Digibus 2017

Experiences with the first self-driving shuttlebus on open roads in Austria

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Authors	Cornelia Zankl, Karl Rehrl
Publisher	Salzburg Research Forschungsgesellschaft mbH
Date of publication	18. September 2018
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Citations	Zankl, C., & Rehrl, K. (2018). Digibus 2017 – Experiences with the first self-driving shuttle on open roads in Austria. Salzburg: Salzburg Research. http://www.digibus.at

All references to persons in this report should be interpreted as gender-neutral, and refer equally to both men and women.

Preface

As part of the Federal State of Salzburg’s mobility project "Mobile Salzburg 2025" and its “2025 Science and Innovation Strategy”, the regional research organisation Salzburg Research is the first research institute in Austria to test self-driving shuttlebuses on open roads in mixed traffic. These test drives have led to valuable new insights and experiences, which have provided both a realistic evaluation of the current state of self-driving technology, and have laid the foundations for future studies in this area.

We would first like to thank the Federal State of Salzburg, and especially regional governor Wilfried Haslauer, who supported this project from the very outset and made the test drives possible. Our thanks also go to the regional construction manager Christian Nagl and the Infrastructure and Transport Department of the Federal State of Salzburg, who have provided this project with both financial and technical support.

We would especially like to thank the Federal Ministry for Transport, Innovation and Technology (BMVIT), as well as AustriaTech's contact point for automated driving for defining the framework conditions for the tests, as well as for their support with the application process for test authorisation.

Our thanks also go to the municipality of Koppl, and especially Mayor Rupert Reischl and municipality construction manager Mr Rupert Viehauser, who enabled the smooth running of the tests by creating ideal conditions for testing on the ground, and quickly responding to new requests on our part. Above all, we would like to thank the residents of Koppl, who generally reacted very positively to, and were very accepting of the self-driving shuttlebus test drives.

Additionally, we would like to thank Mrs Allegra Frommer, managing director of the Salzburg Transport Association, and Mr Michael Lackner, division manager of the Transport Planning Department, who also supported the Digibus Project from the outset.

We are also grateful to the Fuschlsee Mondesee Region (FUMO) and Günther Penetzdorfer of Masterconcept Ltd for their active support during the early phases of the project, as well as their continued promotion of Digibus's activities.

Finally, we thank Navya Tech, who manufactured the self-driving shuttlebus, for their continuous guidance and support concerning technical issues, and without whom these test drives would not have been possible.

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1 Background and Framework Conditions

The Federal Ministry for Transport, Innovation and Technology (BMVIT) presented the Action Plan for Automated Driving in June 2016. The Action Plan defined a set of fundamental conditions which enable research institutes to test new technologies under real-world conditions and develop them further. At the heart of the action plan are seven Use Cases, which define and delimit the possible applications of automated and connected driving.

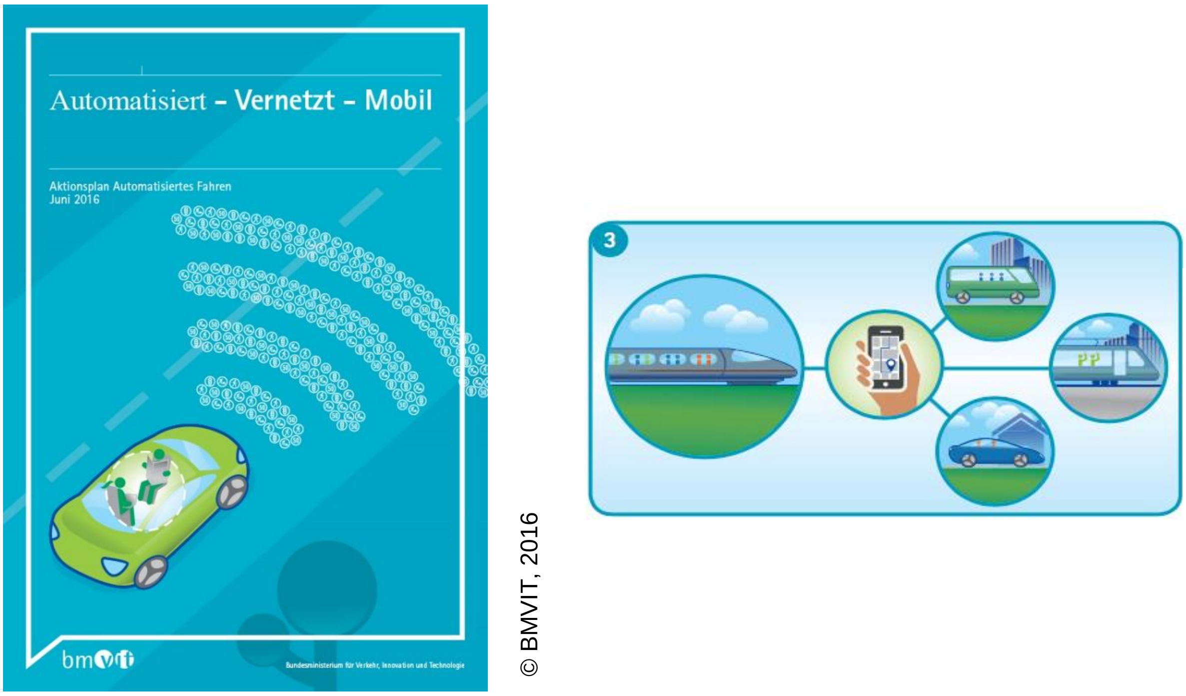

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Figure 1: (a) Automated driving action plan, (b) Use Case 3: New Flexibility

Among these, we find **Use Case 3** with a focus on **New Flexibility,** which has been rated as a priority Use Case. This calls for the use of automated and connected vehicles to enable high levels of flexibility in intermodal transport systems. According to Use Case 3, route optimisation and the adaption of timetables to personal needs, as well as secure and comfortable interconnected mobility services should be assured thanks to new vehicle concepts and information and booking services. These requirements should be tested

- in a virtual laboratory,
- in a physical laboratory and / or,
- in a real-world scenario.

New flexibility should be achieved through automated and connected vehicles, which offer new options that are adapted to user needs. In particular, these can serve as shuttle services to public transport nodes, or to major roads in urban and rural areas. An on-demand service should not only improve flexibility for transport users, but should also have environmental benefits.

In addition to these goals, the action plan defines implementation measures for the tests. One measure allows the test-driving of automated vehicles on public roads. Based on the Use Cases, the BMVIT has issued a Directive on Automated Driving setting the legal framework for tests on public roads.

In 2016, the Federal State of Salzburg adopted the regional mobility concept, salzburg.mobil 2025 (2016-2025). salzburg.mobil 2025 foresees, among other activities, the testing of innovative forms of sustainable mobility. Here, a particular emphasis is placed on improving public transport services regarding the so-called "last mile" (Federal State of Salzburg, 2016).

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Figure 2: Regional mobility concept "salzburg.mobil.2025"

1.1 Framework conditions for automated driving

The international engineering and automotive industry association, SAE, has published norms for differentiating between levels of automated driving. This establishes norm J3016, which divides automated-driving into five levels from 1 to 5 (level 0 corresponds to purely human driving without any automatization). The first two levels describe situations in which the human driver still retains control of the vehicle. From level 3, the machine takes on a higher and higher degree of control of the vehicle. Finally, at level 5, the vehicle takes over all driving functions in all situations (SAE International, 2014).

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 3: The 5 levels of automated driving according to SAE J3016

Because the driver no longer has to continuously oversee the traffic situation, automated-driving level 3 and higher requires an adaptation of the legal framework for driving on public roads. According to the Vienna Road Transport Convention (Austrian Federal Law Gazette 1977 II S. 809, 811), the fundamental regulations in Austria state that a driver must maintain uninterrupted control of the vehicle and adapt its speed to relevant conditions such as weather conditions or traffic density. This is no longer possible in the case of automated vehicles. For this reason, amendment 5bis was introduced to article 8 of the Vienna Road Transport Convention. According to this amendment, automated vehicle systems are compatible with the Vienna Road Transport Convention if a human driver has the ability to take over manual control, or if the system can be turned off. Furthermore, automated systems henceforth conform to the Convention if they meet the standards set by other international agreements on vehicle licencing (Austrian Federal Law Gazette, 1977).

The legal framework for automated driving in Austria is set by the Federal Ministry for Transport, Innovation and Technology Directive on Automated Driving (Automated Driving Directive – AutomatFahrV, BGBl. II Nr. 402/2016). The Directive allows human drivers to transfer certain driving functions to a vehicle's assistance systems or connected driving systems. This applies, on the one hand, to systems which are already authorised and in production (for example congestion assistants), but because of the existing human driver rule, can currently not be used. It also applies to completely new systems in their test phases, which have to fulfil certain requirements. Thus, this law does not constitute a general legalisation of new, non-standardised technologies (BMVIT, 2016).

The following legal requirements apply to self-driving shuttlebuses.

Extract from section 2, paragraph 7 of the AutomatFahrV (Austrian Federal Law Gazette, 2016):

(1) This regulation defines an automated mini-bus as a vehicle of class M1, M2 or M3, which is equipped with a system capable of carrying out all driving functions at speeds of up to 20km/h.

(2) These systems may be tested by automotive manufacturers, system developers and research institutes.

(3) These systems may only be used on roads with open traffic after they have already completed a minimum of 1000 test kilometres.

(4) Autonomous mini-buses may be tested on pre-defined test routes.

(5) As soon as the driver activates the system, all functions are to be transferred to the system. The system must therefore be capable of automatically dealing with all driving situations.

(6) The system must feature an emergency deactivation device. In the event of an emergency, the driver must immediately deactivate the system.

(7) The system may be tested at a maximum speed of 20 km / h.

(8) During the test period, the route may not be operated commercially, and passengers must sit only in designated seats.

1.2 First test drives in Salzburg

On 19th October 2016, Salzburg Research tested the first self-driving shuttlebus in Austria in the historical centre of Salzburg. At the end of 2016, Salzburg Research applied for, and was granted permission to test self-driving shuttlebuses in accordance with the AutomatFahrV (Austrian Federal Law Gazette II Nr. 402/2016) (see section 2.3).

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Figure 4: First test drive with the Navya Arma DL3 shuttlebus in the historical centre of Salzburg

2 Test drive authorization procedures

In order to be able to carry out tests on open roads in Austria, it was necessary to obtain permits for the test operations, a vehicle licence plate, and insurance coverage.

2.1 Vehicle licence plate for the self-driving shuttlebus

Paragraph 4 of the AutomatFahrV states that automated vehicles, that are not approved to drive on public roads, can be tested using a test licence plate (Austrian Federal Law Gazette, 2016). After consulting with the Salzburg vehicle licencing authorities and the regional police, an application was made to the regional police department for a test licence plate for the self-driving shuttlebus. After a positive review of the application, Salzburg Research was issued a test plate with the number S-1IBV. The licensee for the self-driving shuttlebus was Salzburg Research.

Figure 5: Test licence plate for the self-driving shuttle

2.2 Insurance

The self-driving shuttlebus was insured by UNIQA Österreich Versicherung AG. This included vehicle liability insurance for the sum of 20 million Euros, as well as comprehensive vehicle cover.

2.3 Application process for test authorisation

Salzburg Research applied on behalf of the Federal State of Salzburg (Department 6 - Regional Building Directorate) to the Federal Ministry for Transport, Innovation and Technology for a licence to test a self-driving shuttlebus on public roads on the basis of the framework conditions for automated driving (AutomatFahrV) as set out by the same federal ministry. The BMVIT confirmed that Salzburg Research had provided appropriate evidence, and, on 18th April 2017, issued a licence to test a Navya Tech self-driving shuttlebus during the period from the 20th April 2017 to 31st December 2017. The test drives were permitted to be carried out by eight named Salzburg Research employees.

3 Test route in Koppl (Salzburg)

The self-driving shuttle test route was set up in the municipality of Koppl. The municipality is located in the district of Flachgau, and borders the eastern city outskirts of the regional capital of Salzburg. The following table presents some key figures concerning the municipality of Koppl (Municipality of Koppl, 2017):

Key Figures for Koppl (as of 01/2017)	
Federal Region	Salzburg
Number of inhabitants in the municipality of Koppl	3.413
Number of households	1.243
Area	20,9 km²
Altitude	755 metres above sea level
Population density	163 inhabitants per km²
Number of settlements within the municipality	6

Table 1: Key figures for the municipality of Koppl

3.1 Test routes in the municipality of Koppl

During the test period, two test routes were established in the municipality of Koppl. In April and May, a short test route (see figure 5) with 400 meters in length between the village centre and Schützenweg served as a demonstration route, and enabled Salzburg Research employees to gain an initial level of familiarity with the technology. Because of the short journey time of approximately five minutes for one test circuit, this route was above all suited for larger groups of passengers and people who were especially interested in the technology.

The second test route linked the Koppl village centre to the Sperrbrücke bus stop (see figure 5). The length of the test route was approximately 1.4 km one-way, and 2.8 km return. The gradient of this route reaches a maximum of 8 percent, or 65 m difference. Including start and terminus stops, four bus stops were established in each direction on this route. The rural location of this route presents a number of challenges (e.g. lack of points of reference such as buildings or road markings for the reliable positioning of the vehicle), poor GPS signal quality, and poor road infrastructure such as a lack of regulated intersections, as well as the maximal road gradient of 8 percent. Test drives were carried out along this route between June and November.

The map on the next page shows the two test routes in Koppl.

