Autonomous Vehicles to Evolve to a New Urban Experience

DELIVERABLE

D7.10 First Iteration Luxembourg Large Scale Pilot Use Case Demonstration report

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Acronyms

ADS	Automated Driving Systems
AI	Artificial Intelligence
AM	Autonomous Mobility
API	Application Protocol Interface
AV	Autonomous Vehicle
AVL	Autocars de la Ville de Luxembourg
BM	Bestmile
BMM	Business Modelling Manager
CAV	Connected and Autonomous Vehicles
CB	Consortium Body
CERN	European Organization for Nuclear Research
D7.10	Deliverable 7.10
DC	Demonstration Coordinator
DI	The department of infrastructure (Swiss Canton of Geneva)
DMP	Data Management Plan
DSES	Department of Security and Economy - Traffic Police (Swiss Canton of Geneva)
DTU test track	Technical University of Denmark test track
EAB	External Advisory Board
EC	European Commission
ECSEL	Electronic Components and Systems for European Leadership
EM	Exploitation Manager
EU	European Union
EUCAD	European Conference on Connected and Automated Driving
F2F	Face to face meeting
FEDRO	(Swiss) Federal Roads Office
FOT	(Swiss) Federal Office of Transport
GDPR	General Data Protection Regulation
GIMS	Geneva International Motor Show
GNSS	Global Navigation Satellite System
HARA	Hazard Analysis and Risk Assessment
IPR	Intellectual Property Rights
IT	Information Technology
ITU	International Telecommunications Union
LA	Leading Author
LIDAR	Light Detection And Ranging
MEM	Monitoring and Evaluation Manager
MT	MobileThinking
OCT	General Transport Directorate of the Canton of Geneva
ODD	Operational Domain Design
OEDR	Object And Event Detection And Response
OFCOM	(Swiss) Federal Office of Communications
PC	Project Coordinator
PEB	Project Executive Board
PGA	Project General Assembly
PRM	Persons with Reduced Mobility
PSA	Group PSA (PSA Peugeot Citroën)
PTO	Public Transportation Operator
PTS	Public Transportation Services
QRM	Quality and Risk Manager
QRMB	Quality and Risk Management Board
RN	Risk Number
SA	Scientific Advisor
SAE Level	Society of Automotive Engineers Level (Vehicle Autonomy Level)
SAN	(Swiss) Cantonal Vehicle Service
SDK	Software Development Kit
SLA	Sales Lentz Autocars
SMB	Site Management Board
SoA	State of the Art
SOTIF	Safety Of The Intended Functionality
SWOT	Strengths, Weaknesses, Opportunities, and Threats.
T7.1	Task 7.1
TM	Technical Manager
TPG	Transport Publics Genevois
UITP	Union Internationale des Transports Publics (International Transport Union)
V2I	Vehicle to Infrastructure communication
WP	Work Package
WPL	Work Package Leader

List of Figures

Executive summary

In this deliverable, the focus is on the organization, the running and the evaluation of the large-scale demonstrators of the autonomous vehicle services for public transport in Luxembourg.

Different sites all over Luxembourg have been analyzed in order to find a suitable use case for the deployment of autonomous shuttle services within the Avenue project. The industrial zone of Contern as well as Pfaffenthal, an urban living area in Luxembourg-City have been chosen as the ideal use cases for the demonstration of an autonomous mobility solution. The different environments of the industrial zone of Contern and the busy city surroundings in Pfaffenthal are leading to different operational experiences. In both use cases, we were able to successfully implement the autonomous shuttles into traffic and to gain important experience in their deployment and their operation as well as the preceding administrative preparations. Furthermore, we were able to identify areas that need further development in order to improve the operation the shuttles.

Before the start of the trials in Luxembourg different administrative work was necessary. Luxembourg is very open to new technologies and vehicles for research purposes can get a special permit to drive on public roads even if not all parts of the vehicles are homologated yet. None the less different authorizations from different national authorities for the vehicles as well as for the test routes were necessary and could be obtained in a reasonable time span.

Future concepts for both sites have been analyzed and are currently under development. In Contern an extension of the current route will be deployed in Q3 2019 and for Pfaffenthal different future concepts with authorities of Luxembourg-City are currently being discussed.

Especially the Contern trial shows that it is very important to notice that the operation of the autonomous shuttles is linked to very high costs. A lot of companies, cities, authorities, etc. are very interested in such an innovative mobility solution but they are not able to bear the costs for it.

1 Introduction

The aim of the AVENUE project is to offer an on-demand door-to-door mobility solution with autonomous vehicles to complement todays existing transportation solutions that follow a fixed route and a predefined schedule. In order to demonstrate this innovative mobility concept, the objective is to deploy networks of autonomous shuttles in four different European cities: Copenhagen, Geneva, Luxembourg as well as Lyon and at a later stage on three different replicator sites.

The aim of WP7 is to organize, run and evaluate the large-scale demonstrators of the autonomous vehicle services for public transport, targeting different user groups and transport models. The goal is to validate a high quality, safe service, which will enhance acceptance and adoption of autonomous vehicles for public transport.

In deliverable D7.10, the main focus is on the organization, the running and the evaluation of the large-scale demonstrators of the autonomous vehicle services for public transport in Luxembourg.

1.1 On-demand Mobility

Public transportation is a key element of a region's economic development and the quality of life of its citizens.

Governments around the world are defining strategies for the development of efficient public transport based on different criteria of importance to their regions, such as topography, citizens' needs, social and economic barriers, environmental concerns and historical development. However, new technologies, modes of transport and services are appearing, which seem very promising to the support of regional strategies for the development of public transport.

On-demand transport is a public transport service that only works when a reservation has been recorded and will be a relevant solution where the demand for transport is diffuse and regular transport is inefficient.

