Autonomous Vehicles to Evolve to a New Urban Experience

DELIVERABLE

D7.11

Second Iteration XCityX 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
BM	Bestmile
BMM	Business Modelling Manager
CAV	Connected and Autonomous Vehicles
CB	Consortium Body
CERN	European Organization for Nuclear Research
D7.1	Deliverable 7.1
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)
EAB	External Advisory Board
EC	European Commission

EM	Exploitation Manager
EU	European Union
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
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
PTO	Public Transport 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)
WP	Work Package
WPL	Work Package Leader

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 and Esch-sur-Alzette, Esch is the second most populated town in Luxembourg and is located on the border to France in the South of the country around 17 km away from the capital Luxembourg-City. The different environments of the industrial zone of Contern and the busy city surroundings in Pfaffenthal and Esch 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, Contern and Esch 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 was deployed in Q3 2020 and for Pfaffenthal different future concepts with authorities of Luxembourg-City are currently being discussed. Esch will be launched in Q2 2021.
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

AVENUE aims to design and carry out full-scale demonstrations of urban transport automation by deploying, for the first time worldwide, fleets of Automated minibuses in low to medium demand areas of 4 European demonstrator cities (Geneva, Lyon, Copenhagen and Luxembourg) and 2 to 3 replicator cities. The AVENUE vision for future public transport in urban and suburban areas, is that Automated vehicles will ensure safe, rapid, economic, sustainable and personalised transport of passengers. AVENUE introduces disruptive public transportation paradigms on the basis of on-demand, door-to-door services, aiming to set up a new model of public transportation, by revisiting the offered public transportation services, and aiming to suppress prescheduled fixed bus itineraries.

Vehicle services that substantially enhance the passenger experience as well as the overall quality and value of the service will be introduced, also targeting elderly people, people with disabilities and vulnerable users. Road behaviour, security of the Automated vehicles and passengers' safety are central points of the AVENUE project.

At the end of the AVENUE project four-year period the mission is to have demonstrated that Automated vehicles will become the future solution for public transport. The AVENUE project will demonstrate the economic, environmental and social potential of Automated vehicles for both companies and public commuters while assessing the vehicle road behaviour safety.

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 Automated 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 Fully Automated Vehicles

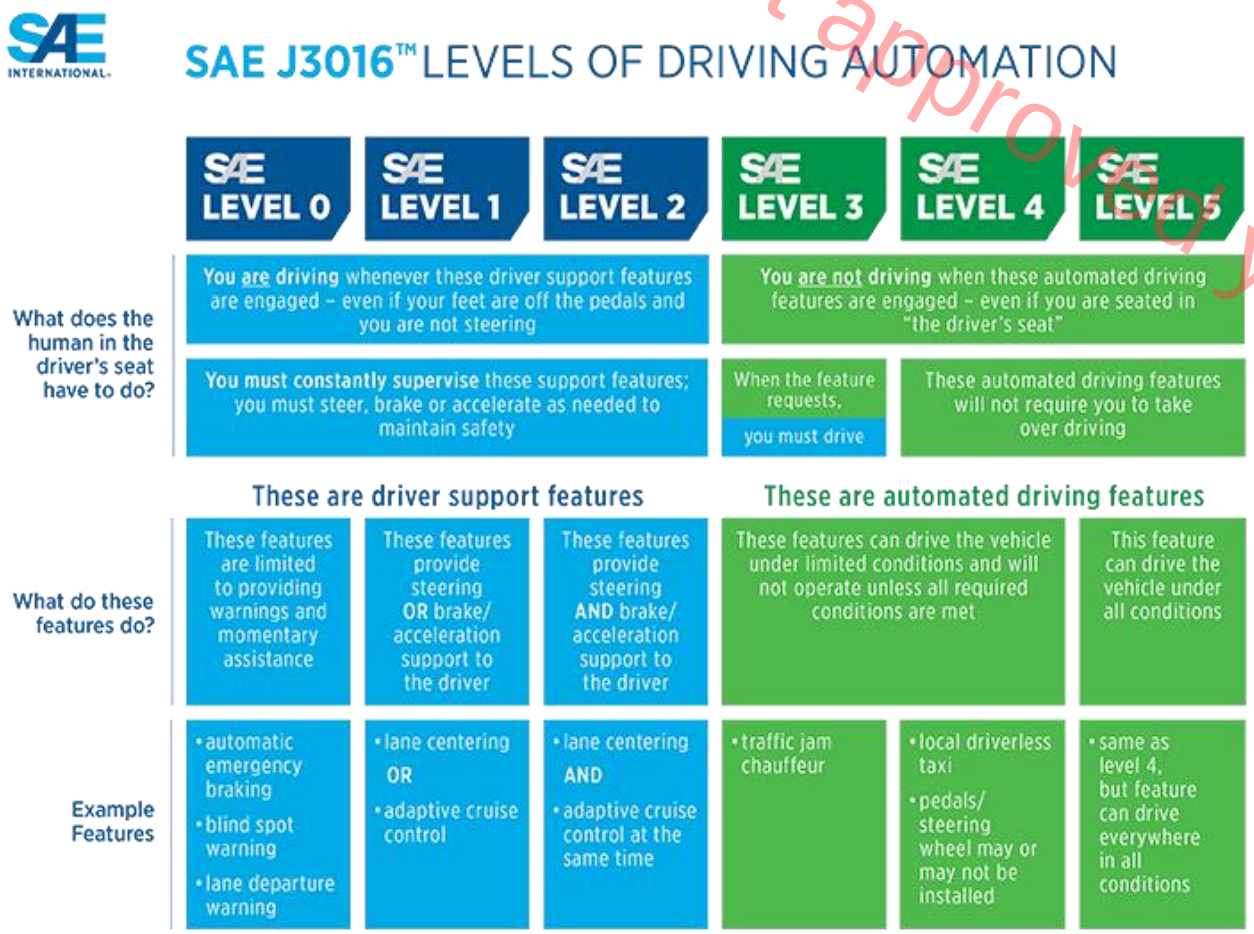
A self-driving car, referred in the AVENUE project as **a Fully Automated Vehicle** (**AV**), also referred as Autonomous Vehicle, is a vehicle that is capable of sensing its environment and moving safely with no human input.