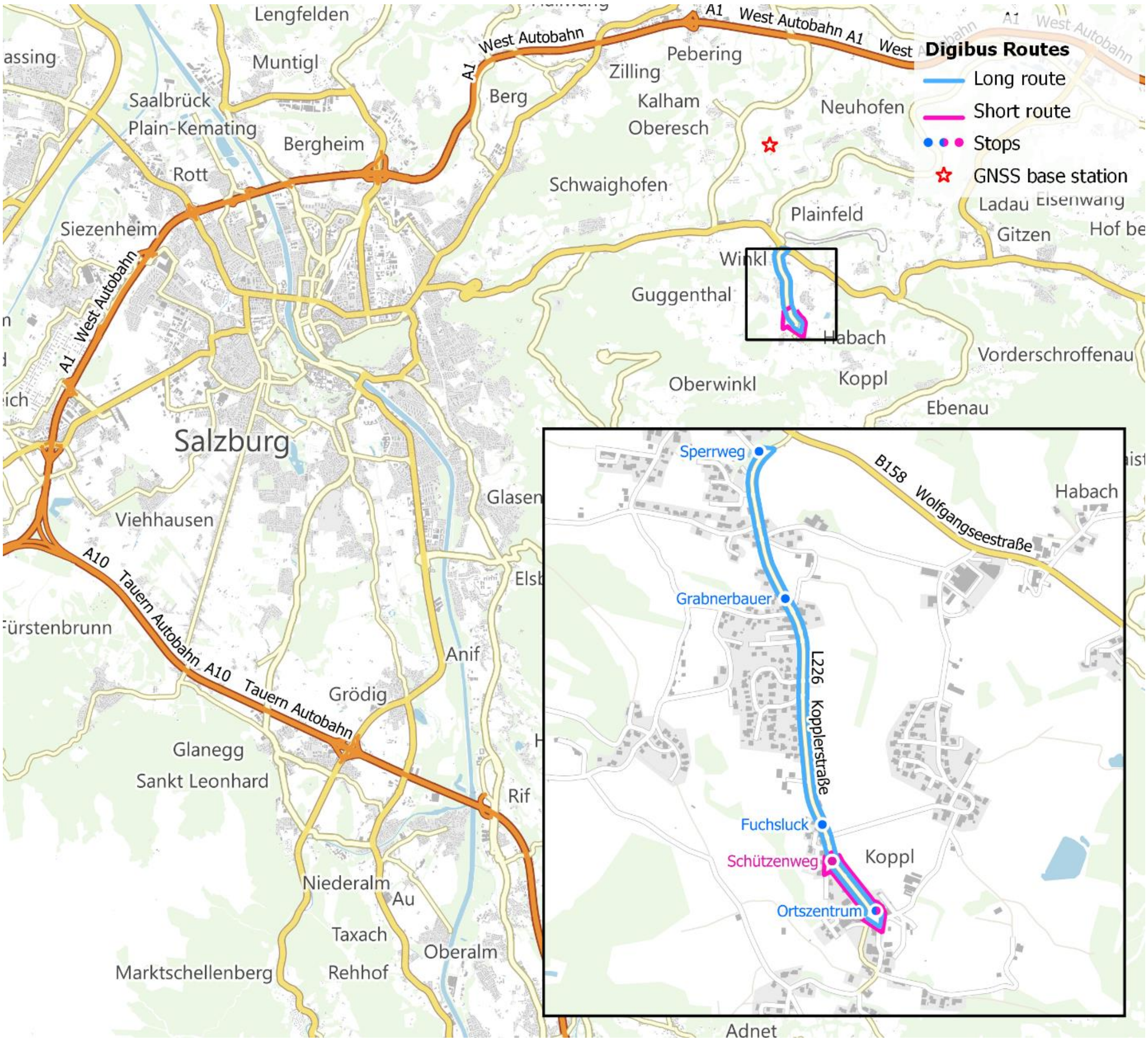

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Figure 6: The two rest routes in the municipality of Koppl, Salzburg

3.2 The first and last miles in local public transport

In local public transport, coverage of the "first and/or last mile" – i.e. the stretch of road between the bus stop and the destination or home – is crucial for customer acceptance. If the distance is too long people prefer to use their private cars instead of the public transport offered. Self-driving buses offering a local shuttle service can render the public transport option significantly more attractive. The trend for automatization is increasingly playing a role in public transport provision. Micro-public transport systems, that is shuttle services to public transport stops, have improved the quality of service, especially in rural areas. However, micro-public transport systems are either expensive to run, or are volunteer-based. Because of this, it is currently not possible to roll-out such systems extensively. Automated transport systems - highly automated vehicles or self-driving shuttlebuses – have the capacity to enable new kinds of micro-public transport systems, which can be used to link rural areas or city quarters to the transport network.

The municipality of Koppl represents a typical example of the first and / or last mile concept. As mentioned earlier, the village centre is situated 1.4km from main road no. 158 (between Salzburg and Bad Ischl), and is thus unconnected to the Salzburg Postbus line 150. The 152 bus links the 150 Postbus with the village centre. However, it runs infrequently due to financial reasons. A self-driving shuttlebus could fill the gaps during less financially viable time periods.

3.3 Potential applications of self-driving shuttlebuses

In the long term, there are many potential applications for self-driving shuttlebuses in a municipality like Koppl. These include shuttle services for commuters and schoolchildren, tourist services - for example to take tourists to the start points of hiking trails - or even a delivery service which could be offered during off-peak hours.

Below, the potential applications of a self-driving shuttle service will be described using the example of the municipality of Koppl:

- **Shuttle service from predetermined bus stops to public transport routes for daily commuters.**

  The self-driving shuttlebus picks up commuters from a predetermined bus stop situated a maximum of 200m from their places of residence and brings them, together with other passengers to the stop for the 150 bus. By coordinating runs using the 150 timetable and real-time travel information, the shuttle always runs on time and avoids unnecessary waiting times. Several predetermined bus stops are situated, according to demand, along the route between the village centre and the bus stop for the 150 Postbus.

- **Shuttle service to public transport routes for daily commuters: on-demand service with pick-up at home.**

  The self-driving shuttlebus can be ordered in advance by app or online, and brings passengers alone, or with others depending to demand at that time, to the 150 Postbus stop. The shuttle picks passengers up directly from their homes at their requested time.

- **Shuttle to the village centre for (day) tourists**

  The self-driving shuttlebus picks up tourists who arrive on the 150 Postbus at the Sperrbrücke bus stop. It brings them to Koppl village centre, or to other destinations as required (restaurants, hiking trails, view platforms etc.). The shuttle can either be ordered in advance by app, or requested directly at the bus stop. When required, the shuttle brings tourists back to the 150 Postbus stop at predetermined times.

- **Village Shuttle**

The self-driving shuttlebus circulates either according to a timetable, or on an on-demand basis between the village centre and the surrounding settlements. This shuttle service supports older residents in their daily activities (shopping, doctor's visits, visits to local government offices etc.), or, according to demand, brings residents from A to B. Example journeys include: bringing children to music lessons, bringing commuters to their voluntary fire-brigade training after work, or older ladies to their card game meet-ups.

- **On-demand delivery Service**

  The self-driving shuttlebus can provide a delivery service during likely off-peak hours. Customer's shopping can be delivered to their homes from the village supermarket, or dirty laundry from the hotel can be brought to the village laundrette. Additional services such as this lead to better utilization of the bus.

3.4 Physical and digital infrastructure in Koppl

In order to enable the Digibus route between Koppl village centre and the Sperrbrücke bus stop to run, some small road works and adaptations were necessary.

Firstly, a turning area was built at the Sperrbrücke bus stop, which allowed the bus to turn around. This turning area serves simultaneously as a bus stop. This bus stop is in proximity to the Sperrbrücke stop for the Postbus 150 line, and is conceived as a connecting stop in the context of the previously-described first or last mile scenario.

Figure 7: Turning area for the Digibus before and after construction work

At both the bus stop in Koppl village centre and the turning area near the Sperrbrücke bus stop, signs were erected to provide information about the test route and the test drive times.

A second bus stop, also identified as such with a sign, was created at the village centre car park, directly in front of the village hall and the volunteer fire station.

Figure 8: Signposted start-of-route stop in Koppl centre

Figure 9: Information about the Digibus test drive times at the bus stop in Koppl centre

The Digibus was parked and charged in a garage not far from the start point of the test route, provided by the municipality of Koppl for the duration of the test period. The garage is equipped with a 400 volt / 32-amp electricity supply, which, with the help of an adapter, was used to charge the shuttlebus (230 volt / 16 amp).

Figure 10: Digibus in its garage

The table below provides an overview of the physical and digital characteristics of the test route in Koppl.

	Physical and structural characteristics	Infrastructure quality
Physical Infrastructure	• Long test route: 1.4 km long each way with; 4 stops in each direction (including start point and terminus) • Short test route: 200 m long in each direction; 2 stops in each direction (including start point and terminus) • Asphalt road • Gradient of max. 8 % (approx. 65 metres difference) • Slightly winding road • Links to public transport (Postbus stop for bus lines 150/155 Koppl Sperrbrücke) • Turning area for the shuttlebus at the Sperrbrücke bus stop • Signalisation of the test route by the means of two road signs • Road markings	• Test route does not contain continuous road markings • Road damage is present along the entire route
Digital Infrastructure	• Digital 3D-map (recorded by the shuttle and edited by hand) • Mobile data connection (3G/4G) • Internet based service for GNSS data correction (APOS) / local reference base station for GNSS-correction data • Satellite coverage	• Connection with at least 14 satellites was not always guaranteed • Continuous 3G / 4G mobile data coverage was not always available

Table 2: Physical and digital characteristics of the test route

4 The Navya Arma test vehicle

The Arma DL3 Navya Tech model ran on the test routes between April and May, and the Arma DL4 model from June until November 2017. Navya Tech is a French company, specialised in the conception, production and running of electric automated vehicles. The company headquarters are situated in Paris and also Lyon (Villeurbanne). Navya Tech (formerly known as Infogames) was founded in 2014 by Christoph Sapet and develops technological solutions for sustainable mobility. The vehicles were delivered by Citroen PSA, as Navya Tech itself is specialised in the software technology (Navya Tech, 2017).

4.1 Characteristics of the self-driving shuttle

As of April 2017, Navya Tech had produced 33 self-driving shuttles. The test vehicle used in Koppl was number 33, i.e. the 33rd vehicle produced by Navya Tech. The main focus of the company is the worldwide demonstration of self-driving vehicles. The Navya Tech Arma shuttlebuses do not have EU type approval. For this reason, it was only possible to carry out the test drives with a test licence plate and not a normal one.

The Navya Arma DL4 shuttlebus has the following characteristics (Navya Tech, 2017):

- Dimensions: 4.75 m long, 2.11 m wide, 2.65 m high
- Engine: electric motor
- Localisation and obstacle sensors:
  - two 360° multi-layer LIDARs (Light detection and ranging)
  - six 180° mono-layer LIDARs
  - stereovision camera
  - odometry (position und orientation using data from its propulsion system)
- Speed: max. 45 km/h (maximum permitted speed for test drives on public roads in Austria 20 km/h)
- Capacity: max. 11 persons (9 persons in test use period)
- Runs on predefined routes
- Emergency deactivation button present
- Experience with mixed traffic and passenger transport present

The shuttle is accessible to wheelchairs and pushchairs by means of a ramp.

Figure 11: Digibus disabled and pushchair access

4.2 Identity of the self-driving shuttle

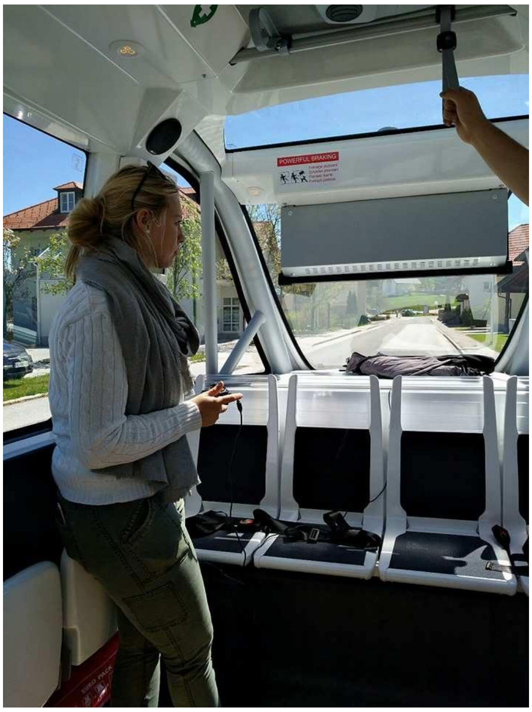
The Digibus 2017 test is part of a longer-term series of tests with self-driving shuttlebuses. For this reason, from the outset, the goal was to develop a brand for the test series, along with a corporate design that was independent from the vehicle manufacturer, because several different manufacturers could be involved in future tests. A common language needed to be found, starting with a name for the vehicle which would henceforth be used in all communication regarding the project. Thus, Salzburg Research commissioned WUGER – Brands in Motion to develop a corporate design. The resulting name, "Digibus", combines "digital" (autonomous driving) with "bus". Regarding the design, simply put, it is about linking two waypoints. The "digital dots" represent waypoints between which electricity and information flow - the domain within which the Digibus circulates. The name "Digibus" was registered by Salzburg Research as a trademark with the European Union Intellectual Property Office. The trademark registration occurred on the 11th October 2017.