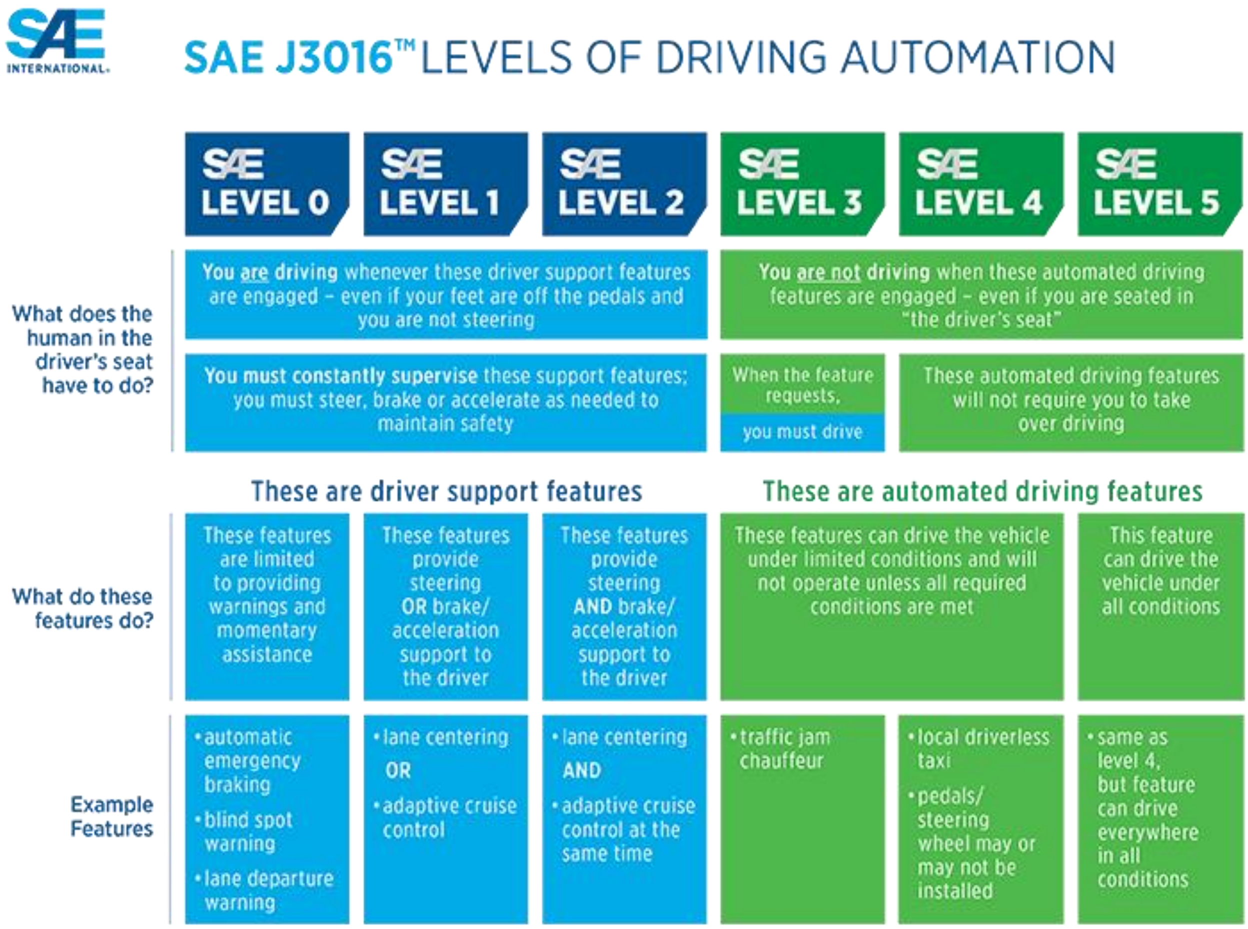
On-demand transport differs from other public transport services in that vehicles do not follow a fixed route and do not use a predefined timetable. Unlike taxis, on-demand public transport is usually also not individual. An operator or an automated system takes care of the booking, planning and organization.

It is recognized that the use and integration of on-demand autonomous vehicles has the potential to significantly improve services and provide solutions to many of the problems encountered today in the development of sustainable and efficient public transport.

1.2 Autonomous Vehicles

A self-driving car, referred in the AVENUE project as **an Autonomous Vehicle** (**AV**) is a vehicle that is capable of sensing its environment and moving safely with no human input. The choice of Autonomous vs Automated was made in AVENUE since, in the current literature, most of the vehicle concepts have a person in the driver's seat, utilize a communication connection to the Cloud or other vehicles, and do not independently select either destinations or routes for reaching them, thus being “automated”. The automated vehicles are considered to provide assistance (at various levels) to the driver. In AVENUE there will be no driver (so no assistance will be needed), while the route and destinations will be defined autonomously (by the fleet management system). The target is to reach a system comprising of vehicles and services that independently select and optimize their destination and routes, based on the passenger demands.

In relation to the SAE levels, the AVENUE project will operate SAE Level 4 vehicles.



1.2.1 Autonomous vehicle operation overview

We distinguish in AVENUE two levels of control of the AV: micro-navigation and macro-navigation. Micro navigation is fully integrated in the vehicle and implements the road behaviour of the vehicle, while macro-navigation is controlled by the operator running the vehicle and defines the destination and path of the vehicle, as defined the higher view of the overall fleet management.

For micro-navigation Autonomous Vehicles combine a variety of sensors to perceive their surroundings, such as 3D video, LIDAR, sonar, GNSS, odometry and other types sensors. Control software and systems, integrated in the vehicle, fusion and interpret the sensor information to identify the current position of the vehicle, detecting obstacles in the surround environment, and choosing the most appropriate reaction of the vehicle, ranging from stopping to bypassing the obstacle, reducing its speed, making a turn etc.

For the Macro-navigation, that is the destination to reach, the Autonomous Vehicle receives the information from either the in-vehicle operator (in the current configuration with a fixed path route), or from the remote control service via a dedicated 4/5G communication channel, for a fleet-managed operation. The fleet management system takes into account all available vehicles in the services area, the passenger request, the operator policies, the street conditions (closed streets) and send route and stop information to the vehicle (route to follow and destination to reach).

1.2.2 Autonomous vehicle capabilities in AVENUE

The autonomous vehicles employed in AVENUE fully and autonomously manage the above defined, micro-navigation and road behaviour, in an open street environment. The vehicles are autonomously capable to recognise obstacles (and identify some of them), identify moving and stationary objects, and autonomously decide to bypass them or wait behind them, based on the defined policies. For example with small changes in its route the AVENUE shuttle is able to bypass a parked car, while it will slow down and follow behind a slowly moving car. The AVENUE vehicles are able to handle different complex road situations, like entering and exiting round-about in the presence of other fast running cars, stop in zebra crossings, communicate with infrastructure via V2I interfaces (ex. red light control).
The shuttles used in the AVENUE project technically can achieve speeds of more than 60Km/h. However this speed cannot be used in the project demonstrators for several reasons, ranging from regulatory to safety. Under current regulations the maximum authorised speed is 25 or 30 Km/h (depending on the site). In the current demonstrators the speed does not exceed 23 Km/h, with an operational speed of 14 to 18 Km/h. Another, more important reason for limiting the vehicle speed is safety for passengers and pedestrians. Due to the fact that the current LIDAR has a range of 100m and the obstacle identification is done for objects no further than 40 meters, and considering that the vehicle must safely stop in case of an obstacle on the road (which will be "seen" at less than 40 meters distance) we cannot guarantee a safe braking if the speed is more than 25 Km/h. Note that technically the vehicle can make harsh break and stop with 40 meters in high speeds (40 -50 Km/h) but then the break would too harsh putting in risk the vehicle passengers. The project is working in finding an optimal point between passenger and pedestrian safety.

1.3 Preamble

The AVENUE project is set up to offer on demand door-to-door solutions integrated within existing public transportation services, and evaluates the feasibility of operating autonomous shuttles with routes and schedules based on real-time passenger demand, instead of following fixed itineraries and pre-determined timetables.

AVENUE's objective is to showcase these customized transport solutions at demonstrator sites in Copenhagen, Geneva, Luxembourg and Lyon, and later duplicate them in several other European cities.

Work package **WP7** aims to organize, run and evaluate these large scale demonstrators of the autonomous vehicle services for public transport, targeting different user groups, and transport models. The goal is to validate a high quality, safe service, which will enhance acceptance and adoption of autonomous vehicles for public transport.

The purpose of task **T7.10** is to integrate autonomous vehicles into the existing public transport services. From day one of the project SLA will promote the new services, the security of the vehicles and the efficiency of the system, which targets to increase the acceptance by citizens, public authorities and other actors through important information campaigns.