The terms *automated vehicles* and *autonomous vehicles* are often used together. The Regulation 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles defines "automated vehicle" and "fully automated vehicle" based on their autonomous capacity:

- An "automated vehicle" means a motor vehicle designed and constructed to move autonomously for certain periods of time without continuous driver supervision but in respect of which driver intervention is still expected or required
- "fully automated vehicle" means a motor vehicle that has been designed and constructed to move autonomously without any driver supervision

In AVENUE we operate ***Fully Automated minibuses for public transport***, (previously referred as Autonomous shuttles, or Autonomous buses), and we refer to them as simply *Automated minibuses* or *the AVENUE minibuses.*

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



1.2.1 Automated 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 Automated 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 Automated 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 Automated vehicle capabilities in AVENUE

The Automated vehicles employed in AVENUE fully and automatically manage the above defined, micro-navigation and road behaviour, in an open street environment. The vehicles are Automatically capable to recognise obstacles (and identify some of them), identify moving and stationary objects, and Automatically 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.

Due to legal requirements a **Safety Operator** must always be present in the vehicle, able to take control any moment. Additionally, at the control room, a **Supervisor** is present controlling the fleet operations. An **Intervention Team** is present in the deployment area ready to intervene in case of incident to any of the mini-busses.

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 T7.11 is to integrate autonomous vehicles into the existing public transport services. From day one of the project TPG 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 D7.11, 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 XCityX, Switzerland.

2 *(Operator)* test sites

Within the AVENUE framework, Sales Lentz runs three test sites:

- Pfaffenthal
- Contern
- Esch sur Alzette

	Pfaffenthal	Contern	Esch-sur-Alzette
Community	Luxembourg-Ville	Contern	Ville d'Esch
Funding	EU + SLA	EU + SLA	EU + SLA + Ville d'Esch
Start date project	01.07.2018	01.07.2018	01.02.2021
Start date trial	19.09.2018	19.09.2018	Q2 2021
Type of route	Fixed circular line	Fixed circular line	Fixed circular line
Distance	2.1 [km]	3 [km]	1.5 [km]
Road	Open road	Open road	Open road / pedestrian zone
Type of trafic	Mixed	Mixed	Mixed
Speed limit	50 [km/h]	50 [km/h]	20 [km/h]
Roundabout	No	No	No
Trafic lights	No	No	In planning
Type of service	Traditional busline	Traditional busline	Traditional busline / On Demand
Concession	Line	Line	Line
Number of bus stops	4	2	3
Type of bus stop	Fixed	Fixed	Fixed
Bus stop infrastructure	Yes	Yes	Yes
Number of vehicles	2	1	1
Timetable	Fixed	Fixed	Fixed / On Demand