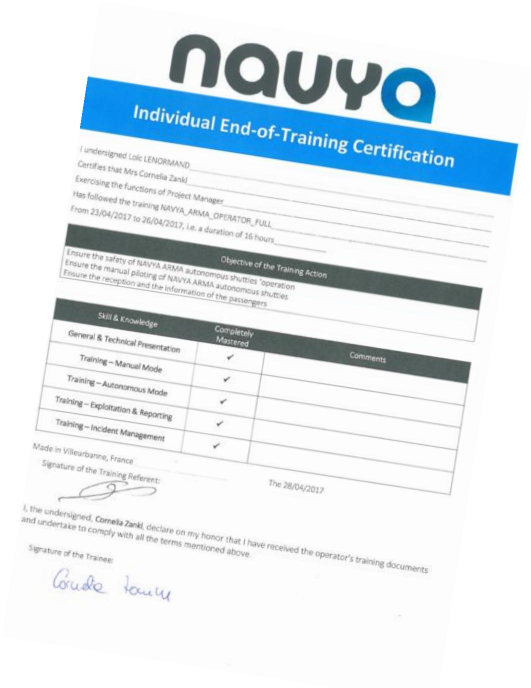
Figure 12: (a) Applying decals to the Digibus, (b) Digibus corporate design

4.3 Operator Training

In accordance with the AutomatFahrV regarding tests on public roads, a trained attendant had to be present on the shuttlebus in order intervene in the case of an emergency. Eight Salzburg Research employees were trained as operators for the test runs in Koppl. The training was carried out by a Navya Tech employee and consisted of the following components:

- Technical specifications of the shuttle
- Manual control of the shuttle
- Autonomous driving procedure
- Monitoring and reporting
- Management of emergencies





navya

Individual End-of-Training Certification

I undersigned Loic LENORMAND
Certifies that Mrs Cornelia Zankl
Exercising the functions of Project Manager
Has followed the training NAVYA_ARMA_OPERATOR_FULL
From 23/04/2017 to 26/04/2017, i.e. a duration of 16 hours

Objective of the Training Action
Ensure the safety of NAVYA ARMA autonomous shuttles 'operation Ensure the manual piloting of NAVYA ARMA autonomous shuttles Ensure the reception and the information of the passengers

Skill & Knowledge	Completely Mastered	Comments
General & Technical Presentation	✔	
Training – Manual Mode	✔	
Training – Autonomous Mode	✔	
Training – Exploitation & Reporting	✔	
Training – Incident Management	✔	

Made in Villeurbanne, France
Signature of the Training Referent: The 28/04/2017

I, the undersigned, **Cornelia Zankl**, declare on my honor that I have received the operator's training documents and undertake to comply with all the terms mentioned above.

Signature of the Trainee:

Figure 13: (a) Driving in manual mode, (b) A Navya training certificate

4.4 Deployment procedure

The shuttlebus can only drive automatically on routes that have previously been charted manually. The test route was learned by driving on it in manual mode (steering using an X-box controller) at a speed of one meter per second. Environmental data was captured using SLAM-Technology (Levison, Thrun, & Montemerlo, 2007) and recorded in the form of a 3D point cloud, or "virtual trajectory". Figuratively speaking, capturing the trajectory resulted in invisible tracks being laid down along the test route. In a post processing stage, all dynamic objects such as bicycles, pedestrians, and cars were iteratively removed from the 3D point cloud and the trajectory, so that the desired driving behaviour was attained. Steering commands for the vehicle were manually added for intersections and bus stops. This process was repeated until both a satisfactory 3D map and trajectory had been created. The process took approximately three weeks for the longer test route in Koppl.

4.5 Positioning and environment recognition

The technical conception of the Navya Arma is based on three cross-cutting tools: environmental sensors, through which the shuttle can recognise its environment and avoid obstacles; programming rules according to which the route and the trajectory are calculated; and a navigation system, which implements the decisions made by the on-board computer and translates these into movement commands.

LIDAR sensors were used for detecting the environment and mapping. These permit the vehicle to locate itself precisely and are necessary for the detection of obstacles. The shuttle features three sensors on both the front and back, and two on each side. The LIDAR sensors were predominantly used for shuttle positioning in the built-up areas of the village. As long as there were buildings to the left and right of the test route which the sensors could use as reference points, the system was able to localise itself with high level of precision.

In addition, because of the rural setting, this system was combined with a Multi-GNSS Real Time Kinematic System (RTK) (Sun, Xia, Foster, & Lee, 2017) because it was not possible to localise the vehicle using only the LIDAR sensors in non-built-up areas. Multi-GNSS RTK is a technology that uses satellite positioning to determine the exact localisation of a vehicle down to a centimetre. Exact GNSS-positioning requires a reliable correction signal from a nearby GNSS reference station. This signal is transmitted over mobile networks (3G / 4G) from an internet-based correction service (for example the APOS service in Austria), or from a local reference station (for example using UHF frequencies). Because of the lack of reliable mobile network coverage on parts of the route, a proprietary Navya Tech GNSS base station was erected in Koppl on the hill opposite the test route. Such "direct eye-contact" is an advantage when it comes to establishing a reliable signal, and thus a reliable correction signal could be received from the GNSS base station over the whole course of the route.

Figure 14: Proprietary GNSS base station opposite the route

In addition, during the route capture process, odometry was used to recognise traffic lanes. In automated driving mode, the odometer is used to confirm the position of the vehicle. Furthermore, the three-dimensional status of the vehicle is determined using an Inertial Measurement Unit (IMU).

4.6 Driving manoeuvres and driving situations

Every manoeuvre of the shuttle must be defined manually in a preliminary stage. Thus for each route section the speed, traffic priority rules, turns etc. must be determined manually. The self-driving shuttlebus can currently only master very simple manoeuvres at low speeds. It is able to stop in front of obstacles that block the way. Driving around obstacles or overtaking over road users, for example cyclists, was not possible during the test phase.

The following manoeuvres were tested in Koppl:

- making a right turn from a side road into a priority road without traffic signalisation
- making a left turn from a priority road into a side road without traffic signalisation
- complying with traffic priority rules, including stop signs
- interacting with other road users (cars, trucks, bicycles and pedestrians)

4.7 Driverless operation

Driverless operation is currently only possible on cordoned-off road sections. In accordance with the AutomatFahrV, automated vehicles always need to be supervised by a trained operator on public roads in Austria. Aside from these legal restrictions, driverless operation is not currently possible with the Navya shuttle due to technical reasons (see chapter 6).

5 Test drives with the self-driving shuttlebus

The following section presents the preventative safety measures taken, the test procedures, and the aims of the test drives.

5.1 Preventative safety measures

Before test runs began, Salzburg Research developed safety measures which regulate how an operator should react in the case of an accident or a dangerous situation. In order to avoid accidents or dangerous situations, a checklist of items to consider before taking control of the shuttle was created, and a more detailed test drive procedure was drawn up. The criteria included the following items:

- What counts as an emergency situation?
- When should the emergency mechanism (emergency stop) be activated?
- Operator behaviour at the accident site
    - in the case of physical injury to persons
    - in the case of property damage
    - in the case of technical faults
- Communication in the event of an accident (internal)
- Contact people to inform in the case of an emergency
- Emergency services telephone numbers

5.2 Announcement of the test drives

In order to inform the population of Koppl and its environs about the activities of Salzburg Research, regular information was disseminated over various communication channels.

5.2.1 Communication through the municipality of Koppl

The Koppl municipal newspaper included regular reports on the test framework and the tests themselves. In addition, information posters about public test times were displayed on A-stands at several locations in the municipality.

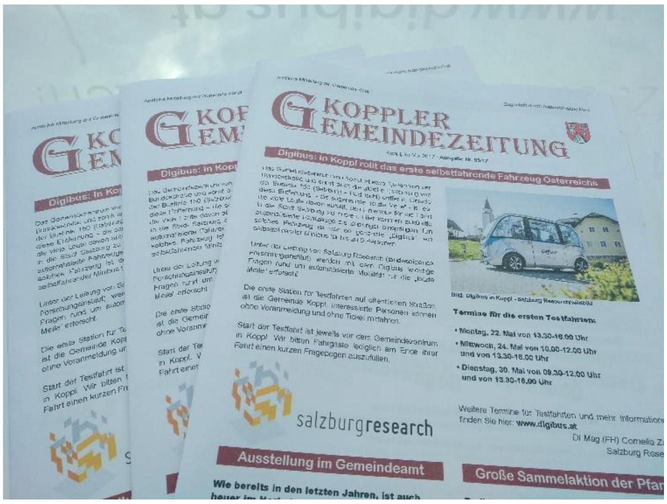


Figure 15: Report in the Koppl municipal newspaper on the Digibus test drives

5.2.2 Website

The Digibus website, www.digibus.at, provided both general information concerning automated driving in Austria, the test route in Koppl, and general technical information, as well as more specific features of the Digibus and its deployment scenario. The website also featured information on the public test times.

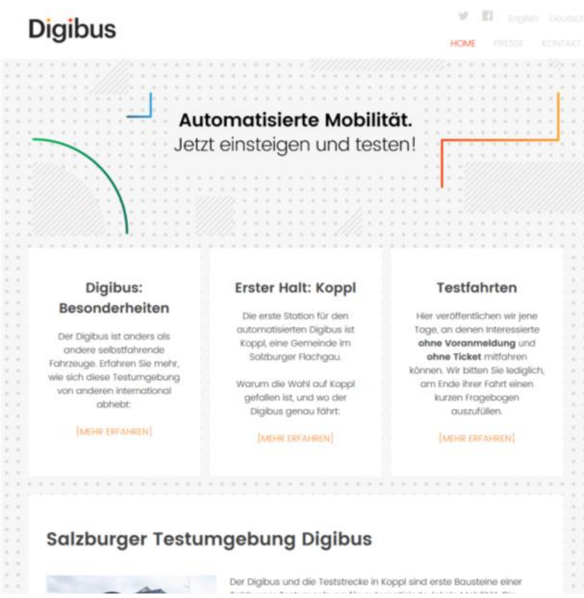


Figure 16: Digibus website

5.2.3 Social Media

The latest information regarding the Digibus was published using a Digibus Twitter account as well as a Digibus Facebook page.

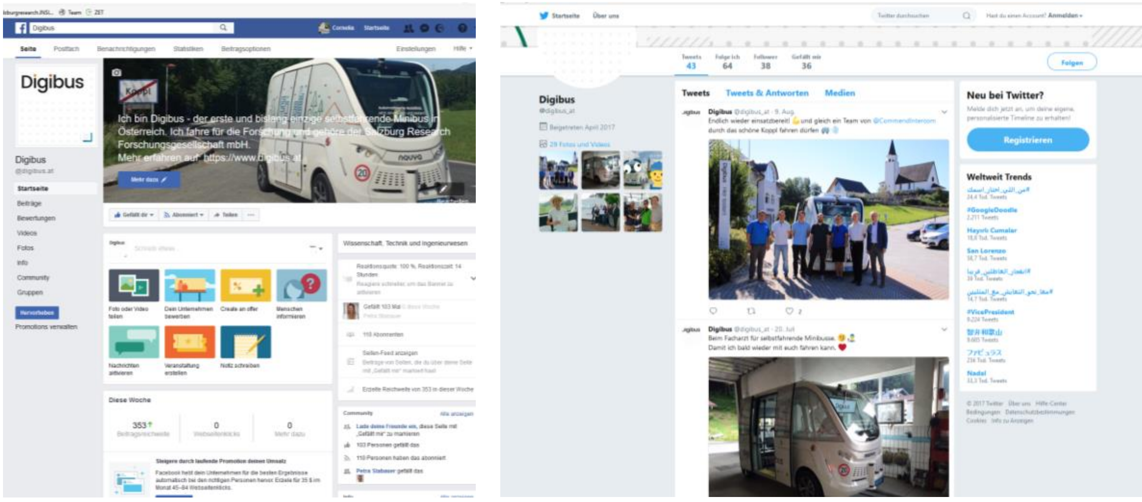


Figure 17: (a) The Digibus Facebook page, (b) Digibus on Twitter

5.2.4 Print media

Besides digital promotional material, print media, such as postcards and posters were also used. These also provided general information about the project, as well as details of the test drives.

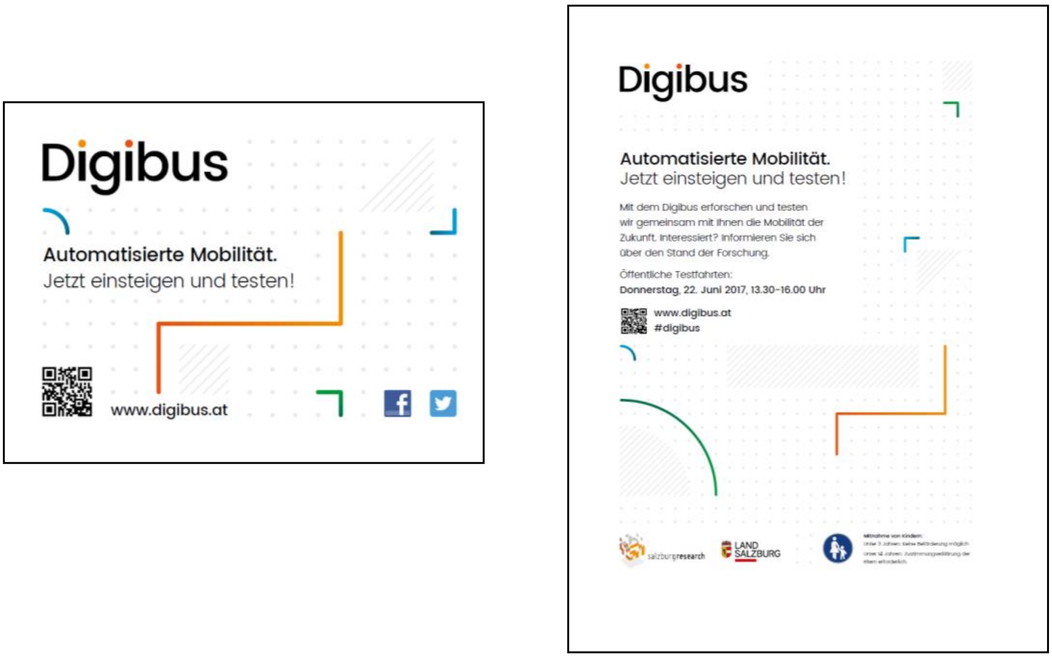


Figure 18: (a) Digibus postcard, (b) Digibus poster

5.3 Test procedures

Each of Salzburg Research's tests followed a predefined procedure. After the shuttle had been transported from the garage to the route start-point in manual mode, a test-run was carried out with only the operator on board. Only once this test drive ran smoothly, did test drives with passengers begin.

5.4 Children on board

According to paragraph 3 section 1 Z 2 2.1.2. of the Austrian Motor Vehicle Act (KFG), the Digibus falls into the category of a passenger vehicle with over eight seats excluding the driver's seat, with a maximum allowed weight of 5 000 kg (M2 class) (Austrian Motor Vehicle Act, 1967). Because the shuttle did not transport passengers on a regular basis, and Salzburg Research cannot be classified as a passenger transportation operator, the Digibus was thus classed as an omnibus not operating as part of a scheduled service.

