6 Automation, public transport and Mobility as a Service: Experience from tests with automated shuttle buses

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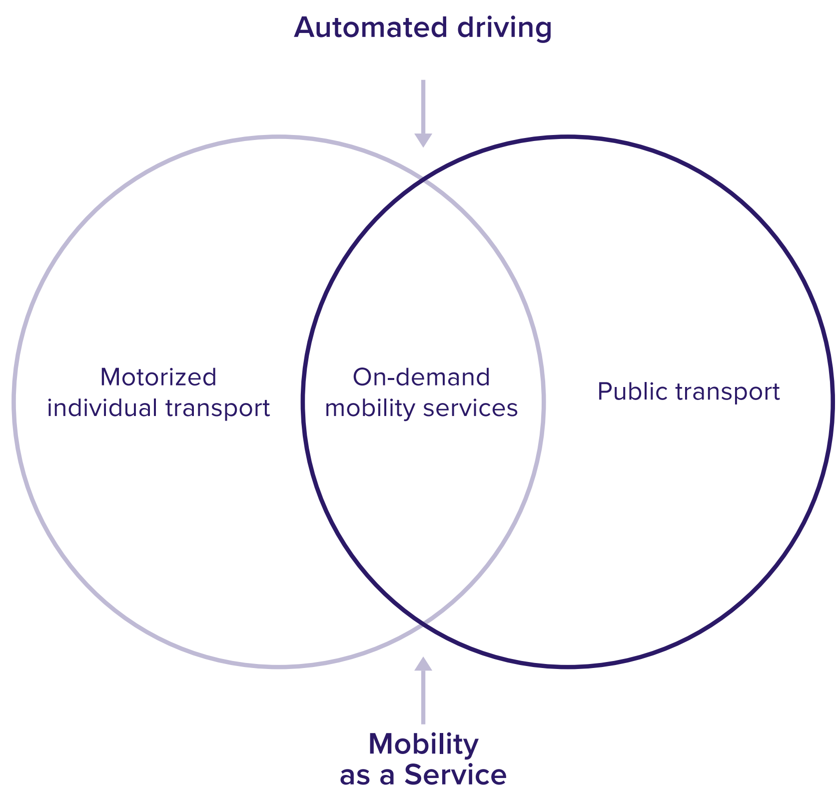
1. INTRODUCTION

Automated driving will fundamentally transform future mobility and will also affect public transport. In this context, there is often talk of a further shift of the boundaries between classic public transport and motorized individual transport, with an area of transition in public individual transport with automated vehicles, or an individualization of public transport (cf. Lenz/Fraedrich 2015: 189; Röhrleef 2017: 15; Bruns et al. 2018: 12; Barillère-Scholz et al. 2020: 16): already today, mobility is becoming differentiated through new forms of services such as car sharing and ride hailing.

Especially in cities, new mobility service providers are offering demand-oriented, individualized transport options – so-called on-demand mobility – thereby extending the mobility offer, which will continue to expand in view of the advance of digitalization (cf. Barillère-Scholz et al. 2020: 15; Buffat et al. 2018: 90; Lenz/Fraedrich 2015: 183). The technological development of automated driving provides opportunities to develop unprecedented business models that will open up the market to further providers: it is conceivable that automation will bring about disruptive developments in the mobility sector and a further transformation of the forms of service offered today (cf. Gertz/Dörnemann 2016: 5). Mobility as a Service (MaaS) is also becoming increasingly significant: this entails combining public and private transport offers, along with different modes of transport, by means of a uniform digital access portal (platform or app), thus offering customised mobility solutions that cater to individual requirements (cf. EPOMM 2017; Jittrapirom et al. 2017: 14).

Automated driving on public roads is also expected to offer potential for improving the economic efficiency of public transport, if personnel costs can be reduced: if a driver is no longer needed and new supplementary forms of service in the form of smaller, more versatile units are provided, and if vehicle concepts are increasingly matched to current demand, there will be greater scope for more economical, efficient and demand-oriented use of mobility services (cf. Hörl 2020: 2; Hörl et al. 2019: 60; Bösch et al. 2018: 7; Gertz/Dörnemann 2016: 22) – even if new or additional costs arise in some cases, for example for scheduling systems or for additional personnel to repair and clean the vehicles (cf. Bruns et al. 2018: 5). Furthermore, unlike the often long-term licensing arrangements in use today, which normally do not allow for any significant modifications or adjustments, the new forms of service make it possible to direct offers more towards individual personal needs, to make specific adjustments and thus to make public transport more attractive and stronger (Barillère-Scholz et al. 2020: 15).

Figure 1: Shifting the boundaries between public transport and motorized individual transport



Source: the authors

Numerous pilot projects are currently being conducted for automated driving on public roads, in the course of which automated technologies are being put into practice at an early stage in selected application cases, and new transport services are being created and holistic vehicle concepts developed. These projects ensure that the operation of on-demand mobility services, data-based traffic analysis and platform solutions are ready today for the automated mobility of tomorrow. The aim here is to provide system modules as a perspective to enable customers such as transport providers, municipalities and cities to operate new forms of mobility in public transport (cf. Barillère-Scholz et al. 2020: 18).

Especially in German-speaking countries, the pilot projects for automated driving on public roads currently focus on the test operation of automated shuttle buses. These run on specially approved, fixed routes and are for the most part still accompanied on board by safety drivers or operators. In most of these projects involving automated shuttle buses, the tests focus on aspects of technological, organizational, operational and economic feasibility (cf. Jürgens 2020).

On the basis of experience gained in a number of pilot projects with automated shuttle buses, this chapter specifically addresses the aspects of (1) technological feasibility and the possibility of operating in streetscapes, and (2) integration of automated shuttle buses into existing public transport systems.

For this purpose, the relevance of automation for public transport is first presented and various use cases of automated driving in public transport are shown. The chapter then specifically examines the use case of automated shuttle buses and provides an overview of the various tests with automated shuttle buses being conducted in Europe, above all in German-speaking countries.

The technical and legal aspects of testing automated shuttle buses will then be illustrated using the example of the “autoNV OPR” project in Ostprignitz-Ruppin in Germany, and the experience gained in operating and integrating the shuttle bus into the existing public transport system will be examined in more detail using the “MyShuttle” project in Zug, Switzerland. Finally, a summary is given of the main findings from the two example projects, along with a derivation of implications for planning and policy.

2. PUBLIC TRANSPORT: CURRENT FORMS OF OFFER AND FUTURE USE CASES OF AUTOMATED VEHICLES

Public transport fundamentally covers all passenger transport offers provided on a regular, commercial basis. These are largely characterized by shared use that is accessible to all under the same conditions (cf. Hörold 2016: 38; Bruns et al. 2018: 15). Since the provision of public transport services is a largely public task within the framework of services of general interest for mobility (cf. Rollinger/Amtmann 2009: 6), public transport services usually do not fully cover their operating costs and are thus publicly subsidized. Public transport services also have the following characteristics, which as a rule are legally founded and thus include the familiar, now largely fixed elements of public transport services such as departure times, stops and routes (cf. Bruns et al. 2018):

- Operation by authorized transport companies on licensed lines or routes
- Obligatory timetable: devising and publishing a timetable
- Obligation to operate: carrying out the published offer, independently of external conditions or momentary demand
- Obligatory tariffs: fixing and publishing conditions of carriage and fares.

In addition to the more classic scheduled transport services, however, some forms of service are more strongly oriented towards the individual needs of passengers through flexibilization of departure times (on-demand transport) and of routes/lines and variable stops (without fixed stopping points) or a combination of these elements (cf. Bruns et al. 2018: 15). A distinction can be made here between flexible forms of service, i.e. micro public transport systems or on-demand services, and alternative forms of service such as car or ride sharing. Sommer (2018: 3f.) speaks in this context of the publicly accessible offers of an “extended” public transport service. Table 1 gives an overview of the various current forms of public transport services. However, elements of the flexible forms of offer are also often combined with those of the alternative forms (e.g. registration of use, etc.).

Table 1: Overview of the characteristics of different forms of public transport services

	Classic regular service	Flexible forms of service	Alternative forms of service
Charac-teristics	Fixed service, timetable and clearly defined route	For use in times and areas of low demand	Usually permit-free and no guarantee of carriage, one-time registration or application required (except for social driving service)
Examples	• Superordinate basic rail-bus network • Local scheduled transport for area coverage	**With timetable:** • Linear service area (line service on demand) • Corridor service area (usually two fixed stops): travels to requested stops (e.g. call bus) • Sector service area (one connection point): sector operation (e.g. ring-and-ride, feeder service) **Without timetable:** • Zonal service area and with trip grouping (zonal operation or zonal service)	**Passenger as ride-sharer:** • Private ride provider • Ride-pooling: provider = transport, taxi or rental car company with obligation to operate, obligation to carry, compulsory travel area and tariff requirements • Ride sharing (public transport offer): journey takes place even if no third person rides or if only persons ride who did not order via a platform; without obligation to operate, obligation to carry, compulsory travel area or tariff requirements (e.g. BlaBlaCar) • Ride-selling and ride-hailing: provider = commercial platform provider such as Uber, Moia etc. without obligation to operate, obligation to carry, compulsory travel area or tariff requirements • Social institution/association as ride provider: social ride service, passenger as self-driver • Car sharing (station-based/“free-floating”): public car
Means of transport	Underground, commuter/regional train, tram, articulated bus, standard bus, minibus (citizens’ bus), shuttle bus	Standard bus, call bus, minibus, shuttle bus, van, call-sharing taxi	Shared taxi/van/car, single taxi/car

Source: the authors, based on BMVI (2016) and Sommer (2018)

The extension and combination of classic scheduled transport with flexible and alternative, and in this case also private, forms of service is currently under discussion above all in the context of Mobility as a Service (MaaS). This combination is implemented via a uniform digital access portal (e.g. platform, app). The mobility offer allows interaction between different modes in such a way as to best meet various personal needs – i.e. individually tailored mobility solutions are offered (cf. EPOMM 2017; Jittrapirom et al., 2017: 14). According to this idea, MaaS should improve the efficiency both of existing mobility systems and of public resources (cf. Hoadley 2017: 5ff.).

