individual personalities were taken into account. Individual personality, in terms of technological savviness, was measured by four items in the questionnaire applied in the third wave. We assumed that this feature did not change over time in the short term, so it was entered into the model as one of the TICs. Familiarity with the underlying technology was included as a TIC. Eqs. (2) and (3) for the second level of the model then become:

$$\alpha_i = \mu_\alpha + \sum_n \gamma_{\alpha n} x_n + \zeta_{\alpha i} \tag{5}$$

$$\beta_i = \mu_\beta + \sum_n \gamma_{\beta n} x_n + \zeta_{\beta i} \tag{6}$$

TICs are denoted as x_n ($n = 1, 2, 3, \ldots, N$), while γ_α and γ_β provide the expected difference in the individual trajectories for one unit change in the TIC. Thus, one unit change in x_n results in a change γ_α in the intercept and a change γ_β in the slope, compared with the baseline case.

TVCs are variables for which the values can change across time. Travel behaviors are deemed to be TVCs. Two travel attributes, the last week's usage of the AB service and the weekly use frequency of public transport as a connecting mode to the transit hub, were considered as moderators to explain the inter-individual difference in attitude change.

We observed that these two variables changed over time at three time points and were considered as moderators to explain the inter-individual difference in attitude changes. Hence, the individual trajectory function in Eq. (1) could be expressed as:

$$y_{it} = \alpha_i + \lambda_t \beta_i + \gamma_t \omega_t + \varepsilon_{it} \tag{7}$$

where ω_1, ω_2, ω_3 represent the TVC at each time point, and influence the repeated measures y_1, y_2, y_3 correspondingly.

Analysis and Results

Capturing the Average Intra-Individual Patterns of Service Evaluation Changes Through an Unconditional Model

We first examined people's evaluations of the AB service over time. Before applying the LGCM, factor scores were obtained for the "functional attribute" construct at each time point. The three indicators were merged into composites that could be considered a single repeated measure. The factor loadings for each indicator at the corresponding time point are displayed in Table 3, and it can be seen that all factor loadings were acceptable. The reliability of the model was tested by checking the composite reliability (CR) values; as shown in Table 3, all CR values exceeded 0.70, resulting in confirmation of the reliability of the measurement model. In addition, the criterion of the average variance extracted (AVE) is met at all three points in time, as all of the values for the AVE are above the threshold value of 0.50, thus demonstrating the convergent validity of the measurement model. Finally, all of the inter-construct correlations are listed in Table 4. All the correlations are less than the square roots of the AVEs, which are on the diagonal. Accordingly, the discriminant validity of the measurement model is tested. In summary, the composition of FA is proved from the perspectives of both reliability and validity. The values for the chi-square test statistics, CFI, TLI and RMSEA, also show that all conditional models have an excellent degree of fit.

After obtaining the composites of 'FA', the LGCM was applied based on three time points. The trajectory parameters for the four unconditional models were estimated separately, and the results are shown in Table 5. The functionality attribute has a significant intercept (coefficient = 1.589, p = 0.000) and slope (coefficient = 0.083, p = 0.000) of the mean trajectory for functional evaluations of ABs. These results indicate that respondents initially evaluated the travel speed and travel time of the AB service as unsatisfactory when comparing the service to a conventional bus and private modes of transportation,

Table 3: Measurement model estimates of the functional attributes at three time points

Construct	Item	Factor Loading	AVE	CR
(Wave I)	Perceived speed of an AB compared to a conventional bus	0.63	0.51	0.75
	Perceived travel time of an AB compared to a conventional bus	0.79		
	Perceived travel time of an AB compared to a private car	0.70		
(Wave II)	Perceived speed of an AB compared to a conventional bus	0.56	0.55	0.78
	Perceived travel time of an AB compared to a conventional bus	0.80		
	Perceived travel time of an AB compared to a private car	0.83		
(Wave III)	Perceived speed of an AB compared to a conventional bus	0.63	0.56	0.79
	Perceived travel time of an AB compared to a conventional bus	0.84		
	Perceived travel time of an AB compared to a private car	0.75		

Table 4: Matrix of the correlation and square root of AVEs for functional attributes

Correlation/Sqr(AVE)	Functional Attribute (Wave 1)	Functional Attribute (Wave 2)	Functional Attribute (Wave 3)
Functional attribute (Wave 1)	0.711		
Functional attribute (Wave 2)	0.554	0.739	
Functional attribute (Wave 3)	0.484	0.647	0.747