Operation Days	Tuesday & Thursday 12h00-16h00 16h45-20h00 Saturday, Sunday & on holidays:	Monday-Friday (5 days) 07h00 – 09h00 16h00 – 19h00	TBD
Timeframe weekdays	10h00-21h00	/	/
Timeframe weekend / holidays	10h00-21h00	/	/
Depot	On site	On site	On site
Driverless service	No	No	End 2022

Table 1: TPG demonstrator site comparison

2.1 Test Site 1

Pfaffental

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.

2.1.1 Partners

Herewith the project partners

- Ville de Luxembourg (VDL)
- Autobus de la Ville de Luxembourg (AVL)
- L'Administration des ponts et chaussées

2.1.2 Objectives

Until the beginning of the project, no transportation solution existed to overcome the distance between the residential area, the multimodal station, and the public elevator. The core objective is to fill this lack of transportation 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.

2.1.3 Site description

Pfaffenthal is a small urban living area located in Luxembourg City, the capital of Luxembourg. This urban area with 1270 inhabitants is 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.

2.1.3.1 Use cases

During the day, residents, employees 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.

2.1.3.2 Site Data

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

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

2.1.3.3 Route (if fixed route)

Driving direction	Clock-wise
Route length	1.2 [km]
Speed limit all traffic	30-50 [km/h] area
Road	Public road

2.1.3.4 Current public transport status

Bus lines (Public transport) stop near Pfaffenthal

Line 23	AVL (AVL, the PTA of Luxembourg-City)
Line 26	AVL (AVL, the PTA of Luxembourg-City)

