9. Lessons from the deployment of the world's first automated bus service on a mixed public road in Stockholm

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9.1 HUMAN, CITY, AND AUTOMATED FUTURE

To achieve a human scale city, in particular 'safe, affordable, accessible and sustainable transport systems for all' (UN, 2019), technology and innovation have been promoted by both authorities and industries to enable viable solutions. Automation and digitalization of transport and mobility systems are at the centre, and enabled several solutions that have been strongly echoed through urban and transport research communities. For example, Milakis et al. (2017) argue that automation will reduce the wasted value of travel time, and subsequently the total costs of travelling by private cars. As fully automated vehicles could perform some activities on their own – for example, picking up shopping, or dropping off children at school – there will be journeys which essentially overcome today's individual time and space constraints (Bagloee et al., 2016; MANTRA, 2019). For further extensive reviews of the plausible impacts of automated vehicles, McGehee et al. (2016), Milakis et al. (2017), Innamaa et al. (2017) and the MANTRA (2019) project report provide a comprehensive description of the plausible societal impacts and policy implementation challenges. Hoogendoorn et al. (2014) discussed the roles of human factors and expected traffic impacts; Chee et al. (2020a) and Nordhoff et al. (2019) reported on automated vehicle (AV) technology acceptance for daily travel; and Do et al. (2019) reported on design and control of the automated vehicle system. More recently, Soteropoulos et al. (2019) provided a systematic overview of different modelling approaches that have been used to explain the impacts of automated vehicles on travel behaviour and land use characteristics.

Although state-of-the-art research studies are very compelling, in reality we hardly know what is really going to happen when self-driving vehicles

are deployed. Most of the literature on use cases for self-driving vehicles is heavily biased towards transportation systems based on (shared) autonomous taxis, and their performance as an alternative to private car usage (e.g., Chen and Kockelman, 2016; Meyer et al., 2017; OECD, 2015), or routing strategies for such systems (e.g., Han et al., 2016; Suganuma and Yamamoto, 2016). Literature on self-driving vehicles in public transport is even more limited, and provides primarily two types of applications. These applications are: complete systems of smaller self-driving vehicles that replace existing public transportation; and first/last mile transportation services, for example, between a public transportation hub and the user's home/work location (Pernestål-Brenden and Kottenhoff, 2018). Many authors (e.g., Guo et al., 2020; Soteropoulos et al., 2019) question whether the assumptions and approaches of such studies are realistic. Several studies (e.g., Milakis et al., 2017; Hoogendoorn et al., 2014) highlighted the unpredictability of individual responses. Furthermore, some studies (e.g., Mladenović, 2019) highlighted plausible negative impacts of the use of active travel modes, and the inequality issue that comes with them. Based on the uncertainties mentioned above, it is extremely important to have a reflection process based on a revealed observation of a real deployment of the technology.

To address the above-mentioned research gap, this chapter provides readers with an overview of lessons learned from an automated bus deployment on a public road in Sweden, and the adoption behaviour surrounding the technology. Further detailed results of each analysis summarized in this chapter can be found in the relevant referenced publications.

9.2 A STEP INTO THE UNKNOWN: DEPLOYING AN AUTOMATED VEHICLE ON A PUBLIC ROAD

In 2018, the Autopiloten pilot project was launched in Sweden. This pilot was a step into the unknown of self-driving vehicles to explore the technology capability in real-life traffic conditions. Located in the north of Stockholm, the project aimed at testing the first self-driving bus as a regular service in Kista, Sweden's Silicon Valley. The project partners were Nobina AB, Ericsson, the city of Stockholm, KTH, Drive Sweden, Klöver and SJ (the Swedish rail company). Operationally speaking, two vehicles, small buses with seats for 12 passengers (six seating and six standing, including the steward) were in service on weekdays from 24 January 2018 to 22 June 2018. The operation was free of charge for the public.