Table 5: Unconditional LGCM parameter estimates

	Variable		Parameter	Estimate	SE	p-Value
Functional	Intercept	(mean)	$\mu_{\alpha 1}$	1.589	0.030	0.000
		(variance)	$\Psi_{\alpha 1 \alpha 1}$	0.310	0.045	0.000
	Slope	(mean)	$\mu_{\beta 1}$	0.083	0.010	0.000
		(variance)	$\Psi_{\beta 1 \beta 1}$	0.030	0.007	0.000
	Covariance		$\Psi_{\alpha 1 \beta 1}$	−0.029	0.015	0.055
Safety	Intercept	(mean)	$\mu_{\alpha 2}$	3.901	0.048	0.000
		(variance)	$\Psi_{\alpha 2 \alpha 2}$	0.391	0.134	0.004
	Slope	(mean)	$\mu_{\beta 2}$	−0.077	0.021	0.000
		(variance)	$\Psi_{\beta 2 \beta 2}$	0.054	0.023	0.017
	Covariance		$\Psi_{\alpha 2 \beta 2}$	−0.089	0.052	0.085
Convenience	Intercept	(mean)	$\mu_{\alpha 3}$	3.053	0.039	0.000
		(variance)		0.265	0.073	0.000
	Slope	(mean)	$\mu_{\beta 3}$	0.015	0.015	0.322
		(variance)	$\Psi_{\beta 3 \beta 3}$	0.020	0.013	0.114
	Covariance		$\Psi_{\alpha 3 \beta 3}$	−0.030	0.028	0.284
Comfort	Intercept	(mean)	$\mu_{\alpha 4}$	3.535	0.038	0.000
		(variance)	$\Psi_{\alpha 4 \alpha 4}$	0.317	0.086	0.000
	Slope	(mean)	$\mu_{\beta 4}$	−0.027	0.016	0.090
		(variance)	$\Psi_{\beta 4 \beta 4}$	0.035	0.014	0.015
	Covariance		$\Psi_{\alpha 4 \beta 4}$.	−0.055	0.033	0.093

although these evaluations steadily increased. In other words, the AB service may not meet users' needs as a mode of public transport in the beginning stages, which may significantly reduce the level of service satisfaction. Thus, as a new and emerging mode of transport, ABs would increase operation speed and shorten travel time to improve high performance.

For the dynamic changes in the safety concerns over the AB service, the results show that both the intercept and slope of the mean trajectory for safety attribute are significant (intercept = 3.901 and slope = –0.077). These values indicate that the safety performance of the AB service is given a satisfactory rating, but that this shows a decreasing trend over time. The findings suggest that people feel safe on the AB when there is a steward on board, although that trust declined throughout the survey period. As an essential requirement of a mode of transit, a high level of safety of the transport service could promote overall satisfaction. These results indicate that there is a considerable risk that the perception of safety will decrease in the future, which will negatively influence the quality of service. As a critical determinant of service quality, perceptions of safety can significantly affect overall satisfaction, regardless of the actual level of performance. To maintain public perception of safety performance at the current level and to enhance passengers' trust in ABs, operators could introduce a steady transition from having a steward available as back-up to having no human supervisor on board.

The results indicate that respondents' perceived level of convenience on board ABs is good, and that an increasing frequency of public transport use positively influences the

perceived level of convenience. Furthermore, it can be observed that the attributes of comfort have a positive intercept (coefficient = 3.535, p = 0.000) and negative slope (coefficient = −0.027, p = 0.090) of the mean trajectory, indicating that the initial evaluation of general comfort is satisfactory but drops over time. As hedonic requirements, comfort and convenience are positioned in the top layer of the hierarchy of needs, and have significant positive effects on the overall service satisfaction. Thus, a downward trend in the ratings of these hedonic attributes needs to be prevented. The speed control pattern of the AB could be optimized to moderate the discomfort caused by acceleration and deceleration, and the overall comfort of the passenger experience could also be improved by refining the design of on-board amenities. Such countermeasures are expected to positively influence the evaluation of riding comfort, and subsequently to affect the overall service satisfaction.

The inter-individual variability around the intercept and slope of the mean trajectory was revealed by the variance parameters of each variable, i.e., the evaluations of functionality, safety, convenience and comfort. These results demonstrate the existence of fluctuations around the mean trajectory resulting from inter-individual diversity. Further analysis of these inter-individual differences therefore needs to be conducted through a conditional model, and the incorporation of moderator variables is required to better explain the variability in growth factors.