In view of the existing forms of service in extended public transport, automated driving provides options for further differentiation of the service, along with opportunities for redesigning inter-mobility, for further flexibilization and individualization, and for temporal and spatial densification of the service (cf. Lenz/Fraedrich 2015: 189). This is made possible by the elimination of personnel costs, which account for a large portion of the overall costs in public transport (cf. Hell 2006: 169). By eliminating or reducing personnel costs, the services could be operated more economically (cf. Hörl 2020: 2; Hörl et al. 2019: 60; Bösch et al. 2018: 7; Gertz/Dörnemann 2016: 22). However, it remains to be clarified to what extent accompanying personnel is still needed to ensure the safety of passengers (cf. Salonen/Haavisto 2019: 13; Mitteregger et al. 2019: 610).

The advance of automation could lead to new forms of service or transport media (cf. Soteropoulos et al. 2019: 104). This includes classic scheduled transport (e.g. automated standard or articulated bus), flexible forms of service (e.g. automated minibus/shuttle bus, automated van, automated ride sharing) and alternative forms of service (e.g. automated shared taxi/ride sharing, automated single taxi/car sharing; cf. Bruns et al. 2018: 21). In classic scheduled services, automation will also extend to large vehicles that will provide a minimum public service, while the flexible and alternative forms of service will tend to be provided by small vehicles. Their market niches result from additional offers and from offers for the first and last mile in combination with regular services, especially in times and areas of low demand (cf. Ohnemus/Perl 2016: 591).

Table 2 (on the next page) gives an overview of the characteristics of various forms of service and transport media in extended public transport, taking into account automation in road traffic. The automated shuttle bus occupies a special position here: its size makes it suitable both for regular service on fixed routes with a fixed timetable and fixed stops, and for flexible use according to demand with request stops.

Particularly in the case of the possible flexible and alternative forms of service with automation, these could come into consideration for different forms of service (see Table 3). The (automated) minibus or shuttle bus is most suited to scheduled service or as a call bus that also travels to requested destinations within a specified area. The (automated) van (ride sharing) and the (automated) shared taxi (ride sharing), on the other hand, are most suitable as ring-and-ride taxis, as a feeder, i.e. for sector operation, or for use in zonal operation or zonal service. The (automated) single taxi (car sharing) is likewise most suited to sector and zonal operation.

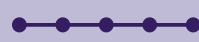
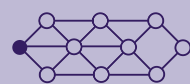
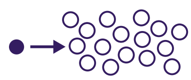
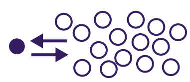
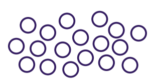
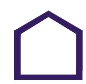
All in all, a wide range of applications are therefore possible for automated vehicles in public transport. These different vehicle concepts must be ideally implemented in future. To sound out their best possible use already today, numerous pilot projects are being conducted for automated driving in public transport. The majority of these projects focus on automated shuttle buses (Barillère-Scholz et al. 2020: 18), which are mostly used here in regular service. Relevant aspects are now already emerging that will retain their relevance in the future for the use of automated shuttle buses or of other automated vehicle concepts in the context of flexible or alternative forms of service. In the next section, the use case of the automated shuttle bus will therefore be examined in more detail, and an exemplary overview of the various pilot projects will be given.

Table 2: Characteristics of different forms of service and transport media in extended public transport, and possible characteristics taking into account automation in road traffic

Characteristics/elements	Commuter/regional train	Underground	Tram	(AT) articulated bus	(AT) standard bus	(AT) minibus/ shuttle bus	(AT) van (ride sharing)	(AT) shared taxi (ride sharing)	(AT) single taxi (car sharing)
Temporal availability									
Fixed timetable	✓	✓	✓	✓	✓	✓			
Transport on demand						✓	✓	✓	✓
Frequency (mins.)	15–60	2–15	3–30	3–60	3–120	5–30/ –	–	–	–
Request time (mins.)	–	–	–	–	–	– /15–45	10–45	5–30	4–20
Spatial or local availability									
Fixed stops	✓	✓	✓	✓	✓	✓			
Stop on demand						✓	✓	✓	✓
Distance between stops (m)	2500–3500	500–900	300–700	300–700	300–700	250–500 / –	–	–	–
Travel speed (km/h)	30–60	30	15–40	15–30	15–30	20–40	25–50	25–50	25–60
Convenience	medium	medium	medium	low	low	medium	high	high	very high
Payment system									
Frequent-use tariff	✓	✓	✓	✓	✓	✓	✓	✓	✓
Payment per trip	✓	✓	✓	✓	✓	✓	✓	✓	✓
Distance-/time-dependent	✓				✓			✓	✓
Vehicle capacity (persons)	1000	750	140–200	75–140	25–75	8–20	5–8	2–5	1–2
Operator	mostly public	mostly public	mostly public	mostly public	mostly public	public/private	public/private	public/private	public/private
Offer type	scheduled	scheduled	scheduled	scheduled	scheduled/ flexible	scheduled/ flexible	flexible/ alternative	flexible/ alternative	flexible/ alternative
Demand	high	very high	high	high	medium	medium	low	low	low

Source: the authors, based on Wolf-Eberl et al. (2011: 27ff.), Weidmann et al. (2011: 89ff.), BMVI (2016: 23ff.), Bruns et al. (2018: 20) and Sommer (2018: 10)

Table 3: Flexible and alternative forms of service with automation

	Designation	Service principle	Fixed timetable	Registration required	Departure from	Destination
 (AT) minibus/ shuttle	schedule		yes	no	H	H
	call bus (to requested stops)		yes	yes	H	H
 (AT) van (ride sharing)	call-sharing taxi (sector operation)		yes	yes	H	
 (AT) shared taxi (ride sharing)	feeder (sector operation)		yes	yes		H
 (AT) single taxi (car sharing)	area operation (area service)		yes	yes		

	Stop served according to timetable	H	Journey from/ to a stop
	Stop served on request		
	Service zone, with boarding and alighting possible at any place		Journey from/ to front door

Source: the authors, based on Wolf-Eberl et al. (2011: 27), BMVI (2016: 23), Mörner (2018: 11) and Sommer (2018: 6)

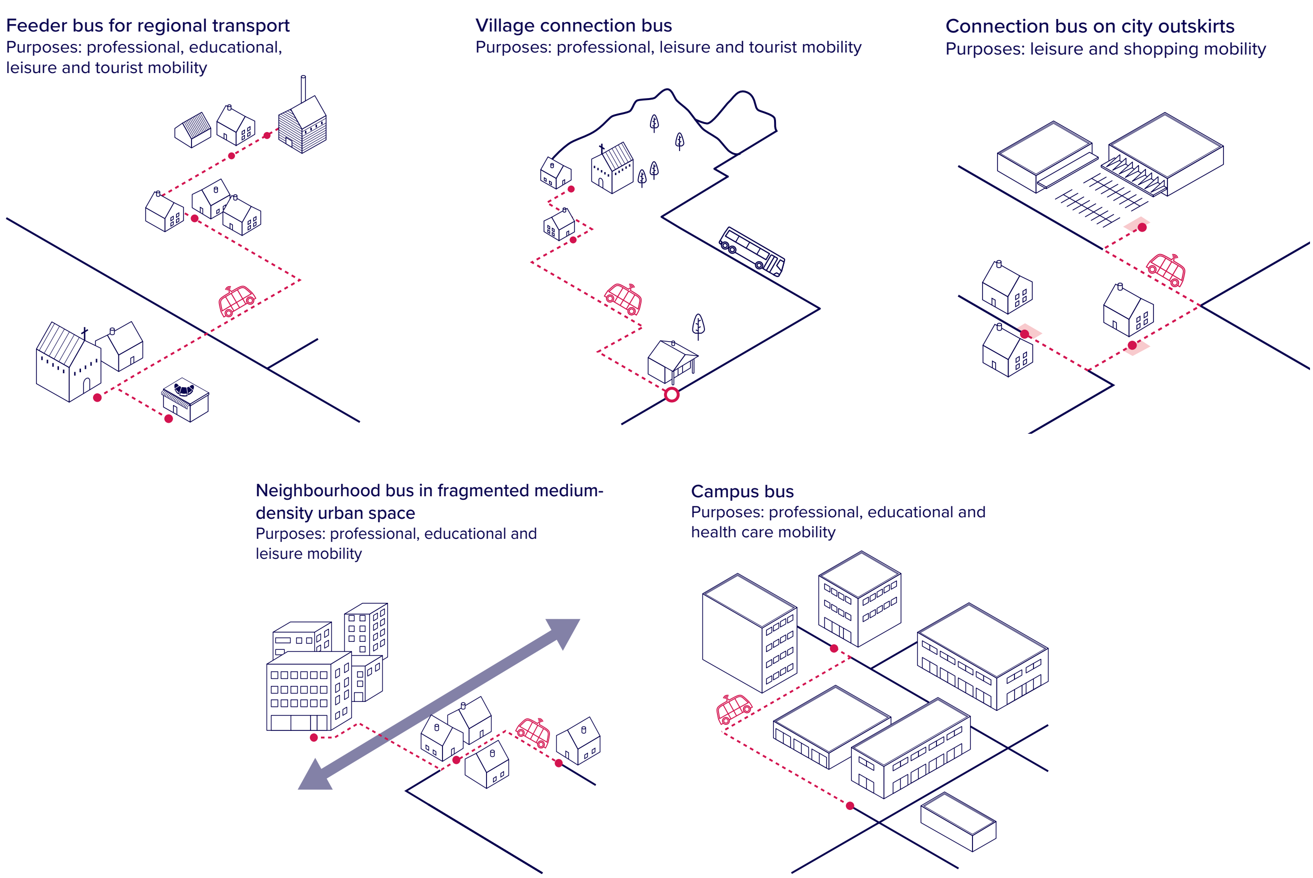
3. AUTOMATED SHUTTLE BUSES AS A PRIORITY USE CASE IN PUBLIC TRANSPORT PILOT PROJECTS

Automated shuttle buses, or driverless electric minibuses, represent a special use case for automated vehicles as described in Section 2, and are currently undergoing testing by public transport companies. The automated shuttle buses that are currently on the market and are undergoing field tests, such as *NAVYA Arma* or *EasyMile EZ10*, correspond to automation level 2 and drive on a specially approved and prepared fixed route on which they assume both longitudinal and lateral control (cf. Rentschler et al. 2020: 320). In most cases, a safety driver or operator is still on board. For an increasing number of test drives, however, vehicles are only monitored from a control centre.