In deliverable **D7.10**, the main focus is on the organization, the running and the evaluation of the large scale demonstrators of the autonomous vehicle services for public transport in Luxembourg.

2 Overall objectives and visions

SLA's overall objectives within the AVENUE project to integrate autonomous shuttles into its existing offer of mobility solutions are:

- Increase safety
- Introduce a mobility solution at places, where no public transport is available today
- Create a complementary transport solution to existing public transport
- Connect public transport stops with urban areas
- Operate on public roads

SLA's vision for the future:

- Autonomous public transport ride-pooling vehicles booked digitally and powered electrically by renewable energy
- In suburban and less populated areas: smart, user-friendly transport services
- Autonomous vehicles used as feeders to public transport stations (bus, tram, train)
- Making flexible, demand-driven transport available where the demand for and supply of classic public transport are insufficient
- Autonomous vehicles could solve first- and last mile issues as well as offer door-to-door mobility solutions
- Autonomous shuttles will be part of a versatile and highly efficient integrated public transport system where citizens will be able to choose the best mobility option through an integrated multimodal mobility platform offering mobility-as-a-service (MaaS).
- The weakest element in the road safety chain is the human being. Autonomous vehicles can learn through artificial intelligence and thus increase road safety. A mistake made once will be corrected and transmitted to other vehicles ("learning community").

3 Project homologation

Luxembourgish authorities are having a positive attitude towards new technologies and the development of future transport modes. The Luxembourgish Highway Code ("Code de la route") includes a paragraph stating that vehicles equipped with new technologies or principles that are not in line with the regulations or not compatible with the different articles stated in the Highway Code can get an exemption allowing them to drive on public roads, if the purpose of these vehicles is to do scientific or technical research ("essais scientifiques").

3.1 Vehicle homologation

An approval of the National Society of Automotive Traffic (société nationale de circulation automobile - SNCA) of Luxembourg for the shuttles is mandatory. This approval includes a technical inspection of the vehicle as well as full technical documentation of the vehicles from Navya.

3.2 Test site homologation

For every test site an authorisation of the Luxembourgish Ministry of Mobility and Public works is needed. This authorisation includes an in-depth documentation of the planned route and the exact vehicles that will be operating on the route. No other route and no other autonomous vehicles than the ones assigned to the route will be allowed on the site. The authorisation is valid for one year. A new authorisation can be requested afterwards.

The following terms are linked to the authorisation:

- No other vehicles than the ones stated in the authorisation are allowed on the route
- No other route than the one documented in the authorisation is permitted (including the shuttle stops)
- Admission by the National Society of Automotive Traffic
- A sign with “scientific research” (“essais scientifiques”) needs to be installed visible on every shuttle
- Shuttles need a valid insurance for the duration of the authorisation
- An operator with a bus driving licence (licence D1) needs to be inside the shuttle at all times
- The passengers need to be informed that they are inside an autonomous vehicle

Furthermore, the Luxembourgish Ministry of Mobility and Public works gets a documentation with the following information:

- Detailed project description
- Technical vehicle documentation
- Operator training certificates
- Maintenance training certificates (SLA technicians)
- Valid insurance certificate for each vehicle

The current operational speed of the shuttles is 18 km/h and the speed limit of the public road in Pfaffenthal was 50 km/h. For this reason, an authorisation to reduce the speed limit from 50 km/h to 30 km/h has been requested in order to reduce overtaking from other traffic users. This authorisation was granted by the Luxembourgish National Roads Authority (Administration des Ponts et Chaussées).

4 Vehicle selection

SLA currently disposes of four vehicles homologated to transport 12 people. 8 seats, 3 folding seats and 1 standing place.

Type	ID	Type	Funded by	Project	Covering
Navya Arma DL-4	P80	Monodirectional	SLA	Contern	Campus Contern
Navya Arma DL-4	P93	Bidirectional	AVENUE	Pfaffenthal	AVL Multiplicity
Navya Arma DL-4	P106	Bidirectional	AVENUE	Pfaffenthal	AVL Multiplicity
Navya Arma DL-4	P122	Bidirectional	SLA	private	SLA

4.1 Technical data

See appendix A at the end of this document.

4.2 Options

4.2.1 General

- Air Conditioning

4.2.2 PMR Ramp

For all buses that are driving for AVL, a PMR is mandatory. SLA took the decision to equip all their NAVYA shuttles with a PMR ramp. The first shuttle P80 acquired by SLA is equipped with a manual ramp for PMR since an automatic ramp was not available at the moment of the shuttle acquisition. The shuttles P92, P106 and P122 are all equipped with an automatic ramp which can be deployed by a button outside and inside the shuttle

4.2.3 Seatbelts

In all our shuttles the seats are equipped with seatbelts.