Capturing Inter-Individual Variability in Changes in General Service Evaluation through a Conditional Model

To identify which factors contributed to the inter-individual variabilities around the mean trajectory pattern of the whole sample, socio-demographic aspects (i.e., gender, education level, employment status, car ownership), individual characteristics (i.e., attitude towards technology and familiarity with underlying autonomous driving technology), and travel attributes were considered as explanatory variables in the conditional models. The repeated measures were regressed on the TVC. The selected TVCs were: (1) the weekly frequency of using public transport to connect to the transit hub; and (2) the frequency of use of the driverless shuttles over the previous week. The remaining random parts of the intercept and slope were regressed on the TICs.

This part of the study examined how the use frequency of public transport influenced the evaluations of the AB service. As shown in Table 6, increasing frequency of use of public transport is found to be significantly positively influenced by the public's perceptions and evaluations of functionality, safety and convenience in general. Although the predictive effects of public transport use in the first and third waves are partially insignificant, the positive effects of public transport use are non-negligible; the more frequently people use public transport (e.g., metro and conventional bus) as a feeder mode, the more satisfactory their evaluations of the service. Hence, current public transport passengers are one of the potential user groups who are most likely to adopt the AB service.

Nevertheless, experience of taking an AB is not found to have a consistent impact on the reported trip comfort, as would be expected. This is probably because the third interview was carried out in winter, and the weather conditions (i.e., temperature and daylight hours) were worse than in the first two waves. For this reason, in the third

Table 6: Estimates of TVCs

Predictor Variable			Estimate	SE	p-Value
Functionality	Frequency of using public transport	(wave 1)	0.035	0.059	0.100
		(wave 2)	0.046	0.064	0.025
		(wave 3)	0.013	0.069	0.582
Safety	Frequency of using public transport	(wave 1)	0.035	0.041	0.393
		(wave 2)	0.074	0.033	0.023
		(wave 3)	0.034	0.039	0.393
Convenience	Frequency of using public transport	(wave 1)	0.011	0.032	0.744
		(wave 2)	0.052	0.025	0.034
		(wave 3)	0.077	0.029	0.008
Comfort	Experience of using the automated bus service	(wave 1)	0.168	0.139	0.227
		(wave 2)	0.226	0.123	0.067
		(wave 3)	−0.495	0.110	0.000

wave, people who were actively using the service were more likely to report a lower perception of comfort with the AB. The explanation for this is supported by a study by Ettema et al. (2017) that highlighted the effects of weather variables on travel satisfaction in Sweden noted that winter in Sweden is characterized by cold temperature and few hours of daylight, while sunshine and higher temperatures make commuters more relaxed and satisfied. This suggests that the negative influence from the current usage of the AB on comfort perceptions in the third wave can be convincingly explained by the season factor.

The study also examined the influences of socio-demographic characteristics and travel attributes on longitudinal changes in users' evaluations of the AB. As shown in Table 8, none of the TICs had significant effects on the intercept factor for functionality evaluations. In regard to the explanation for the slope factor, we note that gender, age, and education level all had significant impacts. The results show that males gave the same initial ratings as females, but that their ratings of the functional performance of the ABs fell faster. Moreover, although their ratings started at the same level, the attitudes of people older than 45 changed more quickly in a positive direction than those of younger people. It was also clear that highly educated people rated the speed and travel time of the AB in the same way as others at the beginning, but that their ratings declined slowly, and that they initially rated the on-board convenience more highly and their ratings were reduced slowly. Thus, the findings suggest that the ratings given by highly educated people for the service characteristics were more stable than others. However, it is worth noting that although gender, age, and education levels were all found to be statistically significant in influencing the changes in functionality evaluations over time, the sizes of these changes were relatively small. More follow-up studies will need to be done to examine the differences between different types of respondents regarding functionality performance.

With regard to the perception of safety, employment status was found to have a significant predictive effect on the growth factors, indicating that the ratings of the safety performance of ABs given by employees were reduced more slowly than for the unemployed group. These findings reveal that people started with considerable faith in the safety of the new bus service, followed by a slow decline, whereas the employed status helped alleviate this recession trend with time.

Similarly, gender and education level were found to have an influence on evaluations of on-board convenience. The results show that men initially rated the on-board convenience of the AB at the same level as women, but with a lower rate of decline in their

ratings. Highly educated people were slightly unsatisfied when they took the AB for the first time, while a propensity of resistance to decline was found for the highly educated group compared with other groups. The reverse effects were found for familiarity with autonomous driving technology.