Due to the low capacity of the shuttle buses, which can usually carry 8 to 12 passengers, these models can function as an appropriate and demand-based supplement to the public transport system. As described above, several fields of application are now emerging for automated shuttle buses in public transport; due to technological limitations, however, these have so far only been tested in scheduled service operation (cf. Derer/Geis 2020: 7; Földes/Csiszár 2018: 2).

In the future, automated shuttle buses could cover a wide range of applications, be used flexibly and thus efficiently replace classic scheduled services in accordance with demand. Especially in cases of low transport demand, in expansive residential and commercial areas, in large-scale hospital centres or on university campuses and at research locations, automated shuttle buses could help to better serve and connect such areas (cf. Derer/Geis 2020: 7). In view of the above-mentioned gaps in the public transport network, tests with automated shuttles are now also being given more attention by municipalities, which are eager to promote a "transit-first" approach to automation (cf. Heinrichs et al. 2019: 248). Figure 2 gives an overview of possible fields of application for automated shuttle buses.

Figure 2: Possible fields of application for automated shuttle buses



Source: the authors

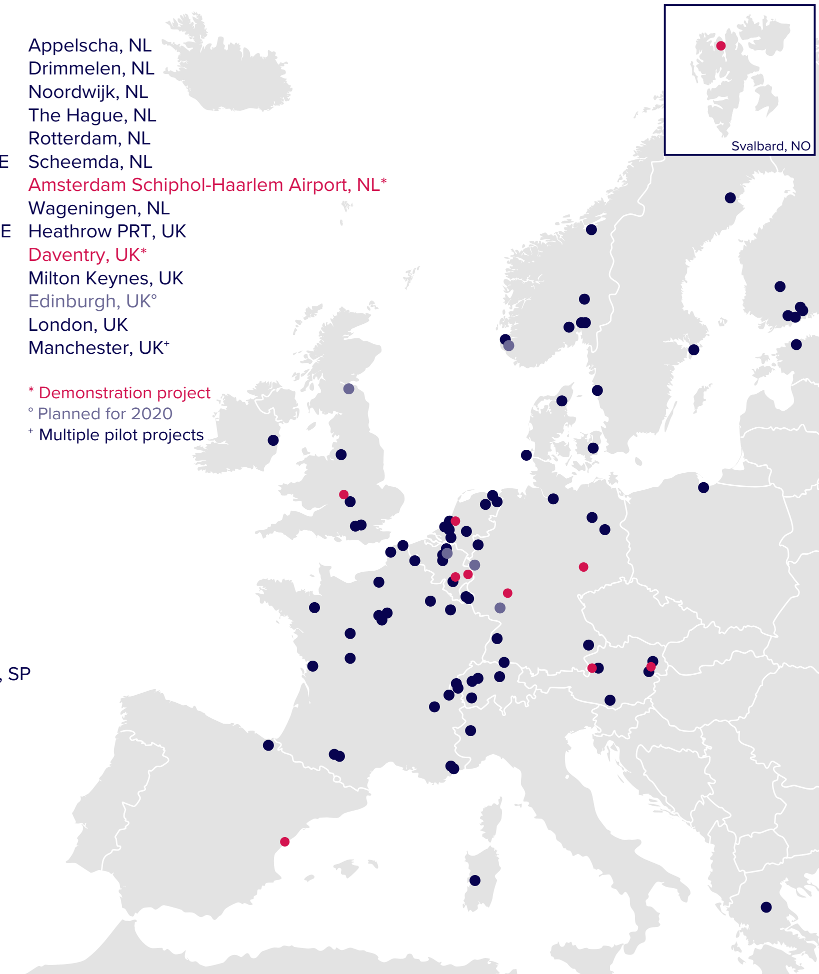
In Europe, the first tests with automated shuttle buses on public roads were carried out between 2012 and 2016 as part of the "CityMobil2" project (cf. Alessandrini et al. 2015). Prior to this, most of the tests carried out were for demonstration projects. Numerous further pilot projects with automated shuttle buses have since been initiated in Europe as a result of research funding and adapted legal requirements. Figure 3 gives an overview of pilot projects with automated shuttle buses in Europe.

Figure 3: Locations of pilot projects and demonstrations with automated shuttle buses on public roads and private premises in Europe since 2008 (without claim to completeness)

Locations

Vienna, AT+
Koppl, AT+
Wiener Neustadt, AT
Teesdorf, AT*
Salzburg, AT*
Pörtschach, AT
Mechelen, BE*
Spa-Francorchamps, BE*
Han-sur-Lesse, BE
Eigenbrakel, BE
Marche-en-Famenne, BE*
Brussels, BE+
Brussels Zaventem Airport, BE°
Aalborg Øst, DK
Nordhavn, Copenhagen, DK
Tallinn, EE+
Vantaa, FI
Helsinki, FI+
Espoo, FI+
Tempere, FI
Kivikko, Helsinki, FI
Antibes, FR
La Rochelle, FR+
Sophia Antipolis, FR
Civaux, FR
Lyon, FR+
Villeneuve-d'Ascq, FR
Rennes, FR+
Paris, FR+
Versailles, FR+
Sorigny, FR
Rouen, FR+
Saclay, FR+
Boulogne-sur-Mer, FR
Toulouse, FR
Pibrac, FR
Verdun, FR
Reims, FR
Dunkirk, FR
Frankfurt am Main, DE*
Hamburg, DE
Aachen, DE°
Weeze Airport, DE
Lahr, DE
Neustadt/Weinstraße, DE
Sylt, DE
Bad Birnbach, DE
Wusterhausen/Dosse, DE
Berlin, DE+
Leipzig, DE*
Trikala, GR
Dublin, IR
Oristano, IT
Turin, IT
Luxembourg, LU
Contern, LU
Svalbard, NO*
Gjesdal, NO°
Gjøvik, NO
Stavanger, NO
Fornebu, NO
Oslo, NO+
Kongsberg, NO
Trondheim, NO
Gdańsk, PL
Castallón, SP*
Donostia/San Sebastian, SP
Varuträsk, SE
Stockholm, SE+
Gothenburg, SE+
Lausanne, CH
Neuhausen, CH
Geneva, CH
Zug, CH
Sion, CH
Bern, CH
Fribourg, CH
Cossonay, CH
Appelscha, NL
Drimmelen, NL
Noordwijk, NL
The Hague, NL
Rotterdam, NL
Scheemda, NL
Amsterdam Schiphol-Haarlem Airport, NL*
Wageningen, NL
Heathrow PRT, UK
Daventry, UK*
Milton Keynes, UK
Edinburgh, UK°
London, UK
Manchester, UK+

* Demonstration project
° Planned for 2020
\+ Multiple pilot projects



Source: the authors, based on Alessandrini (2016), Ainsalu et al. (2018) and Hagenzieker et al. (2020)

Most of the pilot projects with automated shuttle buses have focused to date on the following aspects (cf. Jürgens 2020):

- **Technological feasibility:** technical aspects, especially vehicle technology, infrastructure (physical and digital), interaction with other road users and passengers (human-machine interaction), road safety, data security
- **Organizational and operational feasibility:** legal and administrative aspects (e.g. authorization procedures for commissioning, insurance), operational aspects/service, integration of the automated shuttle buses into the existing public transport system (MaaS, interfaces, data infrastructure)
- **Economic feasibility:** economic aspects and financing (e.g. operating costs), user acceptance
- **Social dimension:** inclusion.

However, the individual pilot projects differ in their intensity of focus. They can also be differentiated in terms of their spatial location and of their integration into the transport system and their operating concepts.

Using the example of selected pilot projects in Europe with automated shuttle buses, the possible points of focus are shown in the following, along with the various spatial deployment environments and operating concepts in which automated shuttle buses are currently undergoing testing. To cover as broad a spectrum as possible, pilot projects in Vienna and Koppl in Austria, in Aalborg Øst in Denmark, in Wusterhausen/Dosse in Germany, and in Zug in Switzerland were selected for this comparison (see also Table 4 on the following pages).

The pilot projects are all similar in terms of technological and formal criteria. The shuttle buses, all of which are used in scheduled services, generally operate on routes 2 to 3.5 kilometres in length and serve up to ten predefined stops. In this sense, the test operations hardly fulfil the expectations of flexible booking or routing, but they do demonstrate both the long-term potential and the limitations of supplementary use in the public transport network. To evaluate these aspects, the forms of operation tested should be seen above all in the context of local conditions and requirements. In the course of these projects, the tests mostly involve connections for the first or last mile with automated shuttles, which however are differently suited in terms of space, topography and demand:

- In the "auto.Bus – Seestadt" project in Vienna, shuttle buses are in operation on the residential streets of a densely inhabited new neighbourhood development to test its connection to the underground terminus in the form of an access bus. In view of the high population density, neither does the vehicle size seem economically viable in the long term, nor does the competition with active forms of mobility and new forms of micromobility appear expedient.