As such, according to paragraph 106 section 5 Z 1 of the KFG, the vehicle driver must ensure that children under the age of 15, who are at least 150cm tall, are only transported when seated and using a seat belt, according to legal requirements.

Paragraph 106 section 5 Z 3 of the KFG also states that drivers of M2 class vehicles that do not operate as part of a scheduled service must also ensure that children under the age of 15 use the safety equipment provided (seat-belts, restraint systems) when they are in their seats. When the child is accompanied by an adult, this responsibility passes to that adult.

As a result, the Digibus transported children under the following conditions:

- Children under the age of 3 could not be transported as there was no safety equipment suitable for them in the shuttlebus.
- Children between the age of 3 and 14 were required to use seat-belts.
- Minors not accompanied by an adult were required to provide a consent form signed by a parent or legal guardian.

Digibus

Zustimmungserklärung
für die Mitfahrt im selbstfahrenden Minibus (Digibus) meines Kindes (bis zur Vollendung des 14. Lebensjahres)

Bitte alle Angaben in Blockschrift machen!

Nachname des Erziehungsberechtigten:	
Vorname des Erziehungsberechtigten:	
Geburtsdatum des Erziehungsberechtigten:	
Wohnanschrift des Erziehungsberechtigten:	

Nachname des Kindes:	
Vorname des Kindes:	
Geburtsdatum des Kindes:	
Wohnanschrift des Kindes:	

Hinweise: Kinder bis zur Vollendung des 14. Lebensjahres dürfen nur auf einem Sitzplatz unter Verwendung der vorhandenen und bestimmungsgemäß gebrauchten Sicherheitsgurte transportiert werden. Abruptes Bremsen ist während der Testfahrt ist möglich.

Ich stimme zu, dass mein minderjähriges Kind an einer Testfahrt mit dem selbstfahrenden Minibus teilnehmen darf.

Ort, Datum — Unterschrift des Erziehungsberechtigten

salzburgresearch

Salzburg Research Forschungsgesellschaft mbH | Jakob Haringer Straße 5/3 | 5020 Salzburg, Austria

Figure 19: (a) Consent form to be signed by parents or legal guardians for the transportation of unaccompanied children in the Digibus, (b) Sign inside the Digibus concerning the transportation of children

5.5 Aims of the test drives

The aims of the test drives in Koppl were as follows.

5.5.1 Internal test drives

Internal test drives were primarily carried out for training purposes and to test the technology and driving manoeuvres. During the internal test drives, employees from Salzburg Research and Navya Tech were on board.

5.5.2 Demonstration runs for business delegations

Many organisations active in the broader areas of autonomous vehicle technology, digitalisation technology, robotics etc. were interested in finding out more about the new technology. Thus test runs were carried out by Salzburg Research for business delegations on request.

Figure 20: Demo runs with Commend Österreich and Salzburg Wohnbau AG

5.5.3 Demo runs at events

Demo runs were also carried out at events as features on their event programs. In this manner, attendees of the 4th Nahverkehrskongress (local transport congress) (26th April 2017), AGIT (Symposium for applied Geoinformatics) (7th July 2017), and the Koppl village fete (16th July 2017) took part in demo test runs.

5.5.4 Public test runs as part of eMobility Playdays

Test runs outside of Koppl were also offered in the context of the eMobility Playdays on 29th and 30th September 2017 in the Red Bull Racetrack in Spielberg (Styria). In this case, it was possible to run test drives for the public on private property and not open roads. On these two days, a total of 60 test drives were carried out on a two kilometre circuit (one kilometre each way), thus transporting 360 passengers. The route consisted of driving on a virtually straight stretch of road and turning around on the road (see figure 21). In order to obtain a reliable correction signal and exact positioning, a GNSS base station was also erected in the Spielberg racetrack. The distance between the GNSS base station and the test route was between 800 and 1500m (beeline). In contrast to the route in Koppl, there was no "direct eye-contact" in this case. The correction signal was transmitted over a mobile network (3G / 4G).

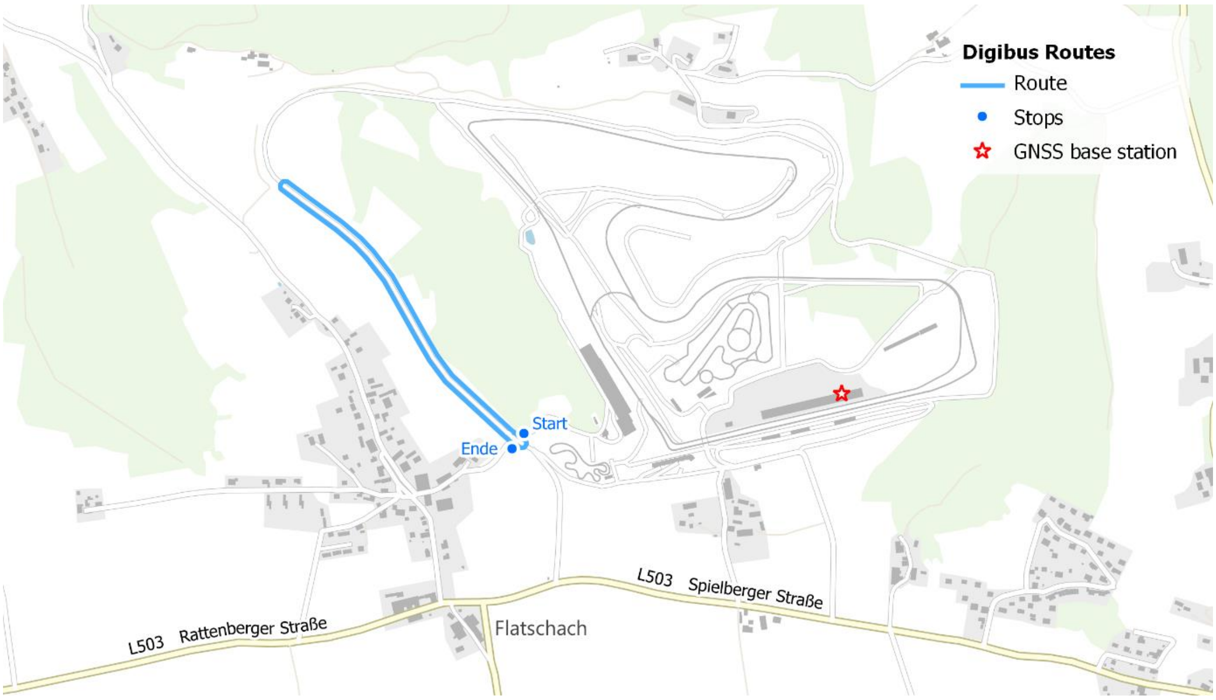


Figure 21: Test route at the Red Bull Racetrack in Spielberg

5.5.5 Public test drives for private individuals

Part of the research project sought to offer interested individuals the chance to try out the shuttlebus for free in Koppl and share their experiences with Salzburg Research. Thus, regular public test runs were carried out so that interested private individuals could take part in a test run on the Digibus. Test run schedules were posted on the Digibus website, on Facebook and Twitter, on the Digibus bus stop information boards, on posters, and were published in the municipal newspaper.

Figure 22: Test runs with private individuals

5.5.6 Test runs with press representatives

The press was also highly interested in discovering the new technology. Both press representatives from print and online media organisations, as well as television reporters were interested in the Digibus test drives.

Among others, the following media organisations either took part in Digibus test drives and / or reported on the tests: ADAC Motorwelt, Falter, der Standard, Die Presse, Kronen Zeitung, ORF, Tölzer Kurier, Salzburger Nachrichten, Traktuell, Wiener Zeitung.

Figure 23: Test drive with the Raum.Film team, who filmed a report on the theme of automated driving for the ORF.

6 Results and insights gained from the Digibus test drives

The 7-month test period provided Salzburg Research with numerous valuable insights. A key insight is that practical experiences with automated driving using public test routes are essential for the testing of this new technology. Regarding the development status of the technology, there were great differences between the vehicle manufacturer's claims and real experiences on the ground. Thus, although the vehicle was able to reliably stop in front of obstacles, despite the manufacturer's claims, it could not drive around them. Contrary to Navya Tech's indications, intersections, especially when turning left, could only be navigated with the help of an operator.

The following section provides details of the results and insights gained from the test drives with the Navya shuttle.

6.1 Key Figures

The following figures provide an overview of the test drives carried out between April and November 2017. This data was recorded by vehicle operators by filling out an online test protocol on a smartphone.

Key figure	Number
Passengers transported	874
Total number of test drives	240
- **of which short route test drives**	138
- **of which long route test drives**	102
Kilometres driven	341
- **of which on country roads**	22
- **of which in built-up areas**	318
Number of accidents	0
Number of critical situations	1

Table 3: Digibus test drive key figures

In the test period between 24th April and 22nd November, a total of 240 test drives were carried out (138 on the short route and 102 on the long route), and 874 people were transported. The vehicle covered a total of 341 kilometres during the test drives. Most test drives (70 %) took place under sunny and dry, or slightly cloudy conditions. 28 % of test drives were carried out during cloudy or rainy conditions. 2 % of test drives took place under very wet conditions, 0,7 % in snow showers. The test drives carried out in very heavy rain and snowfall had to be aborted due to poor weather conditions.

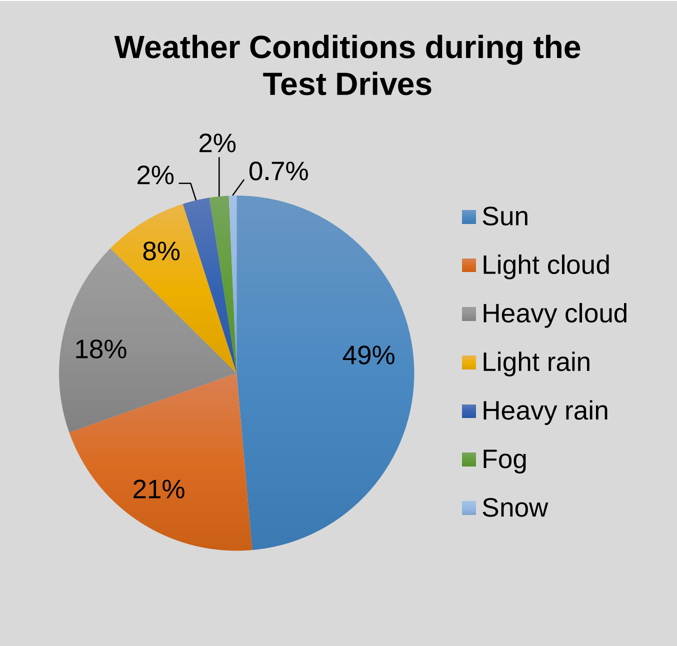


Figure 24: Weather conditions during the test drives

The majority of test drives were carried out as demonstration runs for business delegations, representatives of the public authorities and transport authorities, the press, or private individuals. Approximately 18 % of runs were used for technical testing. These were used, for example, to optimise the guidance system, to update software, carry out brake and functionality tests, as well as to assess the sensor array range. 19 % of test runs consisted of initial training upon receiving the shuttle, during which only an operator was on board. 15 % of runs represent operator training, and 3 % are data collection runs, during which the shuttle learned the route.

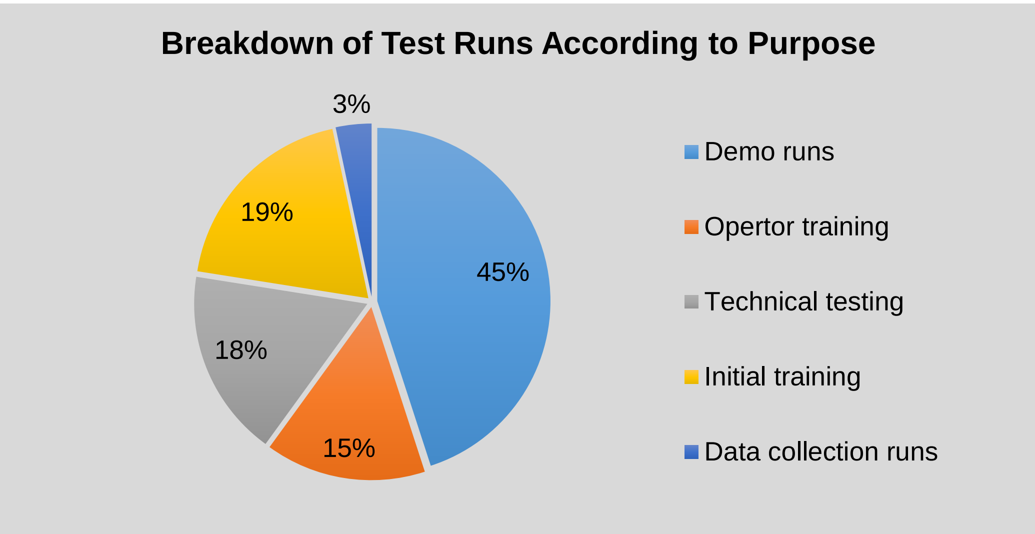


Figure 25: Breakdown of test runs according to purpose

6.2 Accidents and critical situations during the test drives

No accidents or near-accidents occurred during the 7-month test period. One critical situation occurred during a test drive, which is described below.

On 7th July 2017, eight test runs were carried during a period of three hours. The stretch of road had been covered 16 times (out and return = one test run). As previously mentioned, the length of a one-way stretch was 1.4 km. The total mileage that day was thus 22.4 km (16 x 1,400 m = 22,400 m). The maximum gradient of the route was 8 %.