As shown in Table 8, car owners gave lower initial ratings for general comfort compared to respondents with no car in their households. These results indicate that people who have access to private mobility (i.e., with at least one car in the household) appear to feel a lower degree of comfort with the AB service. This argument is in line with previous findings that licensed drivers were less willing to use shared automated vehicles frequently (Bansal et al., 2016; Nordhoff et al., 2019). Furthermore, cumulative riding times significantly explained the variability in the slope factor. These findings imply that although the evaluations given by respondents decreased over the survey period, the more times they rode the AB, the more slowly their evaluation of general comfort decreased over time. Over recent decades, according to the unified theory of acceptance and use of technology (UTAUT), increasing exposure to new technology has led to a more positive attitude towards it. It is also confirmed by this study that more experience of taking this form of public transport has an influence on resistance to the decreasing trend of perceived comfort. More specifically, the comfort ratings given by adopters who used the service more than five times were not reduced over time, and even increased as more rides were taken.

All of the conditional models described above were created based on all respondents, although non-adopters, as a large group of potential users, are also of research interest. To understand the predictive effects of knowledge and attitudes towards technology for the perception of general comfort by non-adopters, four items were selected and incorporated into a latent construct entitled "attitude towards technology." All of the factor loadings shown in Table 7 exceed 0.60, indicating sufficient reliability of the measurement model. We note that the reliability construct was tested based on a CR value of 0.88 (larger than the reasonable value of 0.60), while convergent validity was confirmed by an AVE value of 0.64 (larger than the cutoff value of 0.50).

In the same way as for the model based on all respondents, the ratings given by non-adopters for general comfort started with a satisfactory perception and declined over time. However, as shown in Table 8, in line with the well-proven effect of technological savviness on acceptance of automated vehicles (Nordhoff et al., 2019), individual attitudes towards technology and knowledge about driverless technology were verified as having positive impacts on the comfort evaluations of the AB service. These findings indicate that a good knowledge of autonomous technology results in an increasing trend in respondents' evaluations of ride comfort. At the same time, a general passion

Table 7: Reliability and validity test of the latent construct "attitude towards technology"

Construct	Statement	Factor Loading	AVE	CR
Attitude towards technology	It is important for me to follow technological developments.	0.73	0.64	0.88
	I am always among the first to try to use new technology products.	0.84		
	I am excited about the possibilities of new technology.	0.86		
	I know more than others about the latest technology products.	0.80		

7-point Likert scale from 1 – completely disagree to 7 – completely agree

Table 8: Coefficient estimates for time-invariant covariates

Predictor Variable			Estimate	S.E.	p−Value
Functionality	Gender	Intercept	−0.046	0.059	0.435
		Slope	0.037	0.020	0.063
	Age	Intercept	0.036	0.064	0.572
		Slope	−0.036	0.022	0.095
	Education level	Intercept	0.003	0.069	0.970
		Slope	−0.057	0.023	0.013
	Constant	Intercept	1.512	0.068	0.000
		Slope	0.104	0.028	0.000
Safety	Employment status	Intercept	−0.169	0.109	0.122
		Slope	0.090	0.048	0.061
	Constant	Intercept	3.922	0.140	0.000
		Slope	−0.154	0.065	0.018
Convenience	Gender	Intercept	−0.106	0.078	0.172
		Slope	0.066	0.030	0.028
	Education level	Intercept	−0.220	0.090	0.015
		Slope	0.063	0.035	0.076
	Familiarity with autonomous	Intercept	0.164	0.095	0.084
	driving technology	Slope	−0.021	0.037	0.575
	Constant	Intercept	3.104	0.098	0.000
		Slope	−0.090	0.043	0.034
Comfort	Car ownership	Intercept	−0.157	0.088	0.075
(adopters)		Slope	0.051	0.037	0.163
	Cumulative riding time	Intercept	−0.002	0.059	0.977
		Slope	0.064	0.025	0.010
	Constant	Intercept	3.661	0.080	0.000
		Slope	−0.083	0.033	0.013
(non-adopters)	Attitudes towards technology	Intercept	0.086	0.042	0.038
		Slope	−0.020	0.018	0.271
	Familiarity with autonomous	Intercept	−0.104	0.125	0.402
	driving technology	Slope	0.130	0.054	0.016
	Constant	Intercept	3.573	0.051	0.000
		Slope	−0.061	0.022	0.005

for innovative technology gives rise to a slightly higher initial perception of comfort. Non-adopters with more enthusiasm for technology tend to perceive a higher comfort level for ABs, with a rise in their ratings over time. Hence, targeted propaganda tactics should be applied to tech-savvy user groups; for example, operators could cooperate with technology bloggers and YouTubers to create a good reputation for the AB service on the Internet. When content creators share their ride experience via social networking platforms, they help to improve the public's awareness of the latest technological upgrades of shared automated vehicles. Subsequently, people who are passionate about emerging technologies will become interested in experiencing the shuttle service. Ultimately, the future adoption rate among tech-savvy people is expected to improve.