- On the other hand, in Koppl, a rural village in Austria, the connection of the various districts to a regional bus route was tested as part of the "Digibus 2017" project in order to facilitate commuting to the supraregional centre in the future (feeder bus for regional transport). The potential here is seen in providing demand-oriented access to dispersed settlement areas in the future, thereby creating an affordable alternative to travel by private car for residents, tourists and the transport of goods, and thus stabilizing the location.

- With the "smartbusaalborg" project in Aalborg Øst in Denmark, the gap in the public transport network is being filled by an automated shuttle in the form of a neighbourhood bus that operates on a now central foot and cycle path to connect the various residential areas and facilities in this highly fragmented suburb. The focus here is not only on providing a tangential transport connection, but above all on mobilizing the population and socially integrating a suburban district of Aalborg that has to date been characterized by functionalistic planning principles.

- In Wusterhausen/Dosse, a small town in the northwest of Brandenburg in Germany, mobilization of the residents, and especially of the ageing population, is likewise at the focus of the pilot project. The automated shuttle bus provides access to this small town, connects it to the regional rail network, and in a second phase will also serve more remote parts of the town (village connection bus). In view of the exodus of residents, high commuter numbers and an ageing population, the extension and flexibilization of the local public transport system is seen as an opportunity to make the region more attractive for locals and tourists and to stabilize dispersed settlement areas as residential locations.

- With the "MyShuttle" project in Zug, a small town in Switzerland, the automated shuttle bus was used to better connect the site of the company V-Zug, in the north of the town, to the railway station and thus create a possible service for the company's commuters (*feeder bus for regional transport*). A particular focal point was the integration of the automated shuttle into the existing public transport information systems.

Table 4 gives an overview of the pilot projects examined involving automated shuttle buses.

Table 4: Overview of selected pilot projects with automated shuttle buses

	Vienna, AT	Aalborg Øst, DK	Wusterhausen/ Dosse, DE	Koppl, AT	Zug, CH
Project	auto.Bus Seestadt	smartbusaalborg	autoNV OPR	Digibus© 2017	MyShuttle
Duration of test operation	06/2019–07/2020	03/2020 –06/2021	10/2019–06/2020	04–11/2017	01/2019–12/2019
Regional context or type of area	• Vienna city fringe or city fringe centre • High-density urban development area with mixed use and restricted use of private vehicles • Positive population development	• Suburban or fringe area of urban agglomeration • City fringe area from the 1970s with urban revitalization projects • Positive population development	• Leisure and tourism resort in rural region far from urban agglomeration • Historic village centre, dispersed settlement structure • Ageing and dwindling population • Leisure/tourist traffic	• Rural community east of Salzburg • Dispersed settlement structure • Positive population development • Commuter traffic	• Small town south of Zurich • Historic city centre and dense settlement structure • Positive population development • Commuter traffic
Test environment and route	• Mixed traffic on roads in urban residential area • Length approx. 2 km, 10 stops	• Mixed traffic on a foot and cycle path • Length 2.1 km, 10 stops	• Mixed traffic on village and country roads • 8 km, 18 stops	• Mixed traffic on a country road and village access road • Length 1.4 km, 6 stops	• Mixed traffic on urban local road • Length 1.5 km, 3 stops
Transport connections and urban integration, operating concept	• Linking the underground terminus to neighbouring dense residential areas	• Linking a new district centre with social facilities, fragmented residential areas and a university campus	• Linking the town or city centre with the railway station, shopping centre and supermarket, and an outlying residential area	• Linking the village centre with a regional (public transport) corridor	• Linking the railway station and Metalli shopping centre with the V-Zug company site (first and last mile)
Municipal participation	• Embedded in the public transport company Wiener Linien • Municipal administration involved in coordination processes	• Embedded in the urban and communal administration of Aalborg • Extensive participation of municipal administration	• Rural district of Ostprignitz-Ruppin • Operations of the public transport company ORP-Busse as associated partners	• Provision of framework conditions by the municipality of Koppl	• City of Zug as project partner

Source: the authors

To examine specific aspects of the selected pilot projects with automated shuttle buses in more detail, the following two sections each provide a detailed description of two such tests and give insights into different aspects that are relevant to both the testing of automated shuttle buses and their operation. The first in-depth study, dealing with the "autoNV OPR" project in Ostprignitz-Ruppin, Germany, gives insights into the technical and legal aspects of the use of automated shuttle buses in public transport. The second in-depth study, using the example of the "MyShuttle" project in Zug, Switzerland, sheds light on the operation of automated shuttles and their integration into existing public transport systems.

Table 5: Overview of selected pilot projects with automated shuttle buses

Priority topics in the project					
Project	auto.Bus Seestadt	smartbusaalborg	autoNV OPR	Digibus© 2017	MyShuttle
Technological feasibility					
Vehicle technology	✓	✓	✓	✓	✓
Infrastructure (physical and digital)	✓	✓	✓	✓	✓
Interaction with other road users (and passengers)	✓			✓	
Road safety	✓			✓	
Data security	✓	✓		✓	
Organizational and operational feasibility					
Legal and administrative aspects			✓	✓	✓
Operational aspects	✓	✓	✓		✓
Integration into the existing public transport system	✓	✓	✓	✓	✓
Economic feasibility					
Business aspects/ financing			✓		✓
User acceptance	✓		✓	✓	✓
Social dimension					
Social inclusion		✓			

Source: the authors

4. TECHNICAL AND LEGAL ASPECTS OF TESTING AUTOMATED SHUTTLE BUSES IN PUBLIC TRANSPORT

based on the example of the "autoNV OPR" project in Ostprignitz-Ruppin, Germany
Arne Holst, Alexander Egoldt, Thomas Richter

In a rural area, specifically in the district of Ostprignitz-Ruppin in the north-west of Brandenburg in Germany, the cooperative project "autoNV OPR" is researching the use and effects of automated minibuses in public streetscapes. The project consortium comprises the universities TU Dresden and TU Berlin, the development company Regionalentwicklungsgesellschaft Nordwestbrandenburg, the public transport operator Ostprignitz-Ruppiner Personennahverkehrsgesellschaft and the subcontractors IGES Institut and Büro autoBus. In this project, the general conditions for the use of automated forms of operation in traffic are investigated, along with acceptance on the part of users and stakeholders. Scenarios and effects of automated forms of operation are also being investigated in terms of financing routine for public transport, and statements on transferability are derived. The project was launched in autumn 2017, and the automated shuttle bus line developed in this connection has been in operation since July 2019. In the following, technical and legal aspects of the operation of the automated shuttle bus are examined in more detail.

4.1 THE SHUTTLE BUS

This project uses the second-generation *EZ10* shuttle from the French manufacturer EasyMile (Figure 4). The shuttle is classified by the manufacturer as an automation level 4 vehicle – however, as described above, it actually only corresponds to automation level 2. The dimensions of the shuttle are 4.02 x 2.00 x 2.87 metres (L x W x H). It has six passenger seats, is electrically powered and can be manually remote-controlled. The shuttle has a technical maximum speed of 45 km/h, although it is only approved for this project at speeds of up to 20 km/h. In operation, however, it travels at a maximum of 15 km/h (cf. EasyMile 2019a). By means of GPS, a correction

Figure 4: The *EZ10* shuttle in operation

Photo: www.autonv.de

signal, inertial sensors, odometry and a pre-stored map, the shuttle bus can localize itself and adhere to the specified trajectory (cf. EasyMile 2019b). The map, including trajectory and route environment, is generated in the course of numerous test drives prior to operation. For this purpose, the shuttle bus scans its route environment while in manual operation mode (cf. Rutanen/Arffman 2017). The bus uses roof-mounted lidar sensors for localization and stores all scanned geometric features in the corresponding positions on the map (cf. Regional Transportation District 2019). By comparing the stored geometric features with the data detected in real time, the shuttle bus can locate itself by recognizing these features, known as landmarks. The vehicle detects obstacles at a height of 35 centimetres by means of its four safety lidar sensors, which enable 360-degree obstacle detection (cf. ibid.).

4.2 CHOICE OF ROUTE, INFRASTRUCTURE ADAPTATION AND ORIENTATION OF THE SHUTTLE BUS

With regard to the area used for testing the automated shuttle bus, an initial delineation in the project outline was already made by defining the rural district of Ostprignitz-Ruppin as the test area. To further narrow down possible areas of application, all superordinate traffic nodes (PlusBus and rail traffic) in the district were subsequently recorded in order to provide appropriate connections for the automated bus line. This line thus became part of the public transport network of Ostprignitz-Ruppin, and through this integration can make a contribution to securing provision of public services.

In view of the technical requirements, to date only the last mile has come into consideration for operation of the bus. For this purpose, the next step was to assess the demand on the basis of population figures for the localities and structural data. With these two steps, 25 potential routes throughout the district of Ostprignitz-Ruppin were examined and then assessed in accordance with further criteria such as traffic density, route length, road category, maximum speed, mobile network and the need for adaptation. This process yielded two suitable routes, of which that in the municipality of Wusterhausen/Dosse was finally selected.

The route selected for operation of the automated bus line has a total length of 8 kilometres and connects the railway station of the municipality of Wusterhausen/Dosse, which is located outside the town to the east and also has a PlusBus connection (local public transport service), to the town centre, the supermarkets located there, the nursing home, a housing estate outside the town centre, and the lake landscape on the northern edge of the town. Taking into account the technical capabilities of the vehicle, the introduction of the route was realized in three stages or sections (yellow, red, green), on the basis of which the length of the route can be 2, 4 or 8 kilometres (Figure 5 on the next page).