For the first five runs, two to four people were in the shuttle each time. For runs six to eight, there were nine. This figure represents the maximum passenger load the Navya shuttle is allowed to carry according to the AutomatFahrV, and the operator's driving licence. The goal was to carry out the test drives in automatic mode. On test run number seven, a drop in the electric motor's performance occurred, so that the shuttle was no longer able to cope with the sloped section as normal, and stopped although no obstacle was visible. The operator then attempted to complete the section in manual mode whilst the vehicle was still fully loaded. However, due to the drop in motor performance, this was also unsuccessful. It was no longer possible to move forwards, and in manual mode, the shuttle rolled one to two metres backwards down the slope. The passengers thus disembarked and the air-conditioning was turned off. After several attempts, the operator managed to cover the section, but without any passengers. Once the shuttle reached a flat section, the passengers re-boarded and the run continued to the end of the route. This drop in performance repeated itself during run number eight. On this last run, it was no longer possible to climb the gradient at all, and the shuttle was driven manually back down the slope and to the turning point (Sperrbrücke bus stop). During this manual return trip, strange braking and manoeuvring behaviour was noted. Braking felt jerky, and the manoeuvrability of the controller was limited. The shuttle was then parked and turned off at the turning point for around 1.5 hours. The shuttle was then once again capable of driving back to Koppl village centre in manual mode.

The electric parking brake functioned throughout the test runs, meaning that the shuttle could be brought to a halt even on steep sections of the route. Because of the drop in performance, the electric motor was no longer able to produce enough power to climb the slope, which resulted in the shuttle coming to a stop when in automatic mode. In manual mode, because of the insufficient level of power, attempts to move forwards on the gradient led to the vehicle rolling backwards. When the operator switched from forwards acceleration back to the stop mode, the shuttle halted immediately.

The speed reached during the test runs was 4.5 m/s (16.2 km/h) maximum. The ambient temperature was between 25° und 26° Celsius and it was sunny. The road was dry. At the time of the incident, the battery status was at 50 % charged.

It was not necessary to use the emergency brake (red button in the shuttle). In order not to endanger passengers during the last run, they were asked to disembark from the vehicle as soon as the incident occurred. The run was then continued without passengers. The passengers had to either walk back to the start point or were picked up by a bus.

A thorough investigation of the critical situation was carried out by Navya Tech, which revealed that the problem had occurred due to the electric motor overheating (an engine temperature was measured of more than 150° Celsius). In order to protect the motor, the vehicle had switched into safety-mode which reduced the capacity of the engine (the electrical power supply was reduced). As a consequence, the vehicle lost power, which explains why the shuttle was no longer able to cope with the gradient. Navya Tech had not informed operators that the shuttle could switch into safety-mode in the case of a malfunction. The unusual braking and manoeuvring behaviour described above resulted from driving in the safety-mode.

In order to avoid further overheating during subsequent test drives, Navya Tech fitted the vehicle's electric engine with a cooling fan. It additionally promised to program a "notification window" which would appear on the shuttle computer screen should the engine temperature reach a critical level. This was not fitted before the end of the test phase in November, however.

6.3 Qualitative results

The test drives carried out by Salzburg Research showed that the self-driving vehicle currently does not meet the requirements for a highly- or fully-automated vehicle. The vehicle is in fact a prototype in its research and development phase. The actual capabilities of the shuttle were far lower than expected. Although the manufacturer claims that the Navya Arma DL4 shuttle is the first self-driving vehicle that fulfils the requirements to reach SAE J3016 level 5 ("full automation"), on the basis of our experiences in Koppl, we would classify the vehicle as level 3 at best ("conditional automation"). This means that a human operator has to oversee the behaviour of the vehicle during most manoeuvres in order to intervene if necessary. Some manoeuvres (turning into a road from a side road, turning out of bus stops, left-hand turns, and negotiating unregulated intersections with on-coming traffic) can currently only be accomplished with human intervention.

6.3.1 Challenges during testing

The following points emerged during testing as the greatest challenges:

(1) Organisational challenges: Cooperation with the vehicle manufacturer, Navya Tech proved to be difficult. Responses to our feedback were limited, and sometimes very slow or did not occur at all. We would have hoped that our feedback would have led to further refinement of the technology. This did not occur, however. No technical improvements were made to hard- or software during the test period.

(2) Infrastructure challenges

- Infrastructure challenges emerged from the rural location of this route (lack of points of reference, such as buildings or road markings etc.), which limited the ability to use the LIDAR sensors. There was poor GPS signal quality, and poor road infrastructure, such as a lack of regulated intersections, as well as an elevation difference of 65 m along the route (8 % maximum gradient).
- Because it was not possible to turn the vehicle around in the road or using a side-road at the end of the route, a turning place had to be constructed. This was built by the municipality of Koppl.
- It was also necessary to have a lockable, dry garage with electric charging capabilities nearby in order to store the vehicle and keep it safe when not in operation.
- A place on a hillside overlooking the test route had to be found for the GNSS base station. The base station also needed a lockable area / room with an electricity supply, and needed to be situated in a position that allowed a direct view of the route so that the correction signal could be sent between the base station and the shuttle.

(3) Technical challenges: There were manifold technical challenges including, for example, the following:

- **Deploying a new route** is currently both a complex and resource-intensive process. The automated vehicle lacks both a standardised, manufacturer-independent process for analysing, evaluating and digitising the driving environment, as well as a standardised tool-chain for the (partly) automated generation of a digital driving environment or traffic lane.
- One of the most commonly registered problems was that **the shuttle would come to a halt without any visible reason or obstacle** on the road. Possible reasons for this issue could be branches or bushes along the roadside, unreliable network data transfer (3G / 4G or UHF) which prevented the reliable transmission of the GNSS correction signal necessary for positioning the vehicle, or sensor reflections.
- Concerning **vehicle positioning**, the Koppl test runs revealed that LIDAR positioning functions reliably in built-up areas, so long as reference objects, i.e. buildings, are situated to the right and left of the route. However, as soon as the vehicle leaves built-up areas, other positioning tools are needed, such as Multi-GNSS-RTK positioning. The positioning accuracy is heavily reliant, however, on good quality satellite reception and reliable correction signal transmission. According to the manufacturer, the Arma DL4 shuttle requires contact with at least

14 satellites. Obtaining such a level of GNSS coverage for all sections of the route and all days of the test was challenging in Koppl. On many occasions, we experienced coverage of less than 14 satellites, especially on days with poor weather conditions.

- **Establishing the stable transmission of GNSS correction data** was also an issue. Primarily because of the varying quality of the 3G / 4G network in Koppl, internet-based services (e.g. APOS in Austria) were not reliable enough. The transmission issue was resolved by means of a local GNSS base station which was provided by Navya Tech, and transmitted a generally reliable UHF correction signal.
- Regarding **environmental detection**, the detection of static obstacles generally worked well, and the shuttle stopped reliably in front of obstacles. Problems did emerge from blind-spots, however, which prevented a reliable 360° detection of obstacles. This mainly was caused by the unfortunate positioning of the 360° LIDAR sensors on the top of the roof (the roof edges block the sensors on the side), something which can be easily remedied in future. Other problems resulted from the insufficient spatial resolution of the Velodyn VLP-16 LIDAR sensors. The 16 layers of these sensors are focussed on the area directly in front of and behind the vehicle, meaning that objects in the distance cannot be reliably detected, especially when those objects are moving at speed (over 30 km/h). This problem can be resolved by using higher resolution LIDAR sensors or additional sensors, such as radar sensors or cameras.
- Concerning **manoeuvring**, the tests showed that the shuttle can only carry out simple, predefined manoeuvres. The shuttle is far from capable of automatically carrying out all the manoeuvres along the route that are necessary in mixed traffic. As previously stated, the shuttle does stop reliably in front of obstacles on the route. However, it is not capable of passing these obstacles in automated mode. This must be done manually by an operator. Manual intervention from an operator is also necessary when pulling out of bus stops and turning left.

(4) **Challenges related to weather conditions:** Heavy rain and snow caused the sensors to recognise snow- and rainfall as obstacles, causing the vehicle to stop periodically. In such situations, it was no longer possible to advance in automated mode. Furthermore, the shuttle's ventilation, or air-drying system, was not sufficient to prevent the windscreen from steaming up on the inside in damp weather, meaning that the operator did not have sufficient visibility.

(5) One of the biggest challenges of testing the self-driving vehicle in mixed traffic situations was the **interaction with other road users**. In some situations, it was not clear what the self-driving vehicle was about to do next, and thus how other road users should behave. For example, the shuttle signalled that it was stopping by means of a display on the back window. But did that mean for the road user behind it that it was safe to pass the shuttle, or should they remain behind it? Such moments represented unresolved questions, and no interaction rules exist for interaction with other road users.

6.3.2 Frequency of occurrence of problems encountered during the test drives

The following table provides an overview of the relative frequencies of occurrence of problems encountered during the test period. The data is based on the test protocols which were filled out by operators after each test run. The occurrence of problems cannot be completely quantified, as on the one hand, data was collected through the means of a protocol, and on the other hand, Salzburg Research did not receive access to vehicle data from the manufacturer. It must thus be assumed that the problems recorded may have occurred more frequently, but were not always captured. The table below only lists problems that were actually noted in the protocol. For example, problems that occurred multiple times during a test run were not always recorded separately. In addition, the protocol was designed to be open (free text fields), because before the beginning of the test drives, the team could not predict what kinds of problems could possibly occur. It is recommended, however, that for future tests, the most common issues should be included in the protocol for the operator to simply select, so that they can be recorded more effectively.

Problems occurred during the Digibus test drives	**Recorded frequencies**
Shuttle braked in the absence of a visible obstacle	37
Manual braking / intervention was necessary	18
Not possible to continue forwards in automated mode after driving in manual mode or after a stop	14
Shuttle recognised an obstacle, manual intervention required to pass obstacle	11
Shuttle did not detect on-coming traffic (while turning left, or pulling out from the bus stop)	9
Shuttle lost positioning	7
Shuttle drove out of the bus stop backwards rather than forwards	4
Black box memory full. No further test runs were possible.	2
Acoustic signal indicating the detection of an obstacle would not turn off	2
Shuttle overtaken by another vehicle whilst making a turn	2
Shuttle did not respect traffic priority rules	2
Bus stop selection via the touchscreen did not work	1

Shuttle did not recognise an obstacle on the route	1
Driving manually not possible at speeds over 0.5 m/s. Moving to a higher speed not possible.	1
Complete system failure	1
Multiple stoppages due to sleet	1

Table 3: Recorded frequency of problems encountered during the Digibus test drives

6.4 Quantitative Results of the Passenger Survey

Besides the evaluation of the shuttle's capabilities, the second goal of the test runs was to collect data on passenger experience. After each test drive, passengers were requested to answer questions on their experience by means of an online survey on a smartphone. During the test period a total of 294 surveys were completed.

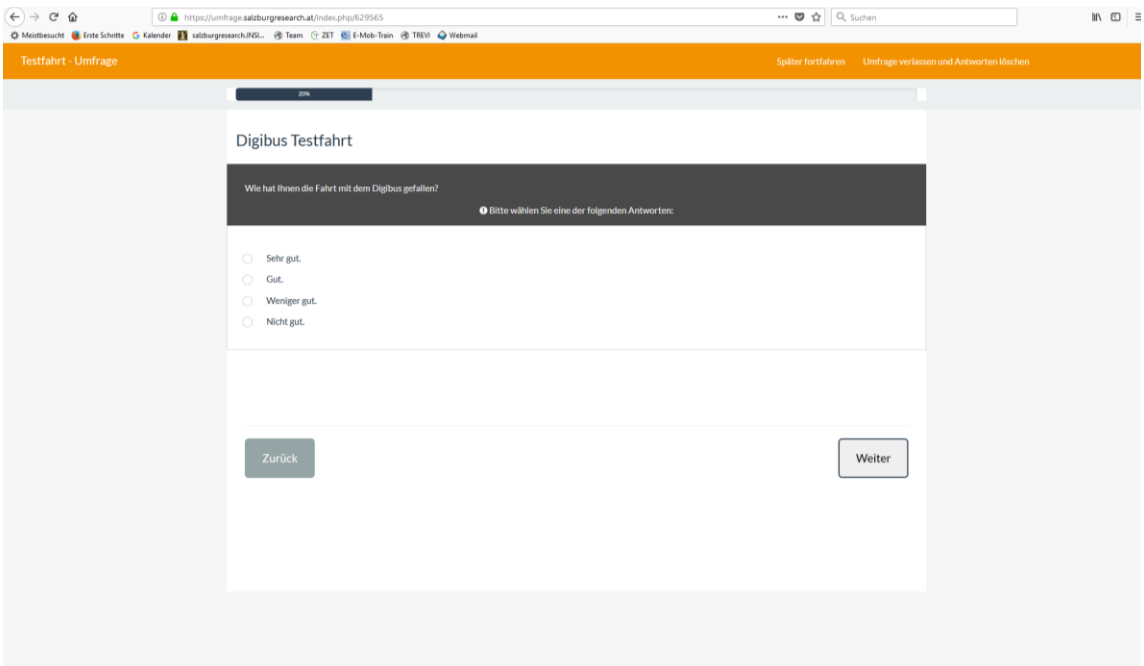


Figure 26: Online Digibus passenger survey

Regarding prior knowledge on the topic of self-driving vehicles, 13 % of passengers indicated they had none. Almost 43 % had heard of self-driving vehicles, 44 % were more familiar with the topic. This high percentage is due to the fact that many of the test passengers were part of company delegations who had relevant knowledge in this area.