4.3 Covering

4.3.1 SLA

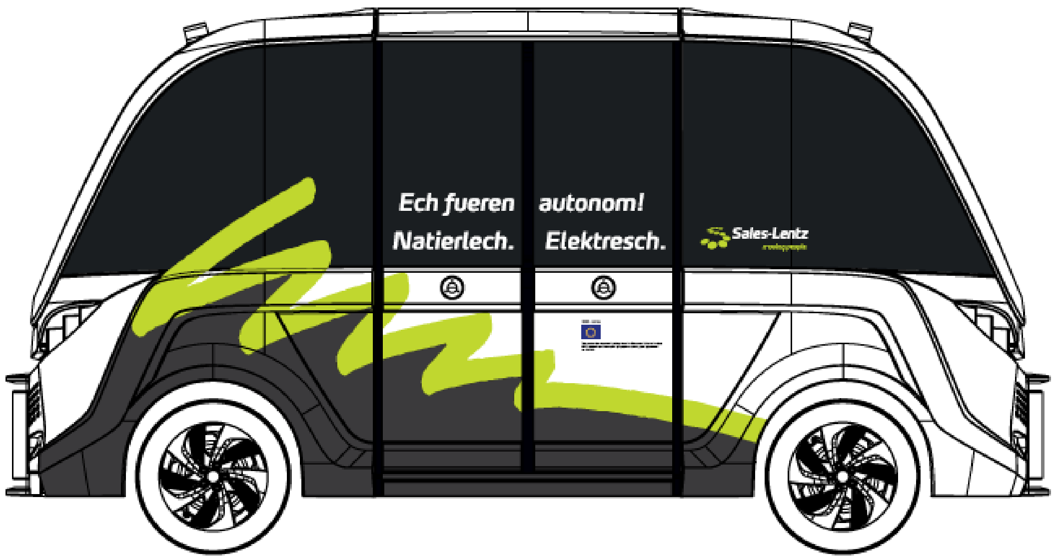


Figure 1: SLA design

4.3.2 AVL-Multiplicity

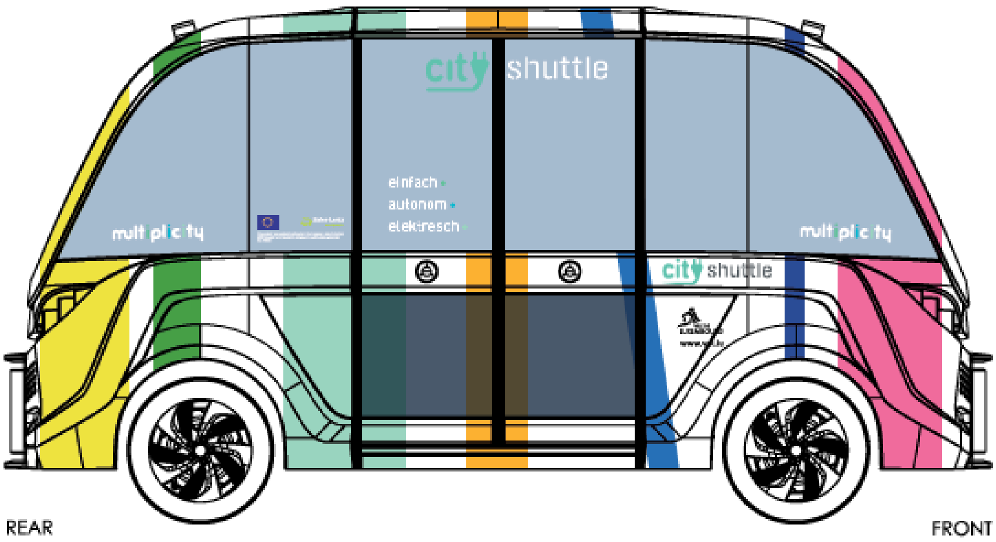


Figure 2: AVL- Multiplicity design

4.3.3 Campus Contern

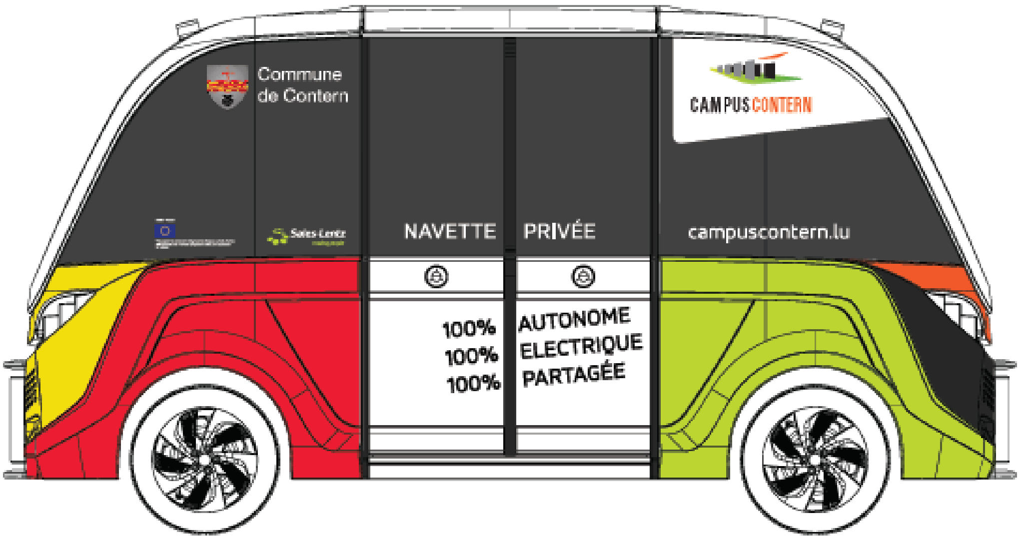


Figure 3: Campus Contern design

4.3.4 Avenue Logo

Vehicles within the Avenue framework and funded by the EU are equipped with an Avenue project disclaimer in English in front, at the back and on both sides of the vehicle.

AVENUE This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 769033

Figure 4: AVENUE Logo and disclaimer

Figure 5:AVENUE logo and text on the shuttles

4.4 Vehicle inspection

The Navya shuttles have to undergo a yearly technical inspection. The first inspection for all our four vehicles is planned for September 2019. This inspection focusses on the mechanical parts. The autonomous system will not be part of this inspection.

4.5 Maintenance

Our technicians have been trained by Navya to do in-house maintenance work on our vehicles from level 1-3 (out of 5). Every maintenance above level 3 is done by Navya. Navya has a special document that explains which parts fall under the different maintenance level.

4.6 Supervision

In case of technical problems with the shuttles, the shuttle operator can instantly contact the technical department of Navya via a phone number, a Whatsapp group or the shuttles intercom. This way Navya's technicians can actively assist the shuttle operator in solving all kind of issues that can occur during the operation of the shuttles. During the operation of the shuttles this possibility has proved to be very effective at finding promptly a solution.

5 Test sites

In a first phase two test sites with different characteristics were selected for the AVENUE Project.

- Pfaffenthal in Luxembourg City, the capital of Luxembourg
- Contern, a city east of Luxembourg city

5.1 Test site Pfaffenthal

The specific characteristics of the Pfaffenthal valley make it the ideal use case scenario for the demonstration of a first and last mile mobility service. Different means of transportation are arriving in the different areas of Pfaffenthal and no connection in between them was available before the start of the project. Furthermore, Pfaffenthal offers a very diverse traffic situation with all kinds of different road users. It will be an interesting showcase to see how an autonomous vehicle can be integrated in such a diverse environment.

5.1.1 Initial situation in Pfaffenthal

Pfaffenthal is a small urban living area located in Luxembourg City, the capital of Luxembourg. This urban area with 1270 inhabitants is located in a valley between the historical centre of Luxembourg City and Kirchberg, the business district of Luxembourg City.

Pfaffenthal is connected to the city centre via a public elevator and to Kirchberg via a funicular. In the surroundings of the elevators entrance at the city centre level, several bus connections are available. The funicular is part of a multimodal station that has been newly implemented in Pfaffenthal. Besides the funicular station this multimodal station consists of a train station, a stop of several bus lines as well as a bike sharing station. On the Kirchberg side, a tram connection is available. Over a day all kinds of different people are transiting through the Pfaffenthal valley on the different means of transportation. During the peak hours in the morning and the afternoon mainly work commuters are passing through Pfaffenthal. During the day, local residents and a vast number of tourists are using the multimodal station in combination with the elevator in order to get to the different parts of Luxembourg City. The public elevator and the multimodal station are separated by 500 m and the residential area and the public elevator by 800 m. This corresponds to 5-10 minutes of walking.

Figure 6: Initial situation in Pfaffenthal

5.1.2 Autonomous shuttle trial in Pfaffenthal

Until the beginning of the project, no transportation solution existed to overcome the distance presented in chapter 5.1.1 between the residential area, the multimodal station and the public elevator. The core objective is to fill this lack of transportation in order to connect the different means of transportation with each other as well as the different areas of Luxembourg City with each other.

AVL, the PTA of Luxembourg-City is responsible for the operation of the buses within Luxembourg-City. Buses driving in Luxembourg-City are either operated directly by AVL or they are operated by private companies under sub-contract for AVL. The autonomous shuttles in Pfaffenthal are operated under subcontract for AVL by SLA.

5.1.2.1 Pfaffenthal route

In order to connect the public elevator, the multimodal station and the residential area with each other, the following route for the shuttle has been selected.

Figure 7: Autonomous shuttle route in Pfaffenthal trial

Route length	1.2 km (round-trip)
Speed limit all traffic	30 km/h
Road type	Public road

5.1.2.2 Shuttle stops

The Pfaffenthal route includes four fixed shuttle stops.