As a preparatory measure for the respective sections, the vehicle manufacturer (EasyMile) provides an assessment, including recommendations for adaptations of the infrastructure. Using the example of the second route section (shown in red in Figure 5), a description of these adaptations with regard to infrastructure and the orientation of the shuttle bus is given in the following.

According to the Road and Transportation Research Association (FGSV; FGSV 2006), the second section, Berliner Straße, is a local access road in the town of Wusterhausen with an average daily traffic volume of 646 motor vehicles per 24 hours (2018 traffic census) and many property access roads. The carriageway is 8.7 metres in width, and parking is permitted on both sides of the road. The speed limit is 50 km/h (Figure 6, left: “Initial situation”). Since the trajectory of the shuttle bus cannot be dynamically changed, it must be ensured that it is not blocked by

Figure 5: Overview of the automated shuttle bus route in the municipality of Wusterhausen/Dosse

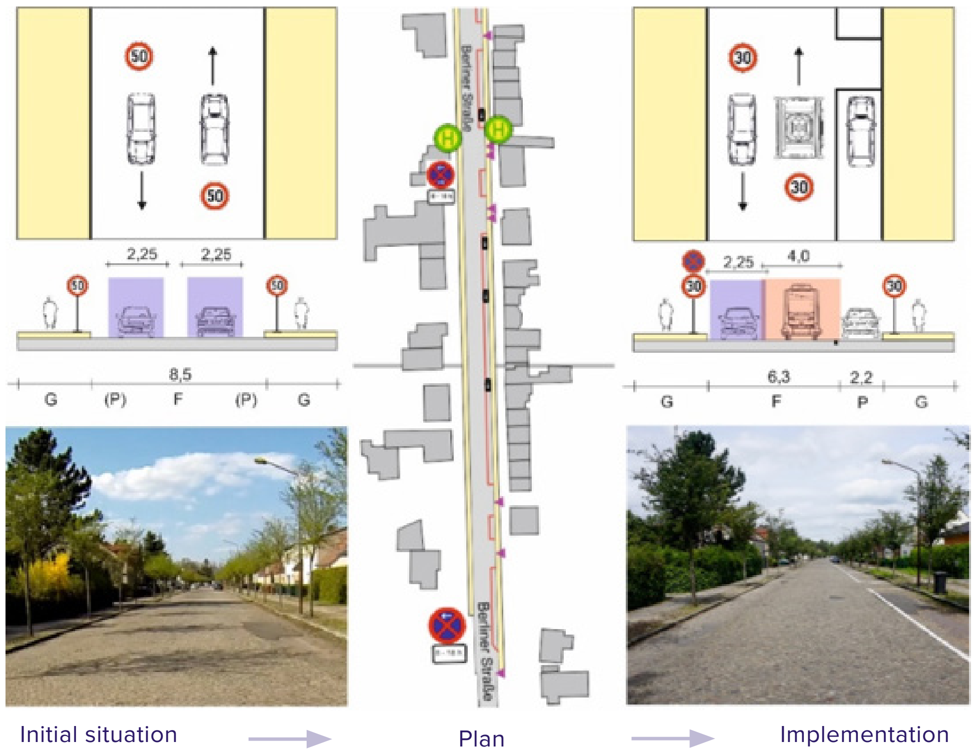
Source: www.autonv.de/fahrplan-strecke

parked vehicles. However, it is not possible to shift the trajectory to the centre of the carriageway, due to the German requirement to drive on the right of the road. In order not to violate this regulation, a one-sided stopping ban was introduced for the western side of the road during operation and longitudinal parking spaces were marked on the eastern side. The southbound trajectory can thus run along the edge of the road and the northbound trajectory adjacent to the parking strip. This prevents conflict between oncoming vehicles in the streetscape of Berliner Straße, since the shuttle bus no longer has to anticipate the behaviour of oncoming vehicles. In addition, the speed limit was lowered to 30 km/h due to the problematical road surface conditions, at times resulting from damage and cobblestones. The plan for the no-stopping zone and parking space markings (red line) is shown in the middle of Figure 6 and the situation following implementation at the right.

The cross sections in Figure 6 show the safety spaces specified by FGSV (2006) and those for the shuttle bus (cf. Rutanen/Arffman 2017). In the cross section on the right, it can be seen that the specifications lead to overlapping of the safety spaces, which in turn necessitates a speed reduction for the shuttle bus at such points. Introduction of a no-stopping zone on both sides was not feasible due to the high requirement for parking space.

For the orientation of the shuttle bus, static geometric features in the surroundings of the route are essential in view of the localization process based on landmark recognition. In view of the position of the localization lidar sensor on the roof of the shuttle bus and its small aperture angle, geometric objects at a height of approx. 3 metres were required (cf. EasyMile 2019b). Build-

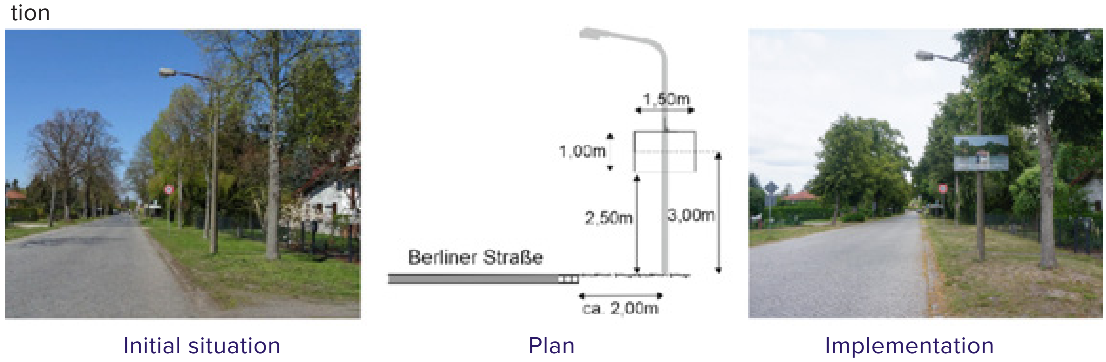
Figure 6: Overview of the infrastructural adaptation for route section 2, Berliner Straße in Wusterhausen/Dosse, in the three phases initial situation, plan and implementation



Source: the authors; left photo 17/4/2018, right photo 4/7/2019; photos: Holst/Egoldt

ings or corners of buildings, which are normally to be found on inner-city streets, can serve this purpose. The southern part of Berliner Straße, however, included an area devoid of buildings where no landmarks were present. After consultation with the manufacturer EasyMile, three artificial landmarks in the form of signs were set up in this area. In order to interfere as little as possible with the streetscape, these were attached to existing lampposts. The initial situation, plan with dimensions, and implementation are shown in Figure 7. The third road section also includes areas without buildings; here, however, trees at the edge of the roadway served as landmarks, since they fulfilled the requirements.

Figure 7: Overview of the road surroundings adaptation for orientation of the shuttle on route section 2, Berliner Straße in Wusterhausen/Dosse, in the three phases initial situation, plan and implementation



Source: the authors; 17/4/2018, photo at right 4/7/2019; photos: Holst/Egoldt

4.3 REGISTRATION AND OPERATION

As with any vehicle used on public roads, operation of the automated shuttle bus required registration, For this project, exemption from this requirement was granted in the form of a special permit. To obtain such a permit in Germany, an expert assessment from an official testing centre is required. Since the route and the time span of the project must also be specified in this assessment, both the special permit and the registration of the shuttle bus are restricted to the nominated route and time span. Once approval was granted, the route concession was applied for. For this purpose numerous documents had to be submitted, such as the exact route of the line including the positions and names of all bus stops, along with registration documents for the vehicle. According to German law, it was only possible to put the line into operation once the route concession was granted. In addition, however, approval was also required from the vehicle manufacturer, which only gave its consent to operation once the infrastructural modifications it had previously specified had been implemented.

For operation of the shuttle bus, test runs without passengers were carried out in the first few days following the release of one section, so that all road users and especially the accompanying personnel could get used to the driving characteristics of the bus. The accompanying persons are necessary not only for legal reasons; they also have to carry out driving tasks. At complex intersections, driving must be specifically activated by the accompanying person so that the shuttle bus can proceed. Due to the safety space for the shuttle bus, on roads with standard cross sections according to RASt 06 (cf. FGSV 2006) braking is always initiated when oncoming traffic is encountered, as the oncoming vehicle then enters the safety space of the shuttle bus. Dynamic overtaking manoeuvres by other road users, followed by cutting in directly in front of the shuttle bus, likewise lead to delays that affect the operation of the bus and were perceived as negative by the passengers.

4.4 INSIGHTS GAINED

Described above are the approval procedure, selection and adaptation of the route, and an assessment of operations after around six months of experience gained. The choice of manufacturer is important for the project, as this factor plays a major role both in the choice of route and in the specification of infrastructural adaptations. The needs of the users are also highly significant. The wish for an extension of the route was already expressed at the time of release of the first section, above all on the part of the elderly population. However, it became clear that a local transport system in a small town must likewise cater to the needs of the passengers, especially in terms of time: firstly, an adjustment of travel speed and an increase in reliability is necessary; and secondly, the timetable must be coordinated with user demand. The provision of a demand-oriented timetable makes it all the more difficult to establish a traditional bus route for a small town in a rural area and requires alternatives to be examined. To ensure smooth operation, infrastructural measures are also currently required, which however could become obsolete with the ongoing development of automated driving functions and should therefore be avoided

5. OPERATION AND INTEGRATION OF AUTOMATED SHUTTLE BUSES IN PUBLIC TRANSPORT SYSTEMS

based on the example of the "MyShuttle" project in Zug, Switzerland

Zoltán László

As part of the "MyShuttle" project, various possible applications of automated vehicles and associated service concepts were analysed, developed and subjected to extensive field tests in the city of Zug (around 30,000 inhabitants) in Switzerland using an automated shuttle bus. The point of departure for this project was the radical transformation of passenger transport triggered by automated driving. In particular, the opportunities opened up by automated driving for a more customer-friendly, efficient, environmentally friendly and cost-effective overall transport system – as a convergence of public and individual transport, with a focus on car- and ride sharing services – motivated the Swiss Federal Railways (SBB) to prepare for these changes so as to be in a position to offer customers a suitable range of services in the future.