The vehicles used in the test were of the brand EasyMile EZ10 generation 2. The speed during the first four months was a maximum 12 km/hour, and afterwards the speed was raised to a maximum of 15 km/hour. The number of travellers during the trial ended at 20 165 people, giving an average of 182

per day, which is higher than expected. The expectation was lower due to the limited mileage and lack of connection to other public transport services and main residential areas (as this was the first ever development of the technology on a public road, the permission given was rather limited). Electricity consumption for transporting 20 165 persons was 2948 kW/hour. With regard to the battery capacity, the buses could be in operation for about 6–7 hours in winter without charge, and during the summer worked for longer hours.

To evaluate users' responses and system-level impacts of this technology deployment, a three-wave survey of more than 500 respondents was administered within the six-month trial operating period, and a professional survey company was employed to conduct the survey. The respondents were recruited by the survey company to take part in all three rounds of online surveys throughout the period from February 2018 to June 2018. The participants who completed all three rounds of surveys were entitled to participate in the contest to win one of ten cash prizes worth 1500 SEK. The survey focused on potential users of the service: people who work, study or live near the trial operation area (the Helenelund commuter train station, and Kista Science City). This area is a science and technology park, hosting many prominent technology companies as well as a technical university. Further information about the project, and the summary of results of all its activities, can be found in Pernestål-Brenden et al. (2018).

9.3 USERS' INTENTIONS, EXPECTATIONS AND REACTIONS

In this section, we focus the discussion on a few basic issues on human adoption of the deployed technology, which are important for our operators and authorities to reflect on whether they will make further investment in this new transport technology. First, we briefly explore the factors that may encourage individuals to use the automated service. Then, given these factors, we discuss what would influence the users' willingness to pay, given different types of possible service deployments. This particular topic is important as no innovation will be adopted by industries without knowing that there is a solid business case and viable business models to be gained from such investment. Lastly, we explore how other road users reacted to this automated shuttle in real-life cases. As the basis of these analyses, a three-wave panel survey was conducted among 500 people who live and work along the serviced corridor. Light detection and ranging (LIDAR) data¹ for a limited time was collected in order to get a glimpse of the interaction between the automated bus and pedestrians, private cars and other road users, in the given road space. The complete analyses of each of these cases can be seen at Chee et al. (2020a, 2020b, 2021, forthcoming).

9.3.1 Factors that Influence Willingness-to-Use

When it comes to socio-demographic characteristics which are found to be significant in affecting acceptance of automated buses, previous studies (e.g., Bansal et al., 2016; Meyer et al., 2017; Salonen, 2018) show that age, gender, income, technology awareness and using multimodal preference are consistently found significant. In terms of service quality attributes, on-board safety, existence of steward, comfort, travel time and travel fare matter. However, the appreciation of these variables is not constant over time, in line with the learning curve of the users (Guo et al., 2020). Thus, in investigating the factors that influence the willingness-to-use, we tested a conceptual model explaining the transition of pre-use value to post-use value, and their effects on willingness to use a shared automated bus before and after use of the service (as shown in Figure 9.1).

The detailed estimation results of the model shown in Figure 9.1 can be found in Chee et al. (2021). In a summary, we found that continuous adoption of first-/last-mile automated bus service does not depend solely on the users' pre-use perceptions (expectations of the service) but also on the post-use perceptions of the service (levels of satisfaction with the service). Results show that users' judging criteria of the service changed after using the service. The issues affecting the users' willingness to use the service before experiencing the service might become irrelevant after the use of the service. Therefore, modelling travel demand of such service only based on pre-use perceptions may result in fallacies of the prediction.

9.3.2 Factors that Influence Willingness-to-Pay

Figure 9.2 shows the distribution of the willingness to pay for: (1) on-demand personalized automated vehicle (PAV) service; (2) shared automated vehicle (SAV) service; and (3) first-/last-mile automated bus (AB) service. Almost half of the respondents (44 per cent) were not willing to pay an additional fee on top of their monthly travel pass for an AB service (which is currently (summer 2020) approximately €90/month for a working adult). The distribution of willingness to pay for a PAV service is more evenly distributed than others: 16 per cent of the respondents were willing to pay up to 200 SEK (about €19) to gain access to a PAV service given the same travel distance. Surprisingly, about 12 per cent of the respondents were willing to pay more than 400 SEK (about €38) on top of their monthly travel pass (Chee et al., 2020a).