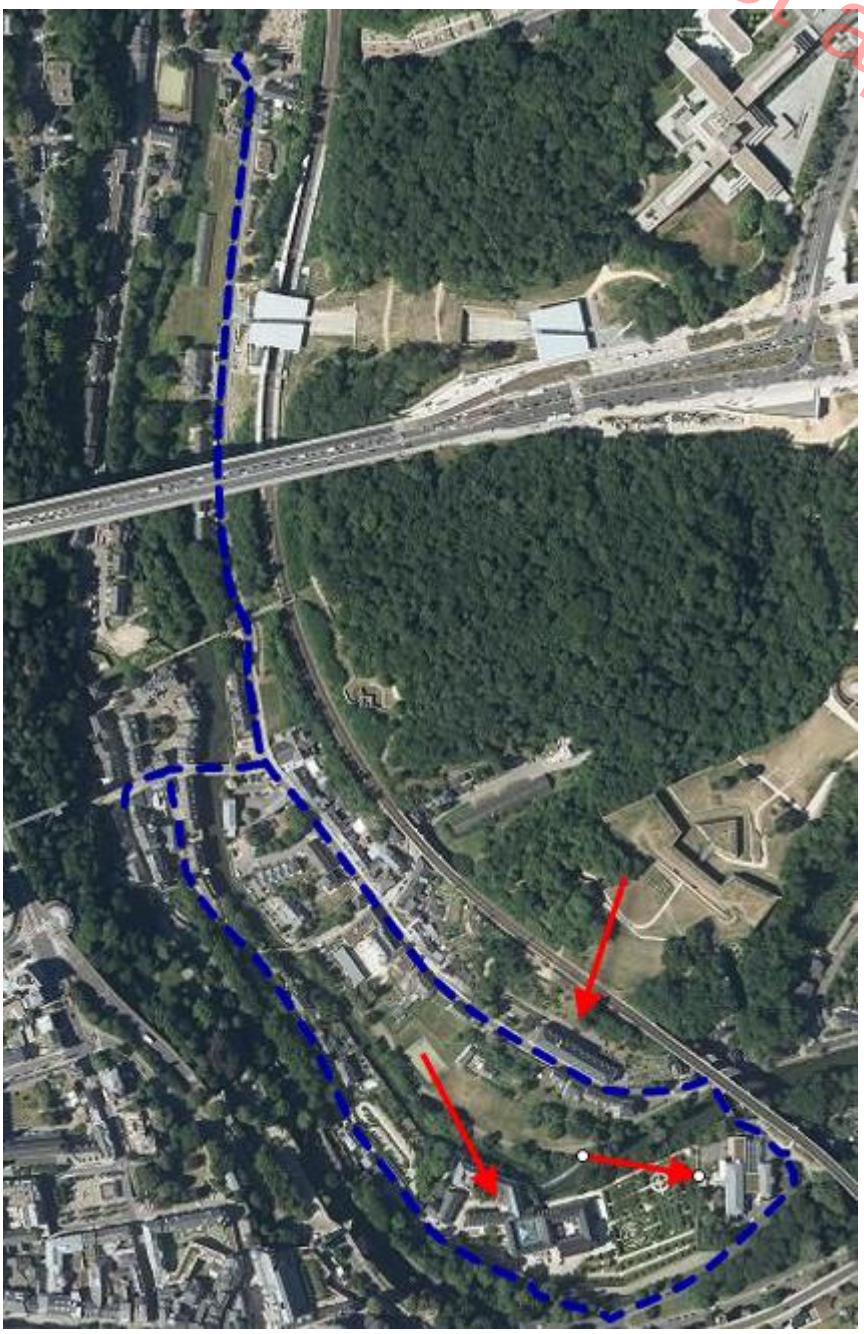
2.1.3.5 Future situation

A future project is in process of being accepted by the City of Luxembourg and at a Political Level.

The objective of this route extension is to provide a transport service to:

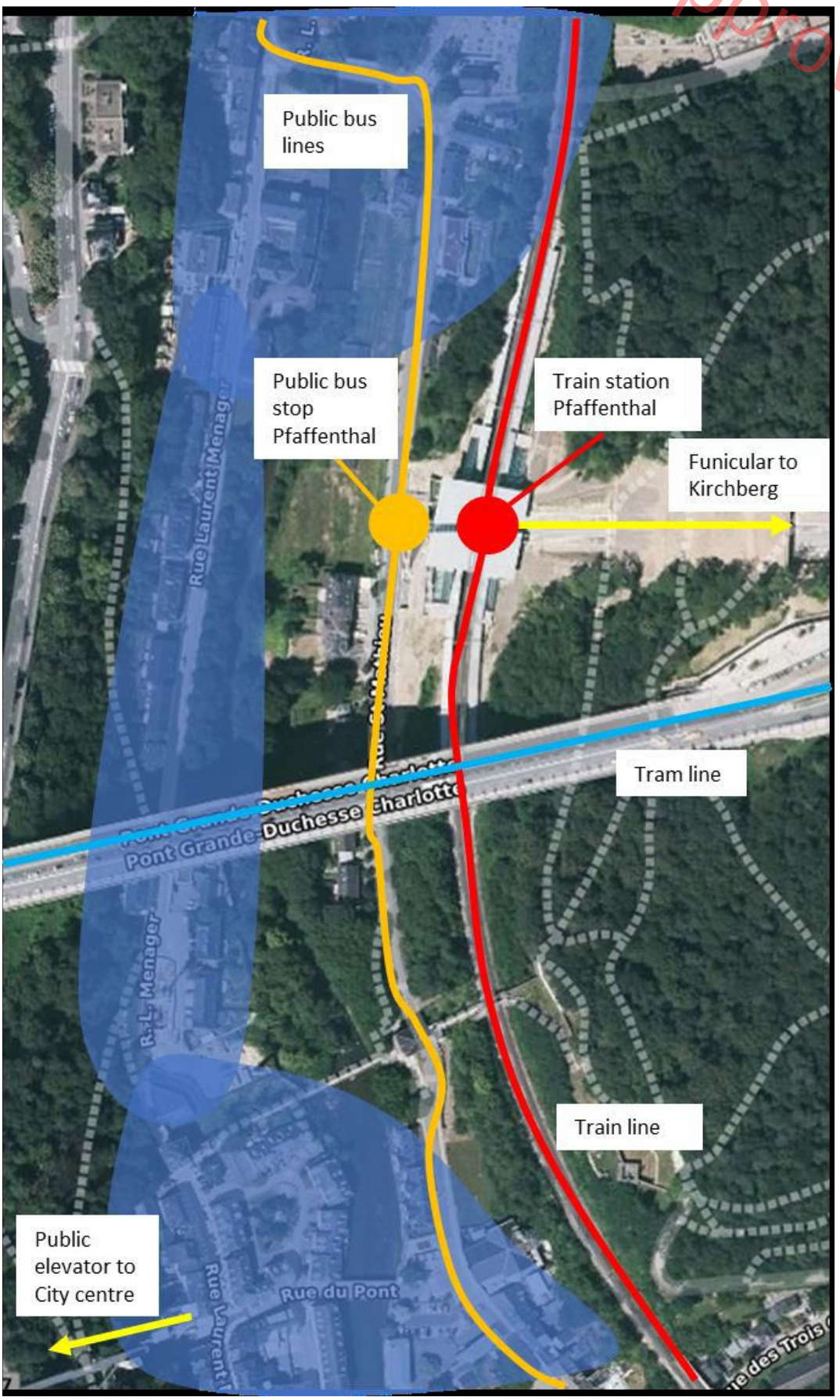
- Hospice de Pfaffenthal (limit in parking space)
- Youth Hostel (limit in parking space
- Servior (limit in parking space)