Shuttle stop 1	Panorama Lift
Shuttle stop 2	Funiculaire-Gare
Shuttle stop 3	Sichenhaff
Shuttle stop 4	Funiculaire

5.1.2.3 Timetable

Shuttle drives every 15 minutes.

From 24.09.2018-05.04.2019	
Monday-Friday	07h00-21h00
From 08.04.2019-today	
Tuesday & Thursday	12h00-16h00 & 16h45-20h00
Saturday, Sunday & every public holiday	10h00-21h00

5.1.2.4 Depot

A provisional depot has been implemented because of lack of space to implement a solid depot in the surroundings of the shuttle route. The shuttles get covered with a protective cover after every service. The implementation of a solid depot is currently being analysed but this depends on the future plans of the Pfaffenthal trial, whether the trial continues on the current route or if the trial will be relocated to another route within Luxembourg-City. This decision will be made by the authorities of Luxembourg-City in September 2019.

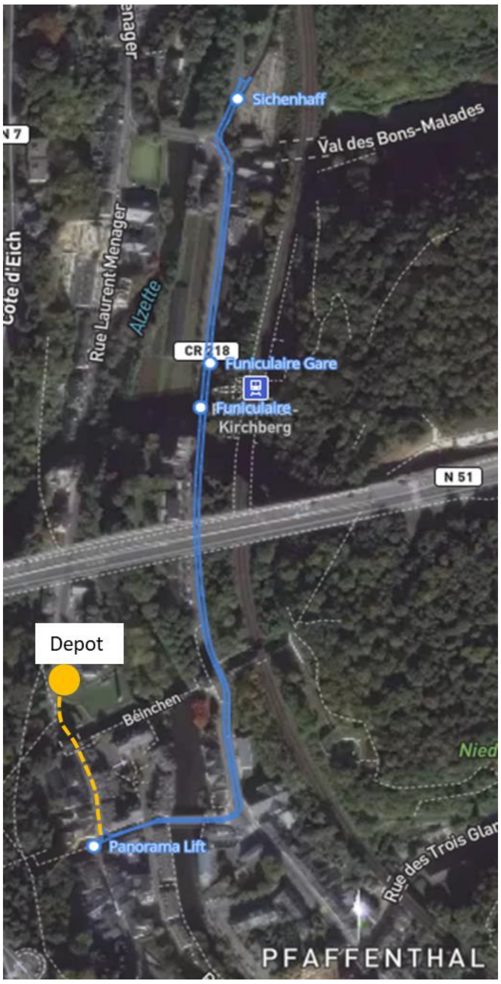


Figure 8: Depot location next to the shuttle route in Pfaffenthal

Figure 9: Temporary depot in Pfaffenthal

5.1.3 Operational experience Pfaffenthal

- **15629 passengers** since 24.09.2018 (until 18.08.2019)
- **8619.1 km driven** with both vehicles since 24.09.2018 (until 18.08.2019)

5.1.3.1 Transfer of GPS corrections

The first months of the operations in Pfaffenthal the shuttles encountered repeated issues related to the transfer of GPS corrections. These corrections are sent via radio signal and 3G/4G connectivity by a base station installed in the surroundings of the shuttles route. The issues appeared repeatedly on the same part of the shuttles route next to a building very close to the road. This building interfered with the signals coming from the base station.

In order to reduce the transfer of GPS correction issues, it is decided to use odometrics and 3D mapping instead of 2D mapping. Since then issues with GPS corrections could not be observed any more.

5.1.3.2 Main reasons that needed a temporarily service stop

Date	Issue
Week 51 & week 52 2018	GPS corrections issue
Week 6 2019	Heavy snowfall
Week 7 & week 8 2019	Windows broken due to vandalism on both vehicles (P93&P106)
Week 10 2019	Heavy rain and wind gusts >70km/h

5.1.3.3 Main issues Pfaffenthal trial

- Obstacles on the shuttles path (wrongly parked vehicles, construction work equipment, traffic signs,…)
- Growing vegetation along the route
- Heavy rainfall or snowfall
- Snow piles along the route
- Massive overtaking by other traffic (cars, buses, trucks)

Figure 10: Obstacles encountered regularly during the Pfaffenthal trial

5.1.4 Vision for Pfaffenthal Trial

The vision for the trial in Pfaffenthal is to deploy more routes within Luxembourg City in order to establish a network of autonomous shuttles that are linked to each other, to the different parts of Luxembourg City and to the public transport of the city. Different routes with the potential of establishing a network have already been analysed.

Public transport of the city of Luxembourg is circulating around the historical city centre. No transport solution is available in this area. Autonomous shuttles would be the ideal sustainable transportation solution to fill this gap without the necessity of adapting the existing infrastructure of the city centre.

Figure 11 shows a map of Luxembourg City centre with existing public transport lines and the potential future routes for autonomous shuttles in order to establish an autonomous shuttle network.

The yellow lines (numbered 1,2,3 and 4) are the shuttle routes and the different coloured lines are current bus lines. The yellow line with number 1 is representing the current shuttle route with a slight modification. The modification consists of driving a full loop instead of doing a round trip on the same route. This routing was not possible in the first phase because of construction works (further information in the attachment).

Figure 11: Public transport lines in Luxembourg City

5.2 Test Site Contern

The trial is the industrial zone of Contern was chosen for its difference environment compared to Pfaffenthal. Whereas Pfaffenthal shows a busy inner-city traffic situation with all kinds of different road users, the traffic in the industrial zone of Contern consists more of industrial vehicles, trucks and individual cars and a lot less cyclists and pedestrians. The morning and afternoon hours in Pfaffenthal are marked by a considerable rise in individual car traffic because of people going to and coming from work. This phenomenon is far less accentuated in Contern. The comparison of how the autonomous vehicles can be integrated in two very different environments will lead to interesting and important results.

5.2.1 Initial situation in Contern

Contern is a city located around 10 km east of Luxembourg city. An industrial zone with different companies has been implemented on its territory. A railway station as well as a stop for public buses are located on the border of the industrial zone. However, no public transport is entering the industrial zone of Contern. No transportation solution from the public transport stops to the different companies is available. For this reason, the vast majority of the companies' employees are using their private car for their work commute as well as for transfers inside the zone.