Discussion and Policy Implications

Developments in vehicle automation technology have been rapid. To enable a successful transfer of ABs from the demonstration stage to a feeder service on a regular basis, it is imperative to continuously monitor the public's attitudes, as these affect user acceptance. However, most previous studies have been based on cross-sectional data, and an understanding of the temporal changes in the attitudes and perceptions of this new form of public transport over the long term is lacking. The majority of existing research has also focused on projects located in science and technology parks, or on short-term

trial operations with limited traffic conditions and operating hours, making it difficult to observe the real changes in people's attitudes. To fill this research gap, a longitudinal analysis was conducted to understand people's intention to adopt a regularly scheduled AB service operating in a mixed traffic environment on public roads. The results of our study reveal that as time elapses after the AB is put into operation, people gradually perceive the speed and travel time to be faster than their initial expectations, while also expressing more concerns in regard to safety, comfort, and convenience. This study contributes to the existing literature by identifying changes in attitude towards ABs that have not been previously reported. The study also gives rise to new findings, such as elderly individuals exhibiting a more rapid shift towards a positive evaluation of service quality, and more highly educated individuals being less satisfied with service quality when first introduced to the AB. Understanding the differences in attitudes among specific groups will help in the targeting of education and promotional campaigns. The findings of this study are important in terms of advancing the implementation of ABs from laboratory and trial operation to real-world traffic environments.

The findings of this research indicate that the ratings of functional attributes started relatively low and increased steadily, while users perceived the safety, comfort and convenience of the AB service as being satisfactory, but that these assessments underwent a moderate decline over time. Although the majority of respondents agreed that they felt safe during the bus ride, in the future, when there is no steward on board, the perception of safety performance might be adversely affected, giving rise to a considerable reduction in overall riding satisfaction. To encourage the future adoption of this new public transport system, it is vital to promote favorable evaluations of service quality. In general, the two sets of potential users who are most likely to adopt the automated bus are current public transport users and tech-savvy people. Having identified these user groups, targeted measures can be developed to better stimulate the conversion of potential users into adopters. For instance, a special discount on SL tickets for the AB may be appealing to public transport users, leading to a shift from conventional buses to ABs. Decision-makers could integrate ABs with other available transportation modes in a MaaS package, providing seamless and integrated intermodal travel. The findings also suggest that it would be valuable to display more updating achievements of the ABs in e-journals and to cooperate with content creators (e.g., technology bloggers and YouTubers) in terms of sharing their experiences to the Internet, so that more people who are passionate about emerging technologies will have a better awareness of the latest technological upgrades to shared automated vehicles, thus generating interest in experiencing an AB service.

The findings also indicate that males, elderly people, highly educated people and employed people are the specific user profile characteristics with a positive influence on the rate of changes in respondents' ratings of service quality. Car owners and highly educated people were less satisfied when they were interviewed about the quality of the AB service for the first time. Lastly, the greater a respondent's experience and knowledge of vehicle automation technology, the more favorable their evaluation.

There are several limitations of this study, which offer potential for future research. Firstly, the hypothesized relationships between variables were examined with restricted numbers of observed items (i.e., the safety attribute was measured by a single item) and based on a relatively small sample (363 responses), which might lead to implications not as expected. In future research, it will be important to refine and tailor the items

measuring service quality, and to attempt to examine the hypotheses based on a larger and more representative sample. Secondly, the inter-individual variability around the intercept and slope of the mean trajectory of various factors such as functionality, safety, convenience, and comfort were examined in this study. The results demonstrate the existence of fluctuations around the mean trajectory resulting from inter-individual diversity. In future research, we will seek to incorporate additional control variables, such as weather patterns and other environmental factors, to better isolate the impact of the AB service on attitude changes. Thirdly, as the quality of the AB service improves, evaluations of this new public transport service should change over time. A longitudinal tracking study could be repeatedly conducted in the future to understand the public's attitudes towards and perceptions of ABs.Notes on Contributors

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No potential conflict of interest was reported by the author(s).

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