With these considerations in mind, the "MyShuttle" project was launched by SBB, Switzerland's largest passenger transport company, together with the Swiss company Mobility Carsharing, the transport operator Zugerland Verkehrsbetriebe, the City of Zug as the local partner, and the Tech Cluster Zug. The operational testing focused on three main areas: (1) the ability of automated vehicles to be integrated into the existing public transport customer information system, (2) specific experience regarding the technical maturity of the available software and hardware, and (3) customer acceptance of automated shuttle services. The one-year pilot operation was launched in January 2019, after a year and a half of planning and preparation. "MyShuttle" was

Figure 8: The *EZ10* shuttle in operation in Zug

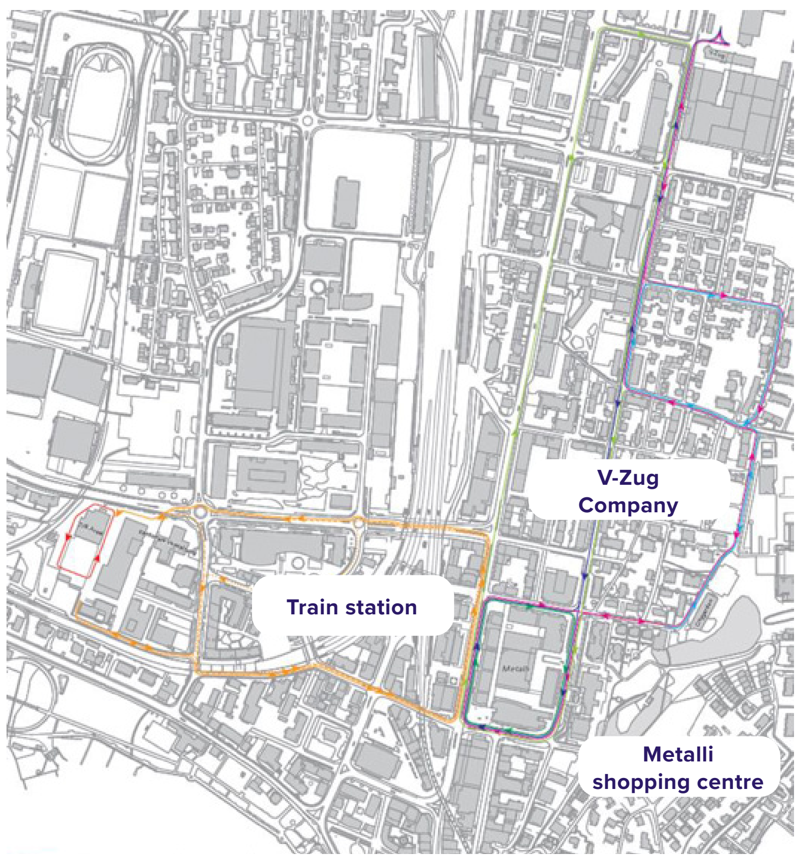
Source: SBB (2020: 1)

thus the first automated shuttle bus in Switzerland to operate in mixed traffic on a public road with a constantly high traffic volume. In the following, the operation and integration of the automated shuttle bus into the existing public transport system is examined in more detail.

5.1 THE SHUTTLE BUS AND ITS OPERATION

Prior to the project launch, none of the leading technology providers or vehicle manufacturers in the field of automated vehicles had agreed to test vehicles in Switzerland or to participate as partners in a pilot project. For the "MyShuttle" project, the responsible parties therefore took a pragmatic approach and procured the most suitable automated shuttle bus available for purchase from the point of view of this project: the *EZ10* model from the French start-up EasyMile (Figure 8, previous page).

Figure 9: Overview of the automated shuttle routes in the city of Zug



Route 1 — Test route, ZVB site
Route 2 – Option A — Round trip, ZVB site
Route 2 – Option B — Round trip, ZVB site
Route 2 – Option D — Round trip, ZVB site (during construction)
Route 3 — Short loop, Metalli shopping centre
Route 4 — City Garden test route
Route 5 — Metalli – V-Zug – Metalli (30 km/h zone)
Route 6 — Metalli – V-Zug – Metalli (via Industriestraße)
Route 7 — Metalli – V-Zug – Metalli (via Baarerstraße)

Property of City of Zug
Property of Canton of Zug

Source: SBB (2020: 12)

In this project, the automated shuttle bus was mainly used to serve the first and last mile within the city of Zug, especially between the railway station and the V-Zug company site. Figure 9 gives an overview of the routes for the shuttle bus in Zug. While Routes 1 to 4 were only used for functional tests of the vehicle or for brief demonstrations, the regular, public operation of the automated shuttle bus took place on Route 5 (pink) between the railway station or the Metalli shopping centre and the V-Zug location, and on Routes 6 and 7 (purple and green), each of which is an adapted, partly shortened form of Route 5 (Figure 9).

EasyMile, the manufacturer of the automated shuttle bus, worked hard to meet the requirements of this project. As a result, it was finally possible for the bus to run in mixed traffic between the station and the V-Zug company site. However, operation of the automated shuttle repeatedly met with challenges: reliably recognizing traffic lights, anticipating the flow of traffic, avoiding obstacles, driving in heavy rain and autonomously "learning" from new traffic situations could not yet be mastered by the vehicle model in the course of operation. Sensor malfunctions due to pollen, turning left at intersections, problems caused by vegetation growth and construction sites necessitated the presence of safety drivers on board. In view of the technical complexity, in the course of this project it was also not possible for EasyMile to offer a demand-driven zonal service (on-demand service within a selected area, where passengers can board or alight at any location). Passengers could only board or alight during intermediate stops at fixed bus stops along the route.

5.2 INTEGRATION INTO PUBLIC TRANSPORT CUSTOMER INFORMATION SYSTEMS

One main focus of the project was to investigate possible integration of the shuttle bus into the customer information systems of the SBB – and therefore into the existing public transport landscape in Switzerland. For this purpose, the project cooperated with Bestmile, a company that provides scheduling and fleet management systems for automated vehicles. The aim was to integrate the automated shuttle bus into the various public transport customer information systems, e.g. displays of (1) departure times on monitors at bus stops, (2) ongoing connections on board trains or (3) departure times in the SBB apps.

Customer information systems inform passengers about the availability of and changes to transport services. Switzerland is a pioneer in this field for public transport: on behalf of the Federal Office of Transport (FOT), SBB bundles information on the majority of public transport services and makes it available to the industry and to customers.

In very simplified terms, these systems are oriented towards current forms of public transport services, i.e. on predefined routes with fixed stops and long-term timetables. As long as services with automated vehicles – such as the line-bound shuttle bus with fixed stops as implemented in this project – adhere to this logic, they can be easily integrated into the current system landscape and communicated to customers. The decisive factor here is not the degree of automation of the vehicle, but whether it runs according to a timetable or is offered on demand. In the course of this project, the subsequent public transport connections were displayed on a monitor in the shuttle bus (Figure 10, left). The scheduled departure times of the shuttle bus from Zug main station were also shown on the departure displays at the station (Figure 10, right). For this purpose the shuttle bus, running as a classic scheduled service, was integrated into the public transport timetable and customer information system as Line 17 and a timetable for the shuttle bus was drawn up.

As mentioned at the outset, automated vehicles open up great opportunities for new forms of offer, especially on-demand transport services. Thanks to their automation, these vehicles can be ordered to arrive at a defined location at a certain time, whereby it is possible to be brought to one's destination without changing. Such an offer would make ownership of a private car

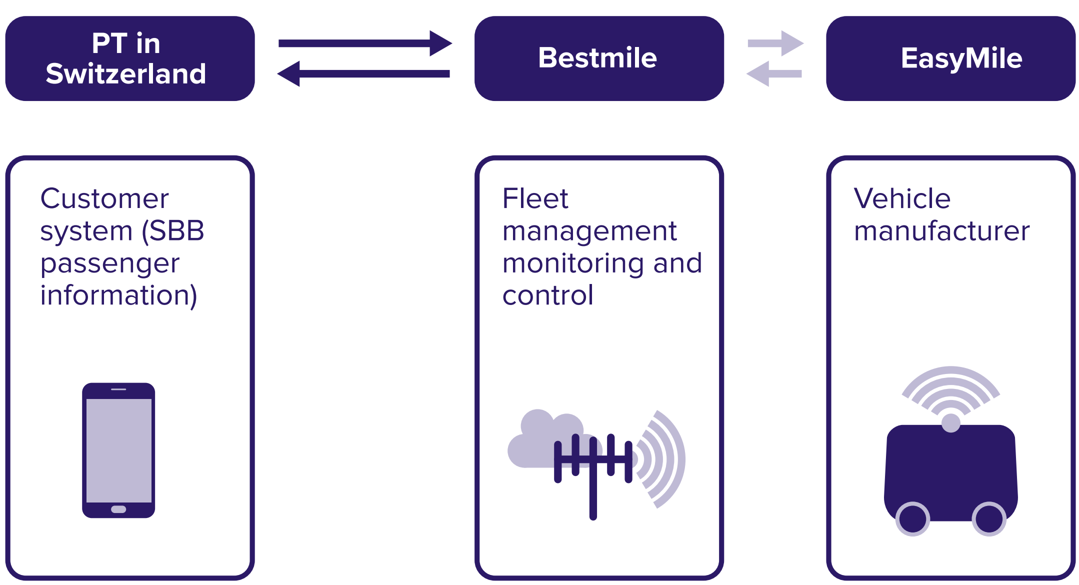
Figure 10: Display of ongoing connections on board the shuttle bus (left) and indication of the shuttle bus on the departure screen at Zug station (right)

Source: SBB (2020: 32)

superfluous. If a number of journeys are then also bundled to increase efficiency, this new form of offer combines the advantages of public transport with those of owning a car. The result is known as public individual transport.