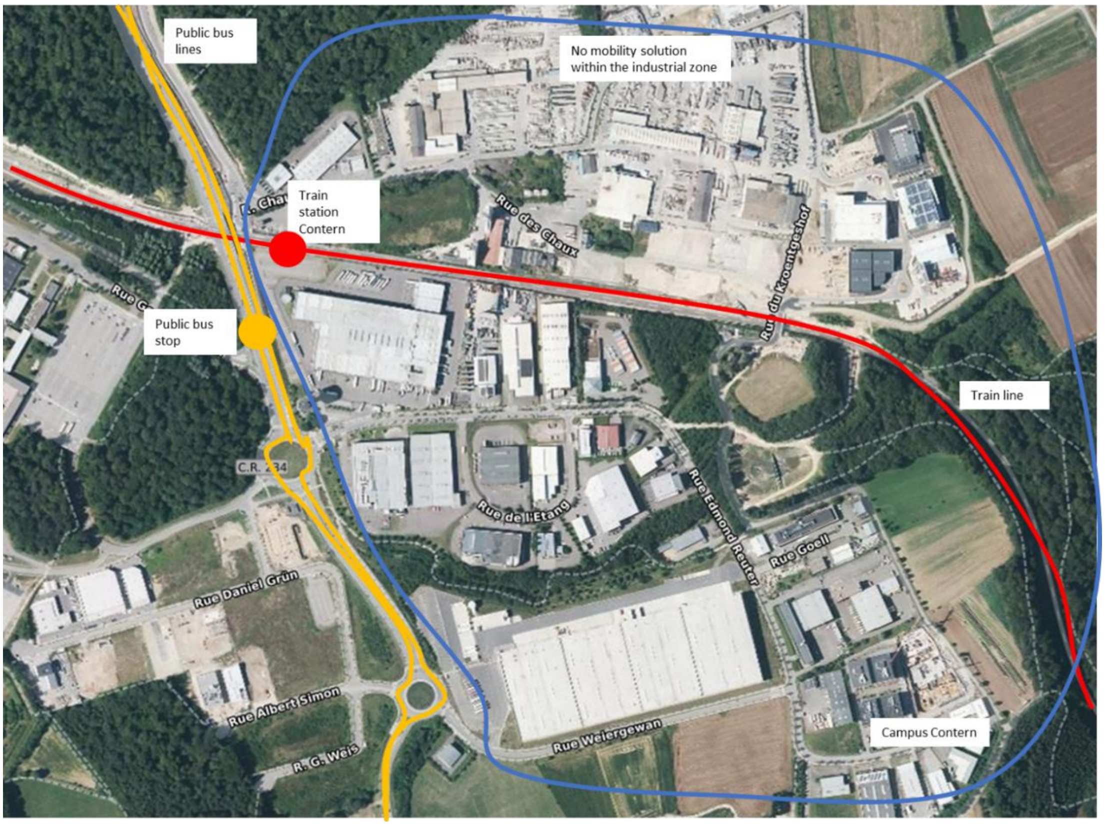


Figure 12: Initial situation industrial zone Contern

5.2.2 Autonomous shuttle trial in Contern

The core objective of this trial is to provide a mobility solution inside the industrial zone of Contern. The aim is to dispatch people arriving by public transport to the different companies in the industrial zone and to provide a mobility solution within the zone. In a first phase the autonomous shuttle is operating between a real estate development company called "Campus Contern" with more than 300 employees and the train station as shown in Figure 13 .

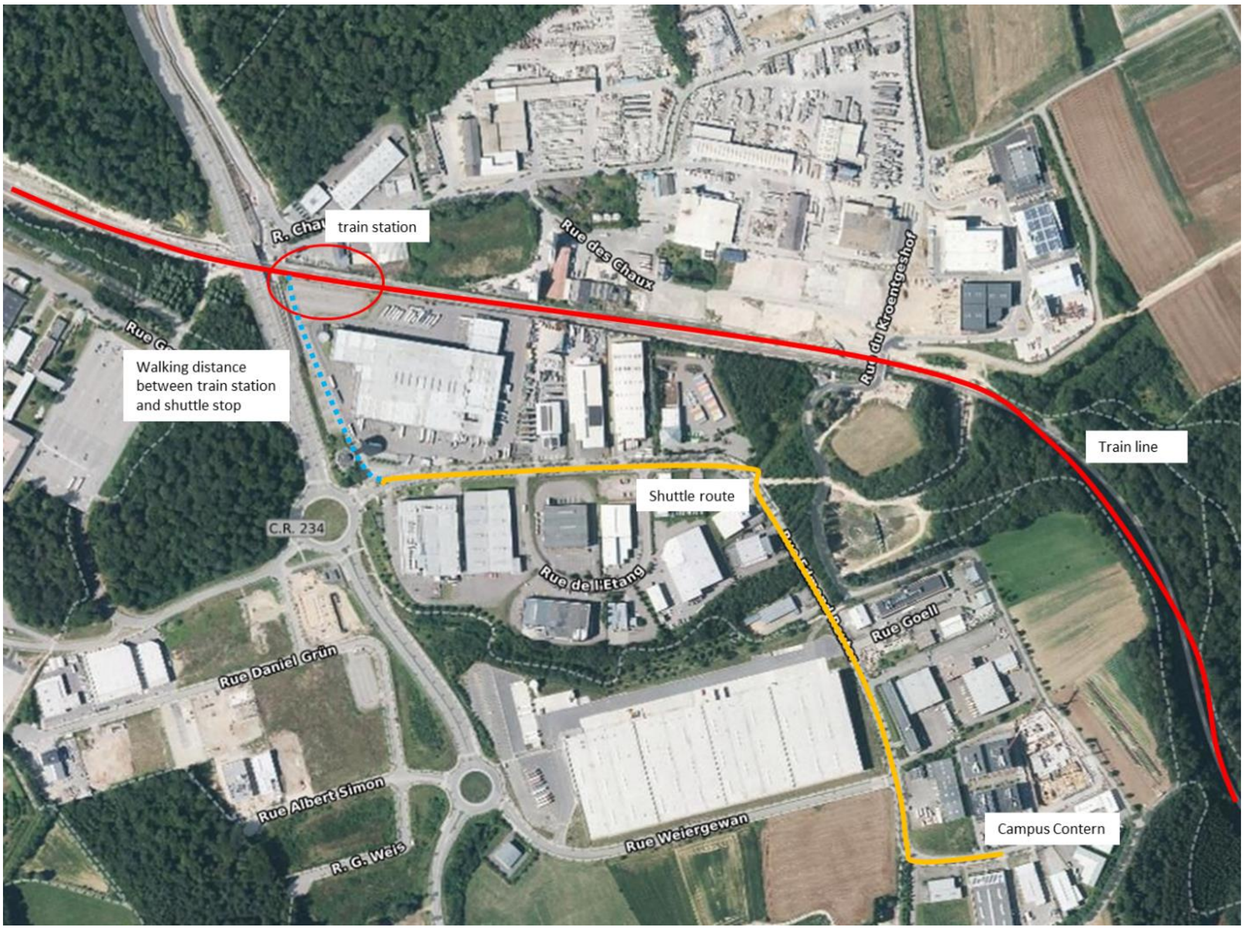


Figure 13: Autonomous shuttle route in the industrial zone of Contern

5.2.2.1 Shuttle route

Figure 14: Autonomous shuttle route in Contern trial

Route length	2.23 km (round-trip)
Speed limit all traffic	50 km/h
Road type	Public road

5.2.2.2 Shuttle stops

The Contern route includes three fixed shuttle stops.

Shuttle Stop 1	Campus Contern
Shuttle Stop 2	Gare Sandweiler Contern A
Shuttle Stop 3	Gare Sandweiler Contern B

5.2.2.3 Timetable

Shuttles runs continuously between Campus Contern and the train station Sandweiler-Contern.

Monday - Friday	07h00-09h00 & 16h00-19h00

5.2.2.4 Depot

A movable depot was built on the premises of “Campus Contern”.