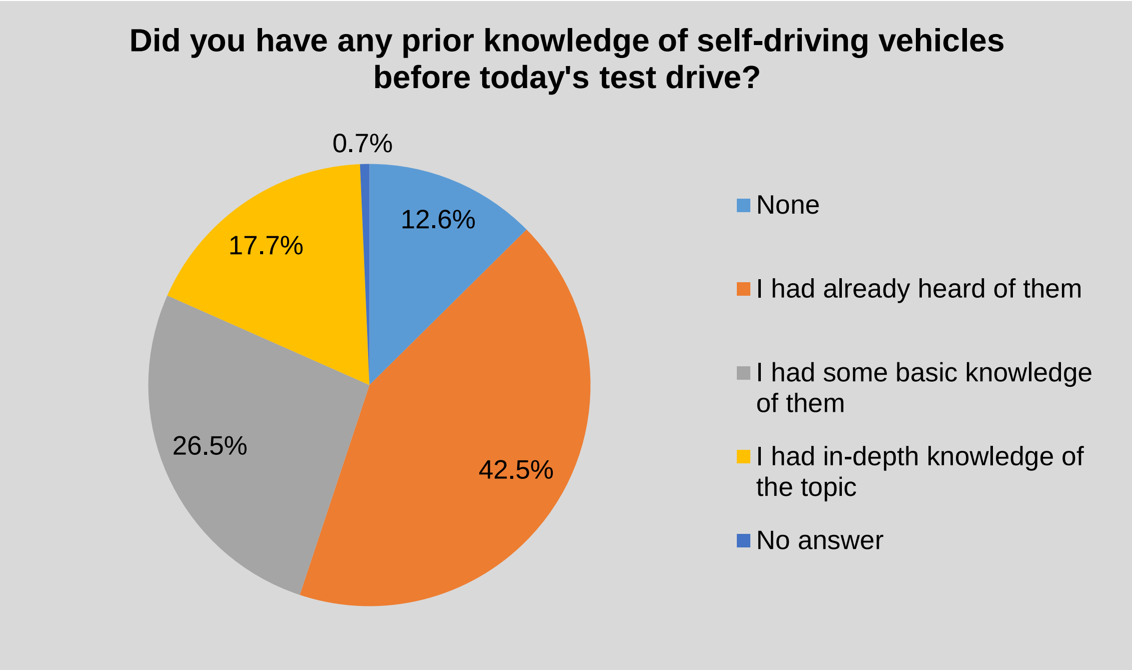


Figure 27: Prior knowledge of automated vehicles

For the majority of passengers (84.7 %), their Digibus test drive represented their first ride in a self-driving shuttle. 9.2 % indicated that they had been on a self-driving shuttle before, and 5 % indicated that they had ridden on the Digibus before.

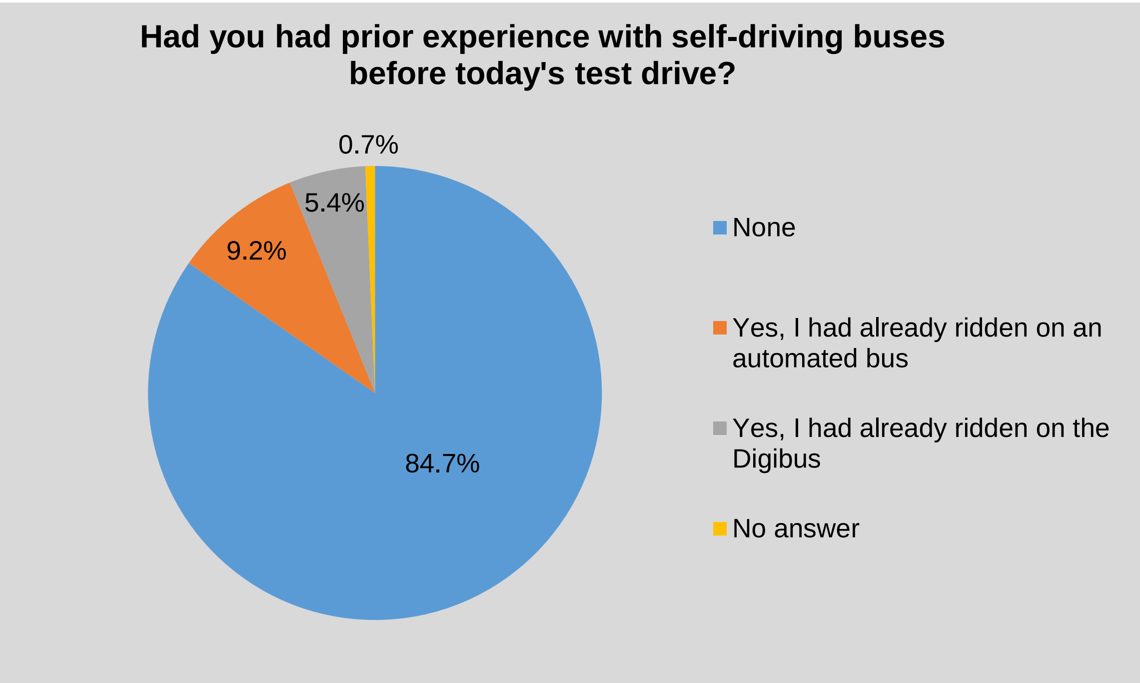


Figure 28: Previous experience of automated shuttlebuses

Reasons for taking part in a test drive were varied and equally distributed: 29.4 % took part out of professional or scientific interest, 25.5 % out of interest in an innovative means of transport, 23.0 % were motivated by curiosity, 20.4 % were interested in the technology.

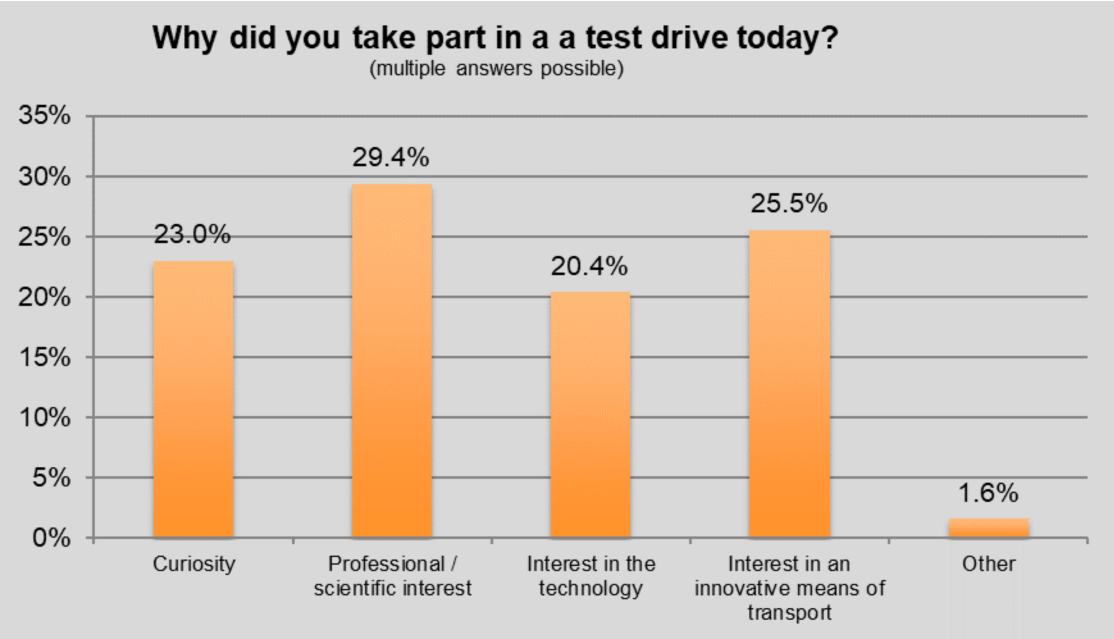


Figure 29: Reasons for taking part in a Digibus test drive

Around 92 % reported enjoying, or very much enjoying their ride on the Digibus. According to passenger testimonies (a selection thereof), they especially appreciated the vehicle's: "comfortable driving style", "feeling of safety", "the automated nature of the driving", or its "reliable detection of other road users or obstacles".

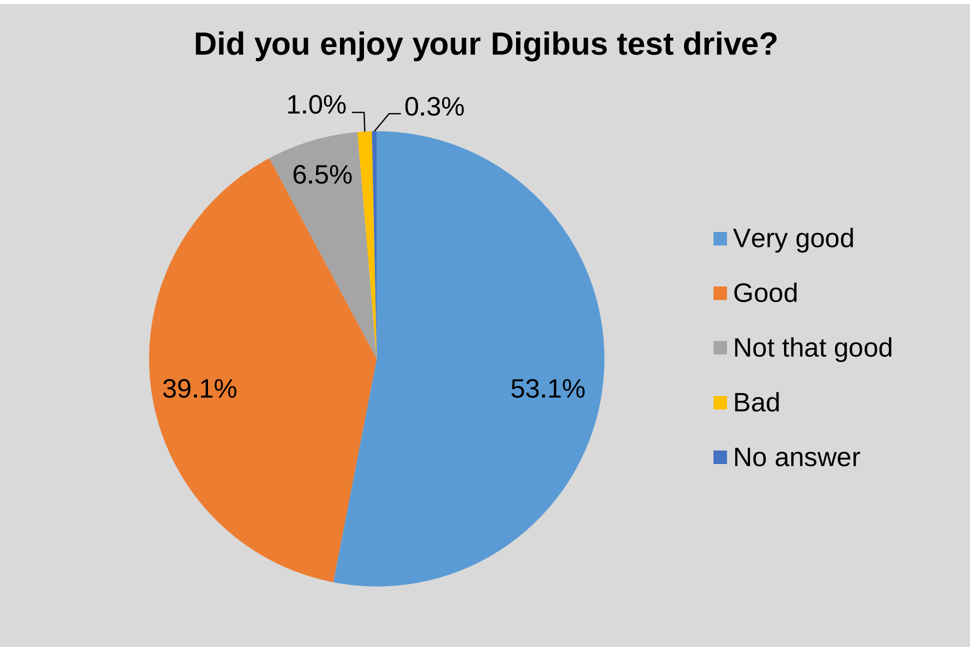


Figure 30: Positive aspects of the Digibus test drive experience

What did you enjoy about the Digibus test drive?	Recorded frequencies
The comfortable driving style	14
Perceived safety / careful driving	9
The automated driving in itself	6
The reliable detection of other road users and obstacles	6
The advanced technology, generally	5
The high driving speed	5
Presence of air-conditioning / comfortable temperatures on board the shuttle	5
No driver necessary	2
The precision of the driving / vehicle positioning	2
The precise approach to bus stops	2
The shuttle's appearance	1
The vehicle acceleration	1
The potential applications (rural areas, last mile phenomenon etc.)	1
The fluid nature of interactions with other drivers	1
The precision of the route programming	1
The novelty of the technology	1
The shuttle as a potential solution for sparsely populated areas	1
The robustness of the shuttle	1
The operator routines	1
The shuttle's fast response time when turning	1
The sensor technology	1
The difference to Tesla technology	1
The forward-thinking approach	1

Table 4: Recorded frequencies of positive feedback from the test drives

Are there elements that surprised you?	Recorded frequencies
Sudden braking, jerky driving	9
Not yet a mature technology / the prototype nature of the shuttle	8
X-box controller as a steering tool / no steering-wheel present	3
The insufficient power to climb the slope (when full)	3
The arduous nature of the route programming	2
The general handling of the technology	2
The complexity of "normal" driving situations	2

The maximum speed of 16 km/h	2
The necessity of manual interventions	2
The fact that the vehicle was far away from being completely automated	2
The high level of reliance on GPS and sensors	1
The angle of the wheels	1
The limited flexibility of the vehicle	1
The advanced status of the technology	1
The shuttle's response times	1
The abrupt shift from manual to autonomous driving modes	1
The seatbelt requirement in the shuttle	1
The lack of detection of street furniture	1
The not yet fully developed status of communication between the shuttle and its environment	1
The unintended stops during the drive	1

Table 5: Recorded frequency of surprising elements of the test drives

A little more than 6 % of passengers indicated that they had not particularly enjoyed their Digibus ride, and 1 % said they did not enjoy their ride at all. Reasons for this included, for example: "the sharp braking or frequent braking", "the prototypical nature of the technology", or "the lack of smooth driving behaviour".

What did you not enjoy about the test drive, or what did you think was lacking?	**Recorded frequencies**
The sharp braking / frequent braking	3
The prototypical nature of the technology	3
The lack of smooth driving behaviour	2
Lack of feelings of safety	2
Unclear / no communication with other road users	2
The low speed	1
The insufficiently developed nature of the technology	1
The lack of comfort	1
The necessity of many manual interventions	1
Shuttle could not climb the slope	1
Sluggishness of the system	1
The complexity of the system for operators	1
The susceptibility to faults	1

Rain prevented correct driving	1
Many stops during the drive	1

Table 6: Recorded frequencies of negative feedback from the test drives

The passenger survey also revealed very positive results regarding perceptions of safety on board. Almost 90 % of passengers felt safe or very safe on board the Digibus. It must be assumed, however, that passengers' feelings of security would probably be lower if the shuttle were completely driverless. Reasons passengers gave for not feeling safe on board were: "abrupt or jerky braking", "lack of confidence in the new technology", "lack of experience", "the poor sensor system", or "the shuttle cannot differentiate between people and vehicles".