To enrich the strong Swiss public transport system with these new forms of service, initial attempts were made in the “MyShuttle” pilot project to integrate such a public individual transport offer, e.g. a shuttle bus with flexible stop requests, into the customer information system. The required chain of information between the existing SBB customer information system, the scheduling or fleet management system of Bestmile and the vehicle is shown in Figure 11. The timetable from the public transport systems is transmitted to the control or scheduling system, which divides the time schedule into individual trips and conveys these in sequence to the vehicle (mission management). The vehicle reports all positional, speed and further data back to the Bestmile scheduling system. The control and scheduling system then calculates the discrepancy between the real position of the vehicle and that indicated on the timetable and reports this back to the customer information system in order to inform customers accordingly.

Figure 11: Schematic depiction of the information chain between customer information system, scheduling system and vehicle



Source: the authors, based on SBB (2020: 32)

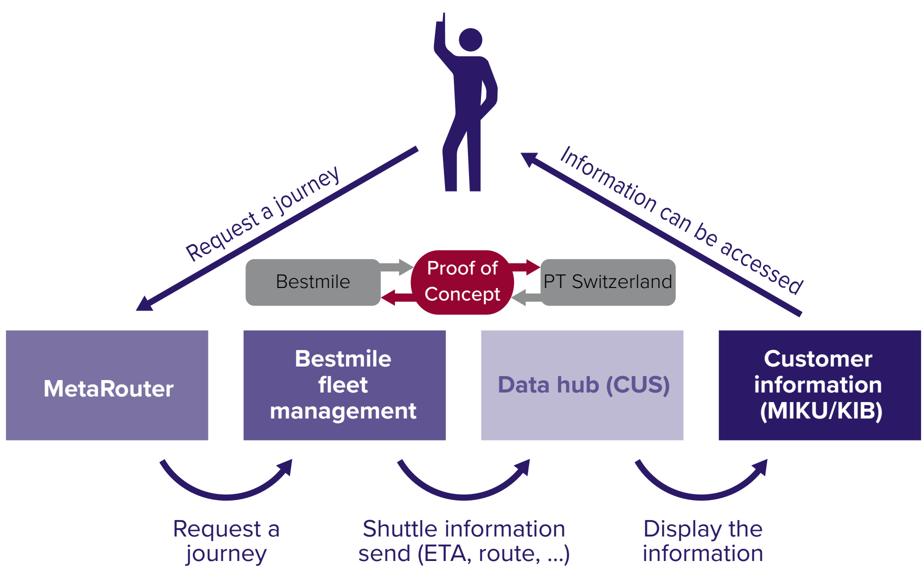
A significant aspect is therefore that the scheduling system sends driving orders, so-called missions, to the vehicle, which it then carries out. The scheduling system must also be able to implement changes to the mission, e.g. in the form of a requested stop of the shuttle bus, during a journey. Due to the technical complexity involved, in the course of the pilot operation of the shuttle bus EasyMile was not able to provide an interface that could process a mission and handle such changes, or provide an on-demand zonal service that enables customers to board and alight at any place. According to EasyMile, as things stand, externally accessing a vehicle in the form of a mission is critical for security and safety reasons and is subject to abuse.

To investigate the integration of such forms of service into the existing customer information system, (1) fictitious vehicles were then "generated", i.e. simulated, in Bestmile's scheduling system for proof of concept, and (2) the functionality of flexible stops for the shuttle bus was evaluated by the safety drivers using an app developed by Bestmile (City of Zug on-demand app) for end customers.

For (1) the proof of concept, the experts set about establishing a link between the SBB customer information system and Bestmile's scheduling system. This was necessary because the formats of the customer information system are currently based on fixed stops and predefined routes and timetables, whereas the scheduling system is designed for a demand-based zonal service. These tests were carried out on test systems; SBB's actual productive systems and customer information systems were not available for this purpose.

For the tests, the Bestmile system and SBB's customer information system (CUS – customer system) were connected by an adapter, which unites the logics of these two systems, and subsequently by a router (MetaRouter) and by the information channels of SBB's MIKU (mobile information tool for customer contacts) or KIB (customer information at the station, i.e. loudspeakers and screens; see Figure 12).

Figure 12: Information flow for integration of public transport and proof of concept, and thus for the adapter between SBB's customer system (CUS) and Bestmile

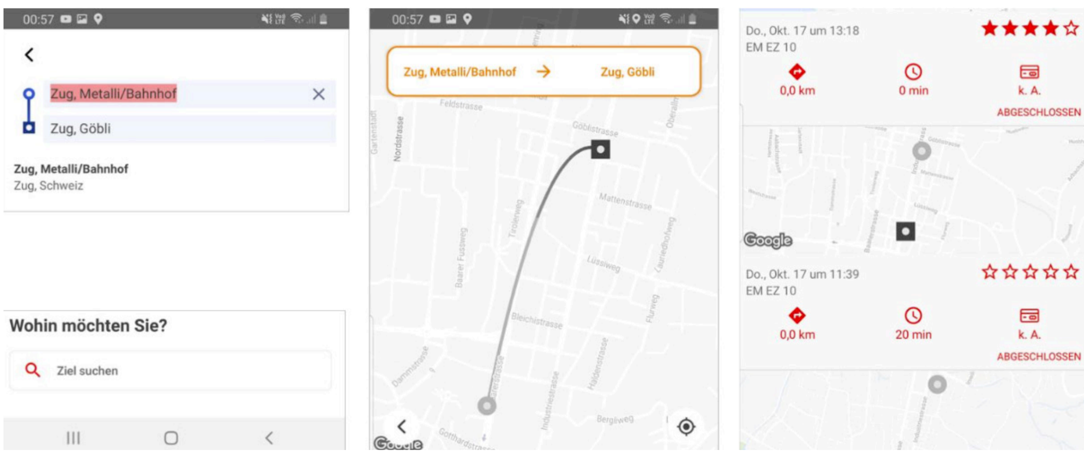


Source: the authors, based on SBB (2020: 26)

However, CUS reached its limits here. As long as operations remained within the framework of scheduled services, the vehicles simulated by Bestmile could be successfully displayed in the core information systems for public transport (see also the successful implementation of scheduled shuttle bus services into departure displays at the station, mentioned above); an upstream logic recognized and even appropriately displayed bundled journeys (grouping together of several bookings from the MetaRouter for assignment to a single vehicle). However, as soon as operations went beyond scheduled service to include zonal services without timetables, or attempted to simulate this feature (trips and stops on demand), the system could no longer process and display the information.

To test the functionality of flexible stop requests (2), Bestmile developed an app for the City of Zug (Zug On-Demand), whereby stop requests were transmitted to the safety driver via the app alone. These then appeared in the app of the safety driver, who could manually accept or reject the displayed requests (Figure 13).

Figure 13: "Train On Demand" app (top) and driver app interface for journey and stop requests (bottom)



Time of booking	Desired pickup time	Planned pickup time	Pickup ETA	Dropoff ETA	Traveler	Assigned vehicle	Status
12/12/2019 at 11:35 AM	12/13/2019 at 11:28 AM	11:28:00	11:21:00	11:30:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:34 AM	12/13/2019 at 11:10 AM	11:10:00	11:18:00	11:27:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:34 AM	12/13/2019 at 10:58 AM	10:58:00	10:58:00	11:07:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:33 AM	12/12/2019 at 3:40 PM	3:40 PM	4:31 PM	4:40 PM	Fahrplan Forcierung	MyShuttle Driver App	Canceled by the operator
12/12/2019 at 11:33 AM	12/12/2019 at 3:28 PM	3:28 PM	4:22 PM	4:31 PM	Fahrplan Forcierung	MyShuttle Driver App	Canceled by the operator
12/12/2019 at 11:32 AM	12/12/2019 at 3:10 PM	15:10:00	15:22:00	16:22:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:32 AM	12/12/2019 at 11:32 AM	--:--	--:--	--:--	Fahrplan Forcierung	-	No vehicle available
12/12/2019 at 11:31 AM	12/12/2019 at 2:58 PM	14:58:00	15:07:00	15:20:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:31 AM	12/12/2019 at 2:40 PM	14:40:00	14:51:00	15:06:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:31 AM	12/12/2019 at 2:28 PM	14:28:00	14:35:00	14:51:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:30 AM	12/12/2019 at 2:10 PM	14:10:00	14:41:00	14:49:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:30 AM	12/12/2019 at 11:30 AM	--:--	--:--	--:--	Fahrplan Forcierung	-	No vehicle available
12/12/2019 at 11:29 AM	12/12/2019 at 1:58 PM	13:58:00	14:32:00	14:41:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:29 AM	12/12/2019 at 1:40 PM	13:40:00	14:24:00	14:32:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:23 AM	12/12/2019 at 11:24 AM	11:34:00	11:40:00	11:48:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:09 AM	12/12/2019 at 1:28 PM	13:28:00	14:08:00	14:23:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:08 AM	12/12/2019 at 1:10 PM	1:10 PM	1:39 PM	1:48 PM	Fahrplan Forcierung	MyShuttle Driver App	Canceled by the operator
12/12/2019 at 11:08 AM	12/12/2019 at 12:58 PM	12:58:00	13:13:00	13:22:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:07 AM	12/12/2019 at 12:40 PM	12:40:00	12:53:00	13:13:00	Fahrplan Forcierung	MyShuttle Driver App	Completed
12/12/2019 at 11:06 AM	12/12/2019 at 11:07 AM	11:21:00	11:40:00	11:48:00	Fahrplan Forcierung	MyShuttle Driver App	Completed

Source: SBB (2020: 32)

While use of the app to transmit stop requests to the safety driver helped to test the functionality of flexible stop requests, some problems were encountered – especially in view of the lean design of the app due to the short development time: addresses were not correctly recognized and at times assigned to the wrong stops, for example, so that customers unnecessarily had to walk long distances. In addition, a destination could only be changed when the bus was stationary. It was thus possible that customers were assigned to a trip but the vehicle, which had already set out on its journey, failed to stop to pick them up. All in all, rudimentary on-demand functionalities could be accommodated in the project, but the software provided by Bestmile did not have the necessary degree of maturity at that time.