Further exploration with structural equation modelling shows that cognitive responses such as service quality perceptions are significant to people's willingness to pay for automated vehicle services. Chee et al. (2020a) reported that people hold different expectations towards each type of AV service.

Source: Chee et al. (2021).

Figure 9.1 Framework to examine the changes of willingness-to-use before and after use of the service

Source: Chee et al. (2020a).

Figure 9.2 *Distribution of willingness to pay for three different automated vehicle service types*

These expectations act as the minimum requirements for people to pay for the AV services. In detail, the respondents are willing to pay more for a PAV service if the service is safe, provides good ride comfort, and they perceive that the service provides better value for money compared to the metro and train alternatives. Other than service quality attribute perceptions, income level, existing travel modes for daily trips, familiarity with automated driving technology and automated bus ride experience are important factors affecting the willingness to pay for the services. These align with the past findings by Bansal et al. (2016). Further detailed analysis on this issue can be seen at Chee et al. (2020a).

9.3.3 **What Matters More in Delivering the Service?**

To make the service attractive for the users, we need to improve the service quality attributes that matter for the service adopters. The majority of previous studies assumed that the relationship between attribute-level performance and overall satisfaction is linear and symmetric (e.g., Susilo and Cats, 2014). However, there is evidence (e.g., Kano et al., 1984; Matzler et al., 2003) to suggest that the service and product attributes have distinct relationship patterns between attribute-level performance and overall travel satisfaction. To

overcome these limitations, the three-factor theory is applied to capture the complexity underlying the relationships between the perceptions and the intention to use a first-/last-mile automated bus service by statistically separating the quality indicators into three categories:

1. Basic factor: when attributes belonging to this category are well delivered, they do not positively influence overall satisfaction, yet when delivered poorly they induce dissatisfaction.
2. Performance factor: this category of attributes can contribute to both satisfaction and dissatisfaction, depending on whether their performance is high or low, respectively.
3. Exciting factor: this category is the reverse of the basic factor. Attributes belonging to this category are unexpected attributes that can only bring joy and satisfaction with the service.

The theory is not widely used in transport, but a few examples of these can be seen in Abenoza et al. (2019), Wu et al. (2018) and Zhang et al. (2017). Detailed estimation of this can be seen at Chee et al. (2020b). The estimation result reveals different levels of essentiality of service quality attribute perceptions in affecting intention to use automated bus services among experienced users, inexperienced users, and all users. It was found that whilst for non-experienced users travel time and fare, compared to regular service, linearly associated with travellers' travel satisfaction, only frequency was found to have similar relationship for the experienced users. Affordable travel fare is a basic expectation for experienced users, whilst ride comfort is a bonus for both experienced and non-experienced users.

9.3.4 On-Road Interaction between Automated Buses and Other Road Users

Whilst it is widely assumed that automated vehicles would enable us to maximize the use of road space (e.g., OECD, 2015), it is not clear whether during the early-stage deployment of automated vehicles on the public road this would be the case. To anticipate different plausible road users' interactions with the automated vehicle, most previous studies used either lab experiments (for example, virtual reality simulation) or a controlled field experiment or a video analysis of comparable real-life road interaction cases. The last two approaches have challenges in dealing with privacy protection issues, in particular if we would like to have a longer observation in order to identify the variance of the interaction behaviour. Using the opportunity that we had through the automated bus deployment, we collected LIDAR footage of other road users' interactions with the operated automated bus. As we are not

allowed to access the data collected by the factory built-in sensors, additional LIDAR sensors were installed on the automated bus on operation.