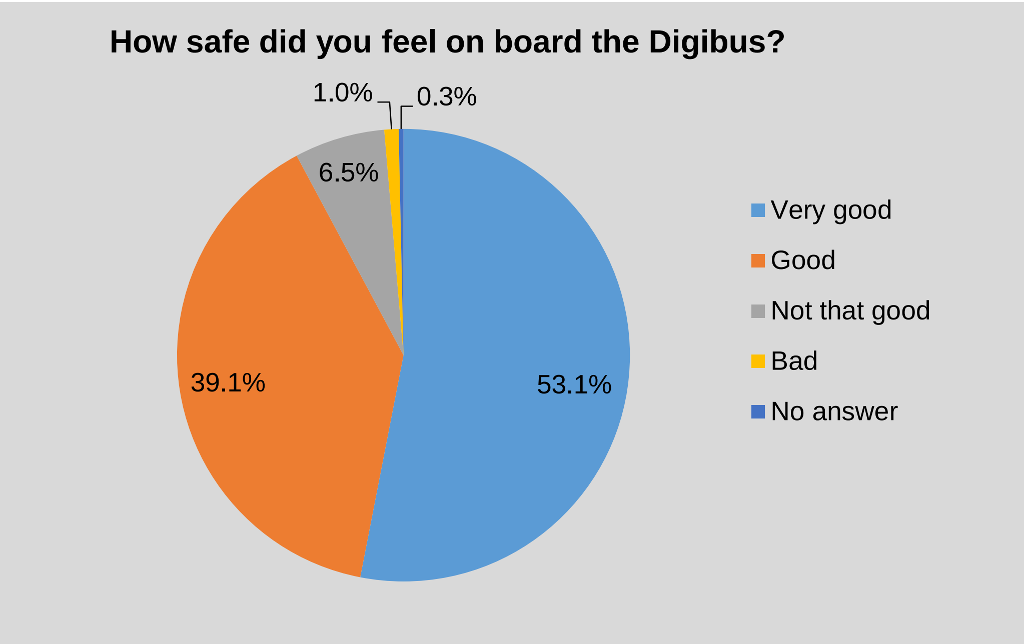


Figure 31: Perceived safety on board the Digibus

Why did you feel relatively unsafe or unsafe in the Digibus?	Recorded Frequencies
Sudden braking, jerky driving	6
Lack of confidence in the new technology	2
The shuttle rolled downhill	2
The shuttle represents an obstacle for other road users	2
Lack of experience	1
Fully automated driving was not possible	1
The shuttle does not recognise traffic signs	1
The shuttle cannot differentiate between people and cars	1
Sensor technology was not good enough	1

Unclear as to how the sensor technology interacts with actuators	1
Loud engine noises	1
Jerkiness of shift between manual and autonomous driving mode	1
Steamed up windows reduced all-around visibility	1
Lack of reliability of the system	1

Table 7: Recorded frequencies and reasons for passengers feeling unsafe in the Digibus

When asked what passengers could imagine using the Digibus for in their neighbourhood, 28.3 % answered they would use it to commute to work or school, or as a shuttle to the next public transport stop. 20.7 % indicated they would use a shuttlebus like this for daily errands, such as going shopping, attending doctor's appointments, visits to local government offices etc. Around 16 % of passengers could imagine the Digibus being used for either leisure activities (trips to football training or music lessons, as a shuttle to ski-lifts or hiking trail start points etc.), as a delivery service for parcels, shopping etc., or as work-site transportation on enclosed company grounds. 1.4 % of those surveyed could not imagine an application for a shuttlebus of this kind.

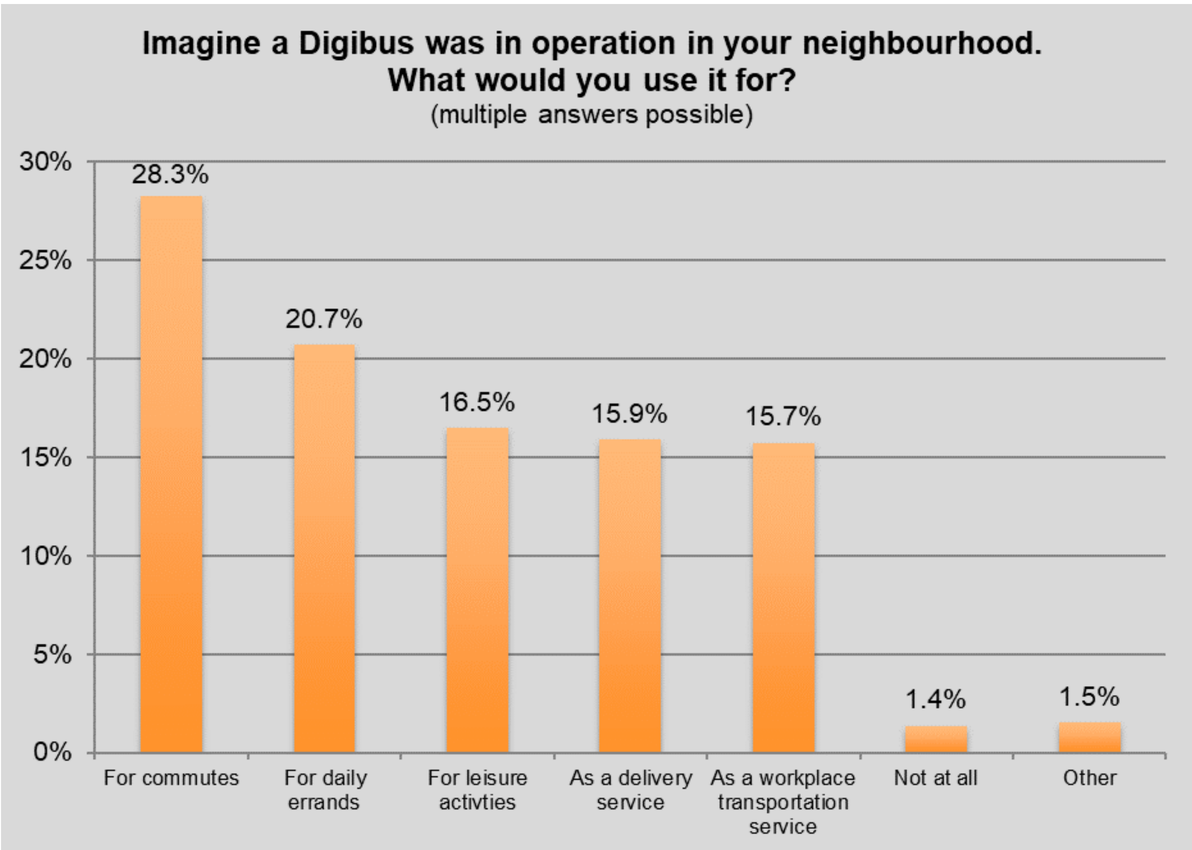


Figure 32: Potential applications for the Digibus

Almost 80 % of passengers own a private car, 20.5 % do not. Almost 40 % of those surveyed said they could imagine that a self-driving shuttlebus in their municipality could remove the need for a (second) car. Around 59 % do not think a self-driving shuttlebus is a realistic option, and could not replace a private (second car).

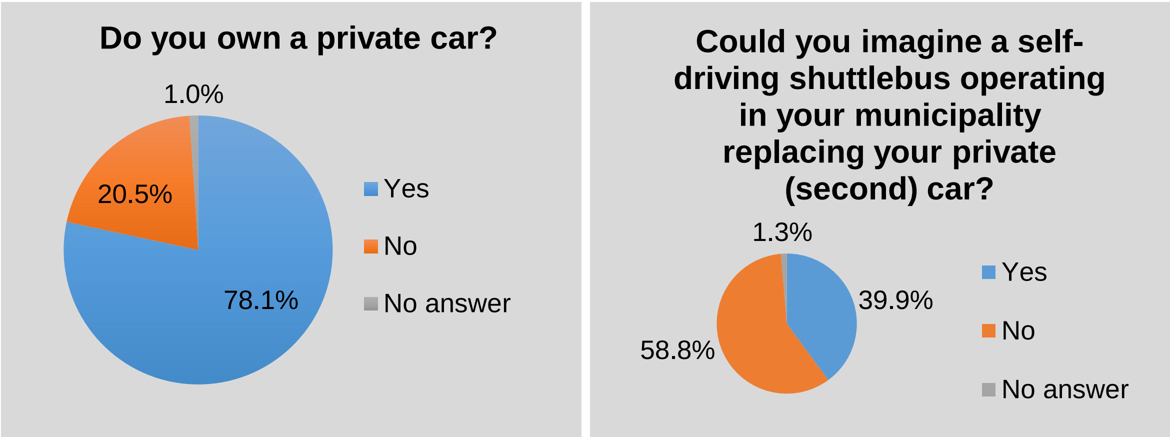


Figure 33: (a) Car ownership; (b) Potential replacement of private car by a self-driving shuttlebus

In terms of demographics, 56.2 % of respondents were male, 41.1 % female.

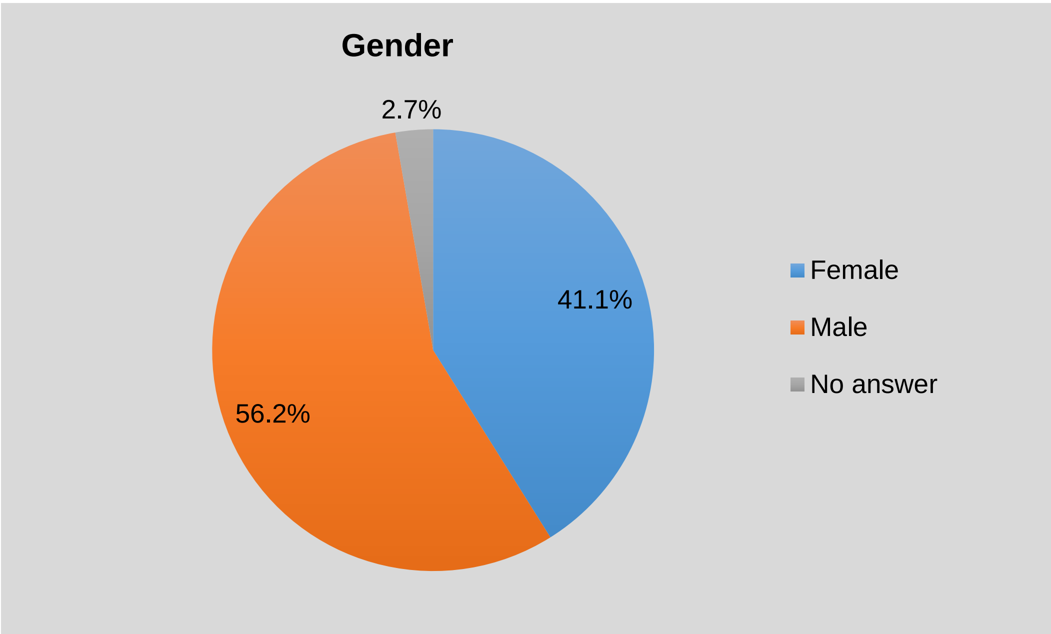


Figure 34: Respondent gender

The majority of passengers were between the ages of 21 and 50. 15.1 % were between 51 and 60, 9.6 % were over 60. Just over 5 % of respondents were between 13 and 20.

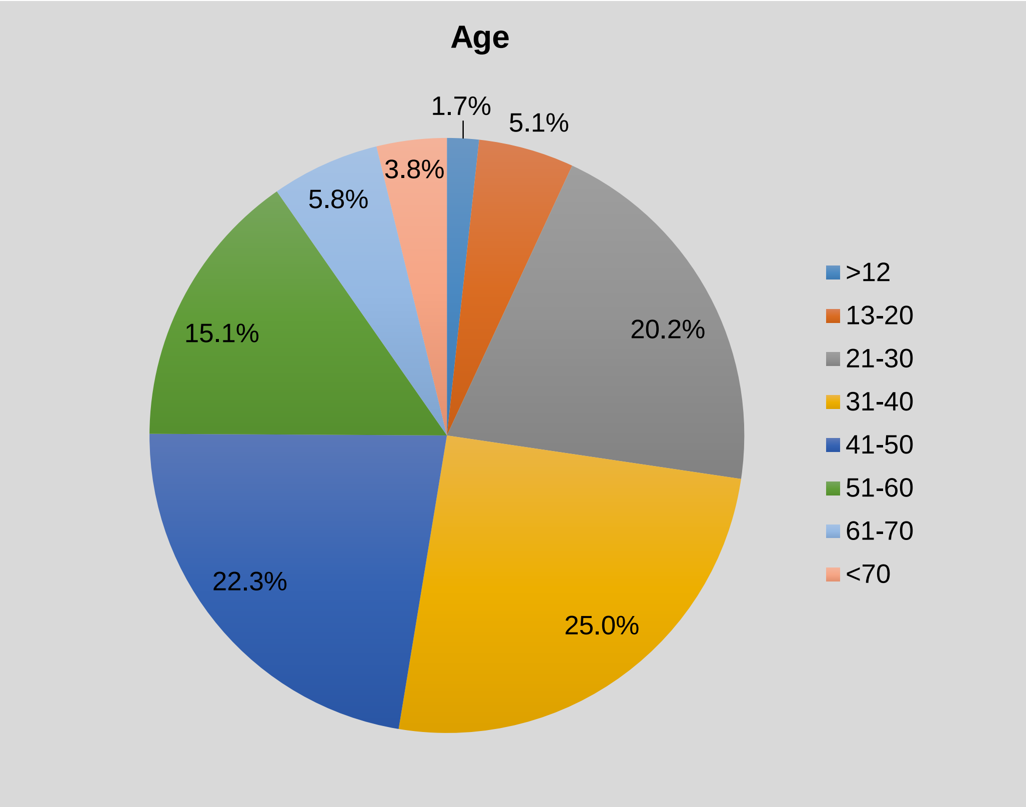


Figure 35: Respondent age groups

Concerning employment status, 65.4 % of passengers were employed, both 11.0 % were in training or were self-employed, and 8.2 % were retired.