5.3 INSIGHTS GAINED

While the project did not achieve all the originally formulated goals, the overarching learning objectives were nevertheless exceeded. Within SBB, essential know-how was built up in this field and customer acceptance of automated driving was reinforced, especially in terms of its integration into the public transport system. To establish automated shuttle buses as a new form of service in public transport, they should be available for ordering, along with the appropriate customer information, via classic public transport channels (e.g. the SBB app). The use of flexible shuttle buses in line with demand must also be planned to match the arrival and departure times of superordinate public transport media. However, the tests showed that today's core public transport systems, which are geared to fixed stops, lines and timetables, cannot yet deal with on-demand transport (without fixed timetables), route changes or flexible stops, but can only handle shuttle buses that operate in scheduled service. This calls for new systems for the integration and development of standard application programming interfaces (APIs) that can be processed by the core public transport systems.

Overall, however, the project was able to provide important insights into new types of services, so that an economically optimized, customer-oriented service for Switzerland can be put in place once the automation technology reaches market maturity. In particular, the findings from the project with regard to the integration of automated shuttle buses or of automated on-demand services into the customer information systems of SBB and other public transport services are now being used to make the above-mentioned systems fit for this new type of mobility.

6. CONCLUSION

Automated driving enables a wide range of possible applications for new forms of service in public transport that could be integrated into the existing public transport system. By merging traditional public transport with more individual forms of service that focus on car- and ride sharing offers, public transport can be made more personalized and flexible in future, and a temporal and spatial densification of the overall service can be achieved. This could ultimately meet the needs of customers more broadly and effectively.

To evaluate the requirements for the best possible use of new, automated forms of service, extensive trial operations are needed – not only with regard to the technological functioning and ongoing development of automated vehicles, but also in order to gain experience in integrating these vehicles into the existing public transport system and in their interaction with the local surrouindings. At the focus of current debate regarding automated vehicles in the sphere of public transport are pilot projects for the operation and integration of automated shuttle buses. These projects are located in various types of area or spatial setting (e.g. on the outskirts of a large city, or in small towns and villages), make use of different operating concepts and also place greater or lesser emphasis on specific aspects (e.g. technological, organizational-operational or economic feasibility). Many of the pilot projects also serve to demonstrate power of innovation and to provide a future-oriented image for the actors involved, such as public transport companies or municipalities (cf. Perkins et al. 2018: 10). However, these example in-depth studies demonstrated that participating in research into future mobility options in public transport and testing them in practice also offer further advantages and potential for those involved. For example, pilot projects with automated vehicles, and in particular with automated shuttle buses in public transport, can serve to

- test possible operating concepts in practice,
- enable various stakeholders to gain experience,
- involve users in the operation and to determine their acceptance,
- acquire know-how with regard to operation, repair and service, and
- create appropriate data infrastructure (e.g. operational and analytical data sets, definition of requirements for data transfer, interfaces etc.) that will be relevant for the evaluation of test operations carried out to date and for future projects.

The pilot projects “autoNV OPR” and “MyShuttle” have shown that the automated shuttle buses used still have limitations in terms of operation, above all regarding aspects of technological and organizational-operational feasibility.

Technological feasibility

- Trouble-free use and operation of the shuttle buses would at present be challenging without modifications to the infrastructure (e.g. installation of artificial landmarks in the form of signs, introduction of no-stopping zones, etc.).
- At complex intersections (especially when turning left), driving must be specifically activated by the operators so that the shuttle bus can proceed. Problems are also encountered in reliably recognizing traffic lights, anticipating the traffic flow, avoiding obstacles, dealing with (sensor) malfunctions due to pollen, vegetation growth or construction sites, and when driving in heavy precipitation.
- Overtaking manoeuvres by other road users, followed by cutting in directly in front of the shuttle bus, result in deceleration that passengers perceive as negative.

Organizational and operational feasibility

- Integrating automated shuttle buses into existing core public transport systems is currently only possible if they operate in scheduled service (with fixed timetables and stops). Demand-based operation of automated shuttle buses, with flexible stops, is hardly feasible as a part of today’s core public transport systems.

Overall, it is worthwhile for public transport operators and urban stakeholders to invest financial resources in the testing of automated vehicles or in pilot projects with automated shuttle buses, as new insights and important know-how can be gained by this means. However, actually being able to use automated shuttle buses as a fully-fledged mobility option to supplement existing public transport services, e.g. in areas of low demand, necessitates the following framework conditions and measures, taking into account the results from the example projects:

1. **Further development of the vehicle technology to enable stable operation and higher driving speeds:** More intelligent and more anticipatory vehicle technology is necessary for the operation of automated shuttle buses in order to reduce possible delays and the need for intervention by the operator, and to ensure stable operation. The driving speed of the automated shuttle bus is an important aspect for the use, attractiveness and operation of the vehicle and should be increased in line with further development of the vehicle technology. This aspect is not as important in the finely detailed development of smaller residential areas, where the automated shuttle buses do not necessarily have to

travel at high speeds, but above all in cases where larger areas are to be developed or where facilities or locations have to be connected over greater distances and the automated shuttle buses tend to travel on larger-capacity roads.

2. **No extensive adaptation of the infrastructure, or only where other modes of transport (e.g. cycling, walking) would also benefit:** Adaptation of the infrastructure, which is already being carried out to a small extent in the course of tests with automated shuttle buses, should also be kept to a minimum in the course of further tests. Extensive infrastructural modifications (whether structural or digital, e.g. "vehicle-to-infrastructure") should be avoided, since the infrastructural requirements of the vehicles can rapidly change, and the costs for such modifications are relatively high. Moreover, the public space is already characterized by conflicts of use, and further land consumption or obstruction of the public space by infrastructure for automated shuttle buses should be avoided. Extensive modification of the infrastructure should therefore only take place where this would be of benefit not only to the automated shuttle buses, but also to pedestrian and bicycle traffic.

3. **Giving in-depth consideration to linking automated forms of service and the environmental network (public transport, cycling, walking):** It is essential to link automated (and networked) forms of service with other modes of transport, especially the existing public transport network. To integrate on-demand automated shuttle buses with flexible stops into existing public transport customer information and booking systems, new systems and standard interfaces or APIs are required that can be processed by the core public transport systems; these must also be adhered to on the part of the providers. With a view to customer convenience, booking rides should be as simple as possible and largely digital. Particular attention must also be given to ensuring compatible connections between the superordinate public transport media and the automated shuttle bus (orientation of demand-based, flexible shuttle bus operation to the arrival and departure times of the superordinate media; cf. SBB 2020: 62ff.).

Further framework conditions and measures are also important:

1. **Orientation of the operating concepts to the transport demand and settlement structure of the respective area:** The use of automated shuttle buses should always be oriented to the transport demand and settlement structure of the respective area in terms of operating time, frequency, route, area coverage etc. It can be advisable to link the use of these buses to the demands and goals described in the respective transport development plans and to integrate them accordingly.

2. **Spatial integration into existing public transport services:** Integration into or linking with existing public transport services is necessary not only from a technological point of view, but also spatially: the focus here should be on flexible and alternative forms of service as feeders to the classic scheduled services and on so-called "transit-oriented developments" (TODs), i.e. above all the functional enrichment and development of a settlement in the vicinity of the bus station should be promoted. The use of automated shuttle buses as feeders to rail services is necessary to prevent automated private vehicles from assuming this function (cf. Sinner 2019) – on the one hand since the space requirements at stations and transfer points are much lower in the case of on-demand buses and feeder services than for automated private vehicles or car sharing services (cf. Sinner et al. 2018), and on the other hand because a spatially facilitated transfer between transport modes can shorten overall travel times and intermodal travel can become more attractive for users (see Chap. 8 by Bruck et al. in this volume).

3. **Involvement and participation of relevant stakeholders:** In the context of further pilot projects with automated shuttle buses, the relevant stakeholders and agents of the municipalities and related administrative units should be involved. Furthermore, opportunities should be created for the local population to participate, in order to align the research and development process with local requirements and goals.

There is also a need for further research into the use of automated vehicles, and especially of automated shuttle buses, in public transport with regard to the following aspects, which should be investigated in the course of further pilot projects:

- **Costs:** Investigation of possible cost reductions through the use of automated vehicles, and of possible newly arising costs (e.g. scheduling systems, accompanying personnel, protection against vandalism, more frequent cleaning).

- **Infrastructure:** This aspect deals with infrastructure necessary not only for the actual operation of the vehicles, but for many further factors in connection with their use, e.g. charging infrastructure or bus stops (traffic areas).

- **User acceptance:** Acceptance by users is relevant not only with regard to the technology itself (e.g. travelling on the shuttle bus, comfort, quality), but also specifically at night (feeling of safety) and regarding the question of whether accompanying personnel are needed at certain times.

- **Dimensioning of fleets:** Investigations must be carried out regarding the profile of the required automated vehicle fleet, e.g. in terms of bundling potential, routes or scheduling.

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