All these three future partners have a lack of parking space and no approximate Bus stops, for people who take the Panorama Lift, to come down from the upper town.



2.1.3.6 AVENUE solution

2.1.3.7 Bus stops



2.1.3.8 Vehicle depot

Finding a depot at Pafendall is still in progress.
Pafendall has one of the highest prices for parking spaces/places in Luxembourg.
Private persons are not interested in renting out their parking places and the city is struggling to find a Depot. We proposed several deposits to the City of Luxembourg, but our demands keep currently unanswered, this approval goes through several services, all this service must agree.

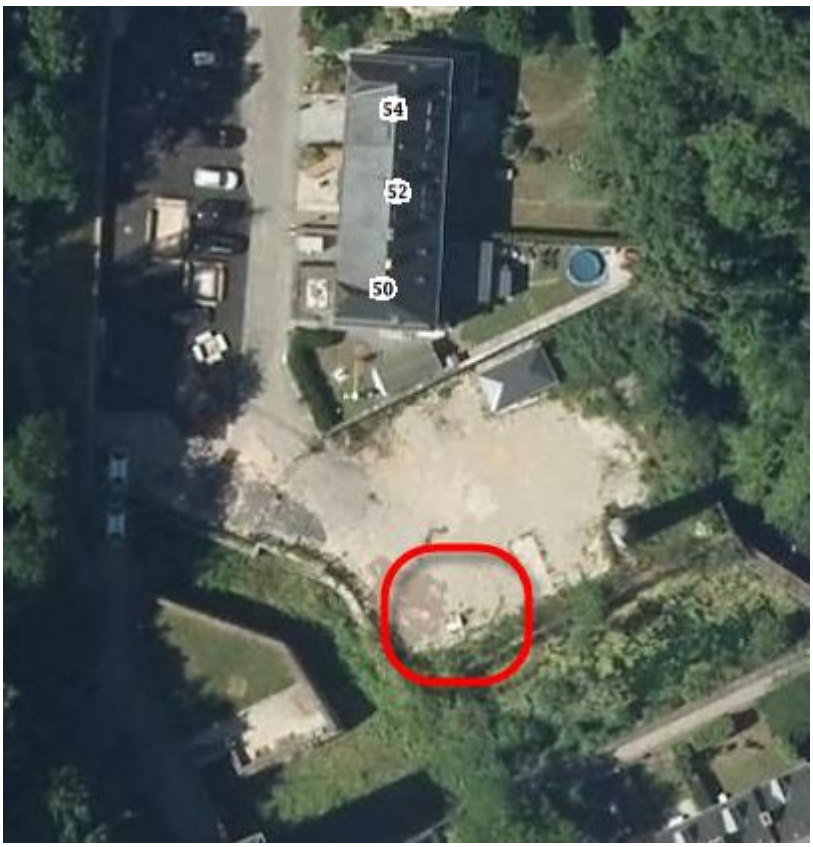
Covid 19 is one of the main causes of the delay in this procedure.