During the observed route, the highest number of occurrences was pedestrians crossing the road without crossing facilities when encountering the vehicle. Out of the 55 observed encounters between pedestrians with the automated bus, there are 30 encounters where the pedestrian took a conscious deflection movement path. Detailed analyses of this dataset can be seen at Chee et al. (forthcoming). Results show that while different groups of road users react differently, the alert distance between an observer agent, for example, pedestrian to cross the road without using crossing facilities, when encountering an incoming automated bus is between 30 metres to 40 metres. Pedestrians accelerated when they crossed the road with distance less than the alert distance.

9.4 CONCLUDING REMARKS

9.4.1 Lessons from the Deployment: The Limitation of Technologies, Users' Unique Travel Needs, and Business Case Framework

There are high expectations for driverless vehicles: that they will provide on-demand mobility services door to door at a low cost. However, the Kista trial results so far (and also elsewhere) show that the technology is currently not able to deliver these services. Consequently, there is a gap between people's expectations of the driverless vehicles and the actual performance of the automated buses, among users, urban planners and mobility operators. Simulations in the research literature show that in ideal cases there is a large potential to replace private cars with shared mobility services (for overviews of simulation results see, e.g., Pernestål and Kristoffersson, 2019; Soteropoulos et al., 2019). In reality, there are still many challenges to overcome (the vehicles are slow, people feel unsafe, and so on). Thus, it is important to be cautious while developing and exploring the current state of technology from a holistic point of view. Simulations, with restrictions on the vehicle's performance (for example, limited speed), can show what parameters are important to develop in order to provide effective services.

It is also important to continue testing the automated vehicles and the services in real trials and deployments, to improve the technology and to let people learn about it. This research has shown that users put high value on feeling safe and secure on board the automated vehicles, and that most of them want to have a steward on board. This challenges the operators' goal of driverless operation to reduce operational costs. This fact is important to consider for operators when developing their operational model, as it might not be feasible to have a completely driverless operation. There are also several technologies

that can be applied to increase the experienced safety on board: for example, control towers that allow for remote operation (Mårtensson et al., 2018), and social robots that can inform and interact with passengers (see, e.g., Furhat Robotics, 2020).

On the users' side, given that people are exposed to an unknown technology, it is important to allow people time to learn, to develop their understanding and to adjust their expectations towards the technology. This is not only for the passengers who use the service, but also for the other road users who share the same road space. This highlights the importance of having a design thinking approach (Veryzer and de Mozota, 2005) in designing a new (public) transport service with new and unusual technologies. In doing so, the choice of the locations of future automated vehicle pilots will play an important role in elevating user acceptance and, potentially, their willingness to adopt the technology.

9.4.2 As a Possible Tool in Supporting a Human Scale, Happy, City

In the last few years, big transport and economic organizations, such as the International Association of Public Transport (UITP, 2017), have consistently argued that automation of the transport system would give benefits of reductions in road fatalities and environmental impacts, and improvements of road traffic parameters such as average travel time and road capacity; the same promises which the World Economic Forum (2018) and many other authorities (e.g., OECD, 2015; EU, 2017) also promoted; that is, as a solution in creating a 'human scale city', 'liveable city', 'sustainable city', 'inclusive city', and the like.

The results described above provide different views, which highlights the importance of deeper reflections from both industries' and stakeholders' points of view. The technology is still very premature, and far from satisfying. Upon technological maturity, increase of speed and safety of the automated buses, future deployment should take into account the needs, the demand and cognitive elements of those demands, as those elements are crucial in attracting and establishing the market of the given service. The study highlights the fact that there will be no single service delivery strategy that fits all groups of users. Different user groups appreciate different quality service attributes, which are also influenced by their level of adoption of the given transport technology. How this aspect will be addressed by the stakeholders in reality will be an interesting subject to follow and observe.

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NOTE

1. The dataset consists of measured distance from the LIDAR sensor on the corner of the bus to surrounding objects, measured via pulse laser sensor(s) which illuminates the target surrounding the moving bus.

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