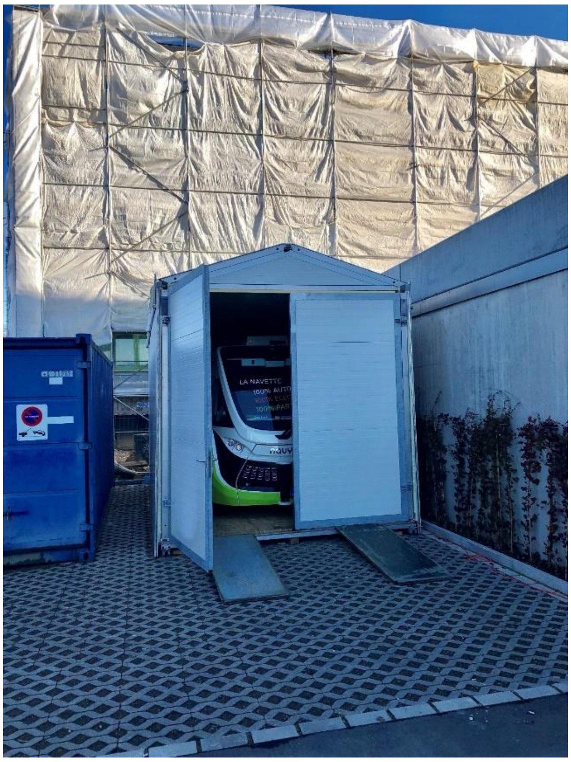


Figure 15: Movable depot in Contern

5.2.3 Operational experience Contern

- **511 passengers** between 24.09.2018-31.01.2019
- **1765.1 km driven**

5.2.3.1 Main issues Contern trial

- Obstacles on the shuttles path (mainly wrongly parked vehicles on the side of the road or partially reaching into the shuttles path)

Figure 16: Wrongly parked cars in Contern

5.2.3.2 Financial aspects

At the beginning of the Contern trial it was not possible to deploy the shuttle on the extended route because of heavy construction works on a specific part of this route. The company “Campus Contern” agreed that the shuttle should run in a first phase on a shortened route to the railway station and in a second phase, as soon as construction works are finished, the shuttle should operate on the extended route. As the shuttle was operating exclusively for "Campus Contern", the total costs were paid by this company. On this extended route the shuttle is driving past more companies and thus could connect more companies to the railway station. Companies along the shuttles route, that are interested in this new mobility solution and that are willing to financially contribute to this mobility solution would allow to split the total costs for the trial among more companies. The extended route could not yet be deployed due to delays of the construction works. On the initial route, the shuttle was not driving past a lot of companies and thus the total costs had to be paid by the company "Campus Contern" alone. After three months of operation in Contern and the extension of the route was still not possible due to the ongoing construction works, "Campus Contern" decided to not renew the contract because it was not willing to pay the high costs linked to the operation of the shuttles alone until the extension of the shuttle route will be possible.

It is very important to notice that the operation of the autonomous shuttles is linked to very high costs. A lot of companies, cities, authorities, etc. are very interested in such an innovative mobility solution but they are not able to bear the costs for it.

5.2.4 Vision for Contern trial

The vision for Contern is to connect more companies to the train station. In the first phase the shuttle is connecting the company "Campus Contern" to the train station. In a second phase an extension of the existing shuttle route is foreseen. In order to deploy the planned route extension shown in yellow (the red line represents the route of the first phase) in Figure 17 construction works on a bridge on the extended part of the route need to be finished. This extension is planned for Q3 2019. This route allows us to drive past more companies and through installing more stops along the route to connect more companies to the train station.

Figure 17: Extension of existing shuttle route in Contern

The industrial zone in Contern could also be a good use case for the establishment of an on-demand mobility system. The demand varies with the time of the day. During the peak hours in the morning and in the afternoon, the demand is mainly between the train station and the different companies. Outside of these peak hours, the demand switches more to inside the industrial zone between the different companies and to points of interest like restaurants.

An extension of the routes to the other side of the industrial zone, as shown in blue in Figure 18, could be imagined and will also be analyzed.

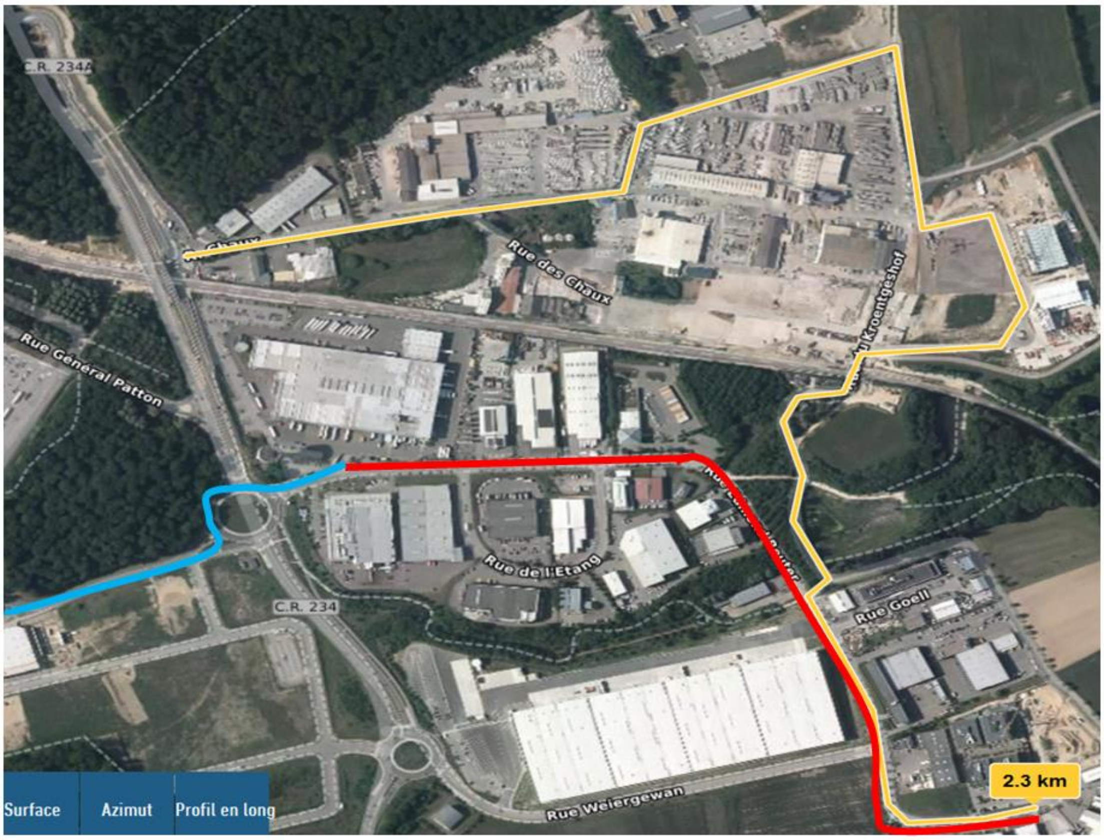


Figure 18 : Extension to other side of the industrial zone

6 Planning for the next months

Trial	Description	Schedule
Contern	Mapping of extended route	October 2019
	Start of trial on extended route	November 2019
Pfaffenthal	Deciding with authorities of Luxembourg City which route will be implemented (continuation of current route, another of the suggested routes, combination of routes (network))	September 2019

7 Conclusion

The two different trials in Pfaffenthal and Contern showed that autonomous shuttles could successfully been integrated into traffic and the number show that passengers are ready to step into an autonomous shuttle. We were also able to identify areas that still need development in order to improve the operation of shuttles.