2.1.3.8.1 Route to vehicle depot

TBD

2.1.3.8.2 GNSS base antenna

The antenna is installed at the old depot. Rue Laurent Ménager



2.1.4 Operations

Operational experience Pfaffenthal

- 25060 passengers since 24.09.2018 (until 01.01.2021)
- 9000 km driven with both vehicles since 24.09.2018 (until 01.01.2021)
- Instantaneous consumption (kwh) per hour > 0.58
- Instantaneous consumption(kwh) per kms > 0.51

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)

2.1.4.1 Timetable (during the week)

We will assure the follow service:

Tuesday & Thursday 12h00-16h00

2.1.4.1.1 Weekend and holidays

We will assure the follow service:

Saturday, Sunday & on holidays: 16h45-20h00

2.1.5 Way to book a shuttle

An on-demand service requires that a client be able to book a ride. The objective is to do this directly by means of an application on your smartphone or indirectly via a telephone-number and the help of an operator.

2.1.5.1 Client Application

This service is not yet available in Luxembourg. Public transport has been free for all users since April 2020.

The Transport Ministry in collaboration with the mobility centre wants to draft a procedure concerning the reservations of a service which integrates a service of public transport. The procedure and the way to book a service of a public transport can only be drawn up by the MMTP.

The Mobility Centre (Mobilitéitszentral) is the communication platform and shop front of the Public Transport Administration of the Ministry of Mobility and Public Works. Travellers can contact the Mobilitéitszentral about all public transport matters, problems, or complaints.

A National application is under development

2.1.5.2 Vehicle dispatching

Vehicle dispatching through Bestmiles' autonomous fleet orchestration platform.
We also use the TomTom webfleet system for geolocation and for the dirver's check-in.

2.1.6 Traveller information

In the near future all users of public transport, bus, train, tram, can get travelling information at the mobility center and at the Leetstell

The Mobility Centre (Mobilitéitszentral) is the communication platform and shop front of the Public Transport Administration of the Ministry of Mobility and Public Works. Travellers can contact the Mobilitéitszentral about all public transport matters, problems, or complaints.

The "Leetstell" occupies a vast command centre within the Public Transport Administration of the Ministry of Mobility and Public Works, located in Kirchberg. Created in 2018, its purpose is to improve the comfort and all-round experience of public transport passengers.

2.1.7 Reporting

2.1.7.1 Safety driver

Safety drivers have to fill-in a report with their findings and interventions during every service.

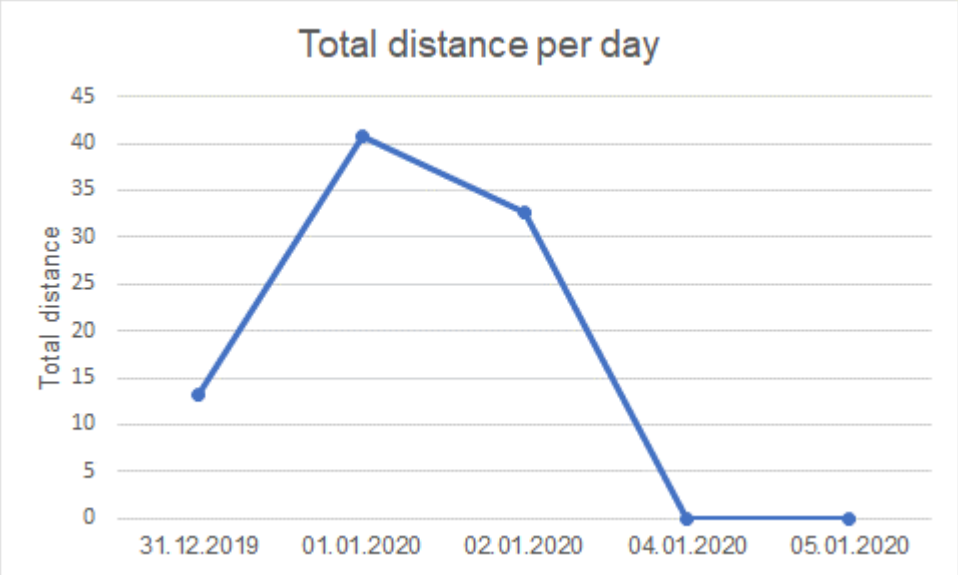
2.1.7.2 Clients

As subcontractor, all contact with passengers must go through the ordering parties in this case Autocars Ville de Luxembourg in collaboration with the "Leetstell"