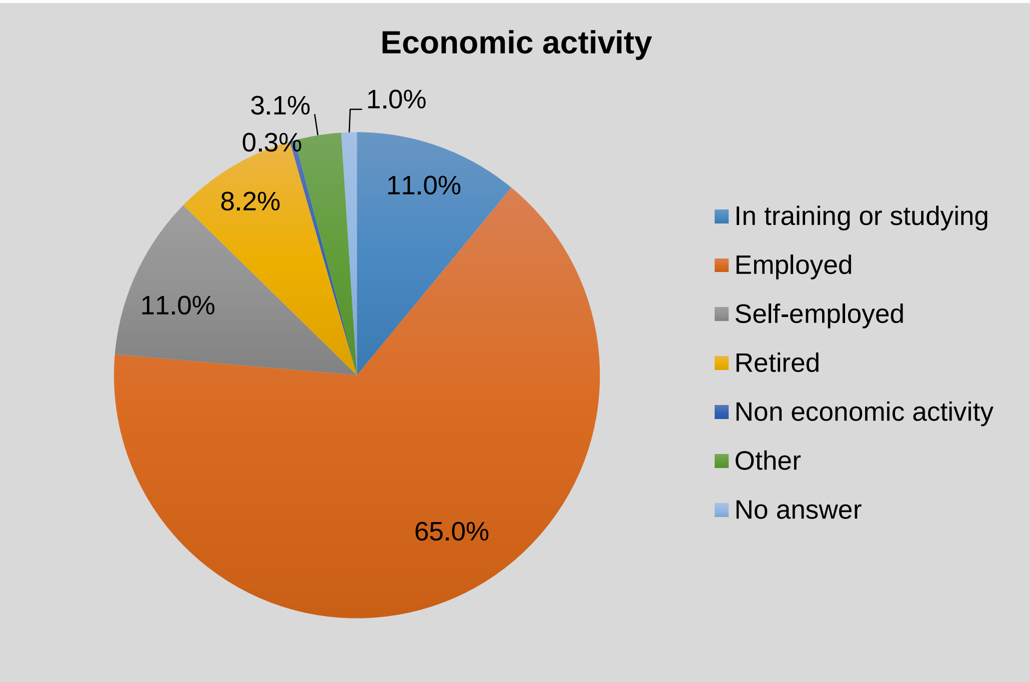


Figure 36: Economic activity of respondents

6.5 Security measures used

Both data protection and anti-cybercrime security measures were employed during the test drives, and road safety was respected at all times.

6.5.1 Data protection

The ARMA DL3 and ARMA DL4 shuttles used recorded trip data with no direct reference to individual persons in an internal memory (black box). This data was stored in an encrypted state in the black box, and was only accessible to the Navya Tech manufacturer. The test drive protocol was recorded separately from this data.

The in-built black box collected data on the operating status of the shuttle. Data was continuously collected from the sensors, and was also only accessible to Navya Tech.

The Salzburg Research surveys did not contain any data that could be linked to individuals.

6.5.2 Cybersecurity

All data transmitted or received by the vehicles was encrypted and sent via a VPN (virtual private network) system. During the course of the test, access to the systems was protected, as customary in this technological area, and was only open to Navya Tech employees. A basic principle of the system is that movement cannot be controlled from outside the vehicle. This security measure was managed by software that received and verified data from the vehicle. If discrepancies were detected, the vehicle displayed a fault warning and came to an immediate halt.

6.5.3 Road safety of the tested system

In the test scenario, road safety was guaranteed at all times by carrying out test drives at a low speed (max. 16 km/h). To ensure passenger safety, Navya Tech programmed security stops into the vehicle at each bus stop, when turning left, and at stop signs. This meant that the vehicle had to be released by the operator by pressing a "go" button before it could continue on its route. These security stops were programmed because the vehicle sensors were not suitable for detecting vehicles approaching at speed (> 30 km/h).

In addition, acoustic signals and visual indicators were employed. A warning was sounded when the shuttle encountered an obstacle on the route. Visual information was displayed for the benefit of other road users on two outward-facing screens. However, these indications were not always clear to other road users, as standards regarding interactions with other vehicles are lacking. Details are found in chapter 6.3.1, sub-section (5). Furthermore, there is no current scientific data or standards regarding what signalisations lead to what behaviour on the part of other road users.

It is important to note that the shuttle is only in its research and development stage, and that extensive further development is needed before it is capable of driving in traffic in fully-automated mode.

6.6 Long-term results and insights gained

These tests in Koppl represent the first time a self-driving shuttlebus has been tested on public roads in mixed traffic in Austria. Because of this, there was a great deal of media interest. Their reports drew the general public's attention to the project, creating curiosity about the tests, as well as interest in the technology among the population.

Tests like these, carried out in real environments, enable the public to experience self-driving vehicles for the first time, and are key to building awareness and trust. It is thereby important to show that on the one hand, self-driving vehicles are no longer the stuff of futuristic dreams, but instead a reality. On the other hand, these tests demonstrated to the wider public the currently limited capabilities of automated vehicles, and what further developments are needed before fully-automated systems can be achieved. A common expectation was that the test drives would constitute a regular bus service, or that one would be established directly after the test phase. During the test drives, passengers themselves very quickly realised that considering the state of current technology, a regular service was still a long way off.

By testing a self-driving shuttlebus in a rural setting, a scenario was consciously selected that brought together the issues of autonomous driving, sustainable public transport and the "first / last mile" phenomenon. If the latter is too far, people prefer to use their own cars instead of the public transport on offer. By functioning as local shuttles, self-driving shuttlebuses can increase the attractiveness of public transport services. Additionally, the trend for transport automatization is growing increasingly important in the area of public transport. Here the need to deal with the "first / last mile" issue has repeatedly been revealed to be key to client adoption of public transport services. Micro-public transport systems, that is, shuttle services to public transport stops, have improved quality of service, especially in rural areas. However, micro-public transport systems are either expensive to run, or are volunteer-based. Because of this, it is currently not possible to roll-out such systems extensively. Automated transport systems - highly automated vehicles or self-driving shuttlebuses – have the capacity to enable new kinds of micro-public transport systems, which can be used to improve access in rural areas or city quarters.

7 Conclusions and next steps

The test operation in Koppl represents one of the first times in the world a self-driving shuttlebus has been tested on public roads in mixed traffic and in a rural environment. Their central focus was to carry out a real-world test of a self-driving shuttlebus in the role of a transport link to cover the first / last mile of public transport journeys. From April until November 2017, 240 test drives were carried out, transporting 874 passengers and covering 341 test kilometres. The accompanying survey, completed by 294 respondents, revealed a high level of acceptance of the new technology, and a sound sense of security on board the Digibus.

The results show that the technology is ready for testing, but still has far to go before it can operate truly driverless, especially in mixed traffic scenarios. In summary, it can be concluded that the tested self-driving shuttlebus cannot yet meet expectations for highly, or fully automated vehicles. However, a key insight gained is that in the area of automated driving, practical experience on public roads with mixed traffic is essential for assessing the technology’s actual level of development under realistic conditions. The real-world tests revealed great differences between the manufacturer's claims regarding the vehicle development status and its real status. Despite recent tremendous technical advances, the real-world tests revealed that, at best, the tested shuttlebus currently can only be classified as a level 3 automated vehicle (“conditional automatization”) (according to SAE J3016).

The 2017 European roadmap for the development of automated driving (ERTRAC Automated Driving Roadmap) includes a development trajectory for automated urban mobility systems (automated shuttles). This roadmap anticipates the introduction of highly automated vehicles to specially-dedicated routes in the period between 2018 and 2024, and their introduction to public roads with mixed traffic between 2024 and 2030. Until then, a huge amount of research and development is necessary (ERTRAC, 2017). The graphic below compares the development trajectory for automated urban mobility systems with that of autonomous cars and HGVs.

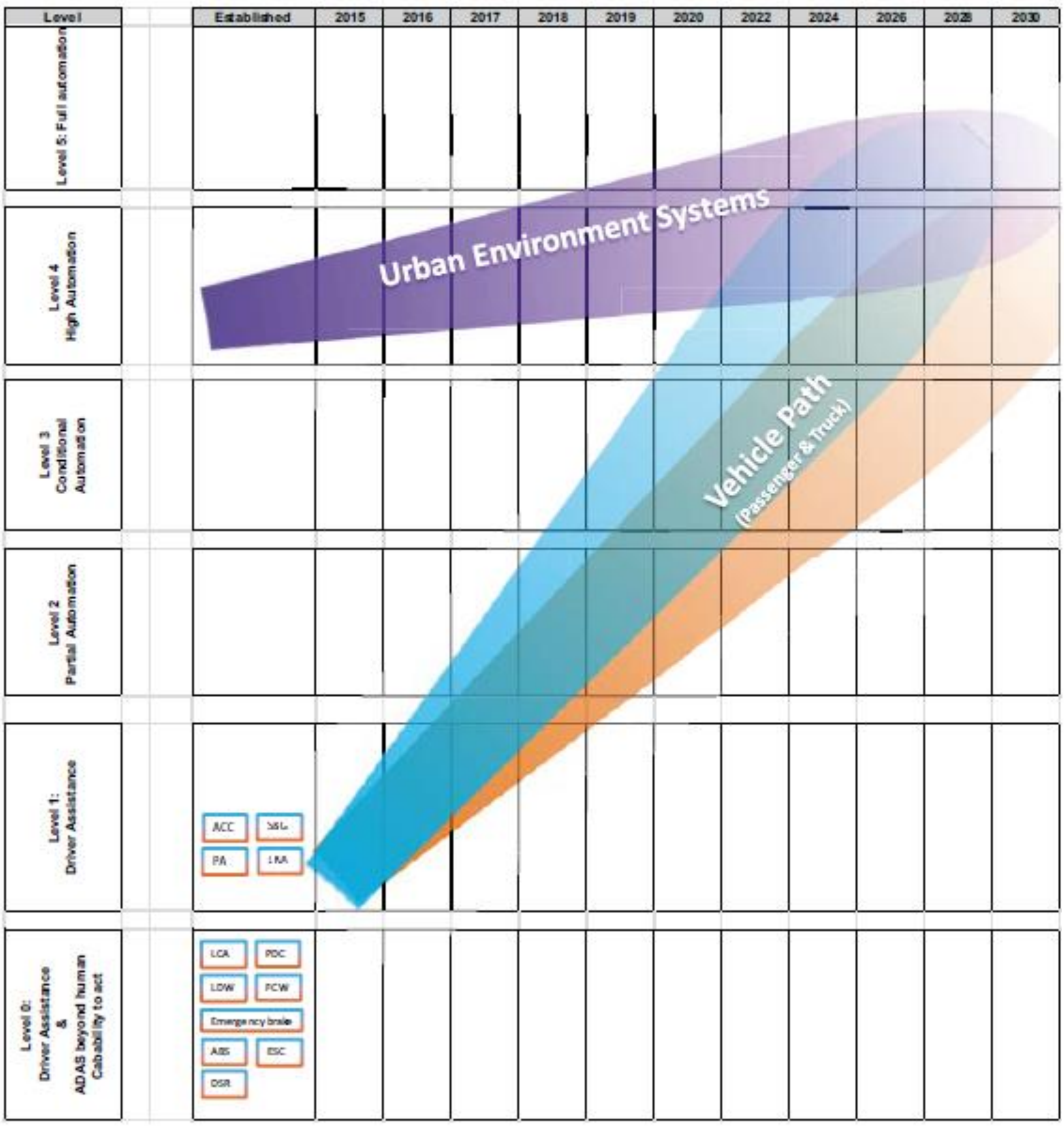


Figure 37: ERTRAC Roadmap: Key development trajectories for automated vehicles

In Austria, according to *automated-connected-mobile* (Automatisiert – Vernetzt – Mobil), the BMVIT action plan for automated driving, automated shuttles should play a key role as responsive shuttle links to- and from public transport nodes (Use Case 3 - New Flexibility) (BMVIT, 2016). Accordingly, steps are also planned for the development of automated mobility systems.

Salzburg Research also hopes to contribute in the coming years to research on automated driving as a part of intermodal public transport systems. In September 2017, in the context of its "Mobility of the Future" framework programme, Salzburg Research submitted a bid to the 9th call for projects of the Austrian Research Promotion Agency (FFG) for the flagship project “Digibus Austria” in the area of automated driving in public transport systems, and was granted funding. Digibus Austria began in April 2018 and will run for 3 years. It is led by Salzburg Research, and involves a top level consortium of leading companies (Kapsch TrafficCom, ÖBB

Holding, PRISMA solutions, Commend, Fluidtime, HERRY Consult, EasyMile), as well as research institutes (Virtual Vehicle Research Centre, AIT Austrian Institute of Technology, the University of Salzburg – the Centre for Human Computer Interaction, The University of Natural Resources and Life Sciences – Institute for Transport, Factum) along the entire public transport value chain, from the vehicle manufacturer to the public transport provider.

The goal of the project is the research and testing of methods, technologies and models for the reliable and safe running of automated local public transport vehicles functioning as shuttle services as part of a regional intermodal mobility system. Although globally, an ever-increasing number of test projects have been announced or carried out, until now, there have been few whose aim is the systematic further development of automated shuttles in order to achieve a higher level of automatization. The project should lay the groundwork for the realisation of a level 4 system ("highly automated"), thus leading to the development of a next stage of automatization. Specifically, Digibus Austria will seek to investigate and find answers to the following questions:

- **Digital and physical infrastructure:** What methods can be used to analyse and evaluate the suitability or characteristics of an environment or route for a highly- or fully-automated transport shuttle? How can the environment or route be automatically digitalised for a highly- or fully-automated vehicle?
- **Connectivity:** Which technologies (LTE-V, ITS G5) are suited to meeting the connective requirements of highly- or fully-automated shuttles? How can they be used to improve the reliability of vehicle positioning or communication?
- **Road safety and suitability for open roads:** What methods can be applied to test the road suitability or road safety of a highly-automated shuttle? What driving scenarios can a highly-automated shuttle master in a manner that is safe and compliant with the rules of the road on roads with mixed traffic**?**
- **Human factors:**
  (a) What solutions can be found to facilitate interactions between highly- or fully-automated vehicles and other roads users? Additionally, which insights into road user interactions can be gained from simulations and real-world testing?
  (b) What multimodal tools, especially speech-activated or video technology, would be suitable for facilitating interactions between passengers and driverless vehicles? How can these tools be used to establish levels of trust between passengers and the system, similar or higher to those they currently experience with driver-based systems?
- **New mobility services:** What tools are suitable for the integration of highly- or fully-automated shuttles into an intermodal, regional mobility system? How can these be integrated into current mobility services?

- **Regulations:** What parameters (technical, organisational, legal, social, economic) should be taken into account for the real-life testing, or at a later stage, for the operation of a highly- or fully-automated shuttle? How can these be used to construct a reference framework for future applications?

These methods, technologies and models will be tested on both a private road as well as two open-road test routes. The results of these three tests will lay the groundwork for an Austrian model of reference for the real-world testing and operation of highly- or fully-automated vehicles as part of public transport services.

Further information on this project can be found at: https://www.digibus-austria.at

8 Literature Review

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