The different environment in Pfaffenthal and in Contern led to very different operational experiences. In Contern very few issues occurred during the operation that were caused by external factors. Some software problems occurred during the trial but these are neglectable. All in all the operations in Contern passed very smooth. The GPS correction base is installed on the highest building in the area and no other infrastructure could interfere with the GPS corrections. As a result, in Contern we didn't encounter this problem seen in Pfaffenthal. There is less traffic in the industrial zone of Contern compared to Pfaffenthal, so the shuttle encountered less over takings. The main issue encountered were vehicles that were parked illegally on the shuttles path.
In Pfaffenthal the traffic situation is very different. The shuttle is sharing the street with all kinds of different traffic users going from cyclists and pedestrians to trucks, buses and individual cars. Even with the speed limit of 30 km/h, the shuttle encounters numerous over takings which cause harsh breakings of the shuttle. Complex traffic situations around the shuttle cause a rough driving behaviour of the shuttle. The shuttle needs to identify other traffic and not only detect it. The shuttles speed of max. 18km/h is slowing down traffic in Pfaffenthal, especially in the morning peak hours when the traffic is very dense and the drivers seem to be very nervous and hectic. This is also the reason of the change of the operational hours in Pfaffenthal on the 08.04.2019. It was decided to keep the shuttles out of the morning peak hours in order to prevent the shuttles from slowing down traffic.

The main technical areas of the shuttle identified during the trials and that need to be improved are:

- Higher operational speed to 25 km/h
- Object identification (and not only object detection) in order to prevent unnecessary and harsh breakings

These two improvements will lead to:

- Higher acceptance among passengers and other traffic participants
- Higher safety

Appendix A:

Description	value
Capacity	
Passengers	15
Sitting	11
Standing	4
Dimensions	
Length	4.75 [m]
Width	2.11 [m]
Height	2.65 [m]
Clearance	0.20 [m]
Tyres	215/60 R17
Wheels	Steel wheel rims
Empty weight	2400 [kg]
Gross weight	3450 [kg]
Engine	
Drive wheels	2
Engine	Electric
Power	15 [kW] nominal
Maximum speed	45 [km/h]
Operating speed	25 [km/h]

Maximum slope	12 %
Energy	
Battery	Battery pack LiFe P04
Capacity	33 [kWh]
Average theoretical autonomy	9 hours
Charge duration for 90 %	8 hours at 3.6 kW, 4 hour at 7.2 kW
Charging technology	Induction / Plug
Charging temperature	0 to +40 °C
Operating temperature	-10 to +40 °C
Direction	
Steering wheels	2x2
Turning radius	< 4.5 [m]
Equipment	
Airconditioning	Automatic
Heating	Central
Doors	Double wings
Body	Polyester
Windows	Glass
Visual information	15” touchscreen
Sound information	Speakers
Lighting	Unidirectional
Sound warning	Buzzer/claxon
Safety	• Handholds (4) • Supporting bar (2) • Emergency hammer • Triangle • Safety vest • First aid kit • Fire extinguisher • Interior camera
Wheelchair access	Manuel ramp
Localization & object detection	

Lidar 1	Two 360° multi-layer lidars
Lidar 2	Six monolayer lidars
Cameras	Front stereo vision cameras
Odometry	Wheel encoder + inertial unit
Safety	
Emergency stop button	2 buttons
SOS intercom	1 button / via supervision
Emergency break	Automatic
Parking brake	Automatic

Appendix B:

Modification of the current shuttle route in Pfaffenthal. Instead of driving a round trip the route could consist of a full loop. The full loop solution was not possible in the first phase because of construction works that are now finished.

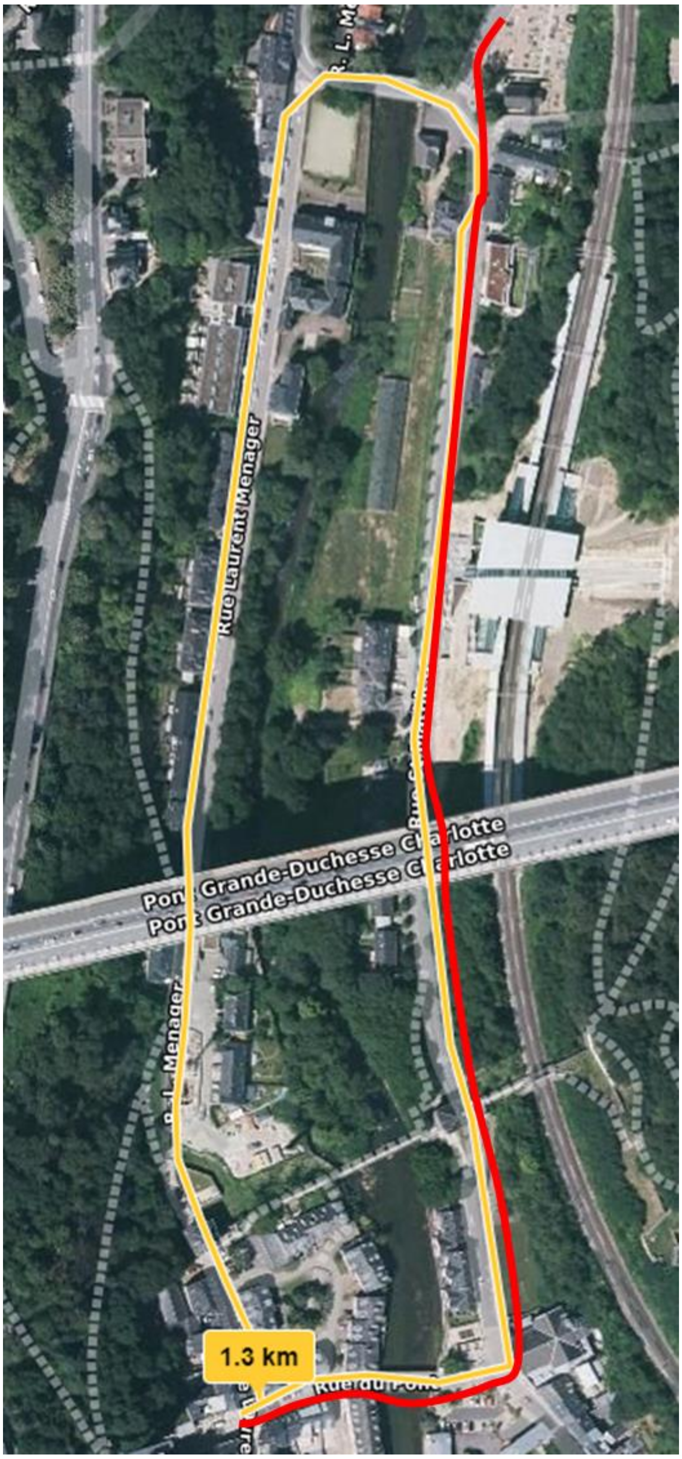


Figure 19: Modification of the current shuttle route