2.1.7.3 Authorities

A monthly report must be sent to the City of Luxembourg with:

- Daily distance of the two shuttles (distance per day)



- Number of passengers

	31.12.2019	01.01.2020	02.01.2020
7h00-8h00	/	/	/
8h00-9h00	/	/	/
9h00-10h00	/	/	/
10h00-11h00	/	6	/
11h00-12h00	/	13	/
12h00-13h00	22	8	10
13h00-14h00	3	9	14
14h00-15h00	problème technique	7	15
15h00-16h00	problème technique	5	22
16h00-17h00	7	16	/
17h00-18h00	13	11	10
18h00-19h00	6	9	0
19h00-20h00	0	6	0
20h00-21h00	/	2	/
Total :	**51**	**92**	**71**

- If there were any anomalies during the week

For example, here, a truck parked in front of the shuttle stop.

2.1.8 Deployment

Due to road works (start January 2020) and changes on the route, a new deployment will have to be organise.

- A feasibility analysis has to be done from Navya
- If Navya recommended to install fixed obstacles or to do some works an authorization to “the service de voirIe” (road service) will have to be done

2.1.9 Evaluation

During the last months of service, we encountered the following issues:

- 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)

2.1.9.1 Operations related.

86% of the operating time the Automated Shuttle drives automated and 14 % in manual.

See point 2.1.4

2.1.9.2 Vehicle related

Our shuttles have been victims of vandalism. On two different dates, unknow people broke several windows of the shuttles.

9.01.2019

13.02.2019

2.1.9.3 Infrastructure related

The current location of the GNSS antenna will soon be under construction. We must make a request to the Ville de Luxembourg to know where and when we can move the antenna.

See also point 2.1.3.10

2.1.9.4 Safety drivers related

Safety drivers receive a technical and operational training at Bascharge (our headquarters)
A training trip and an Automated Shuttle are also available for our Drivers.
This training is followed by a “marche a blanc” on the operation site without passengers.

2.1.9.5 Covid-19 related

The following protective and preventive measures must be observed until further notice by all operators and users of public transport to minimise the spread of the COVID-19 coronavirus among the population:

- Wearing a protective mask is mandatory for travellers: Passengers must wear either a medical mask, a homemade fabric mask, a bandana or a scarf when using public transport.

- Drivers don’t have to wear a mask if they keep a 2-metre distance to passengers, or if they are separated by a protective shield > In the shuttle a 2 meter distance cannot be respected
Our driver should have his mask on non-stop

- The front door of the bus remains closed. Travellers are asked to board and disembark using the rear doors.
- The 1st row of passenger seats should be kept unoccupied as far as possible.

- Travellers are requested to keep their distance > With this measure the shuttle can only transport one passenger or a family

Due to Covid 19 our Shuttles are out of service since March 2020
Luxembourg-City gives us an ok with the measures put in place by Sales-Lentz, but because of the confinement this request has been rejected.

We are in permanent communication with the Luxembourg-City, but there is a lack of decisions and communication between there services. It is extremely difficult and time consuming for us.

2.1.10 Recommendations

In order for the vehicle to be better accepted by other road users and clients we have to develop:

Develop:	• Driveability • Object Identification (not only detection)
In order to enhance:	• Security • Acceptance
Which enables us to:	• Increase Vehicle Speed
Which leads to:	• Experience / comfort / fluidity

2.1.11 Future developments

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.

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

Figure 11 shows a map of Luxembourg City center 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 colored lines are current bus lines. The yellow line with number 1 is representing the current shuttle route with a slight modification.

This network will only be authorized when an automated vehicle reaches a speed of min 40 km/h. A drop in speed on several roads in town will not be approve from Administration des ponts et chaussées

2.2 Second site

2.2.1 Partners

Contern partners :

- Campus Contern Sàrl
- Administration communale de Contern
- L'administration des ponts et chaussées

2.2.2 Objectives

The core objective of the phase one was to provide a mobility solution inside the industrial zone of Contern. The aim was 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 this first phase the autonomous

shuttle was operating between a real estate development company called “Campus Contern” with more than 300 employees and the train station as shown in Figure 13

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.

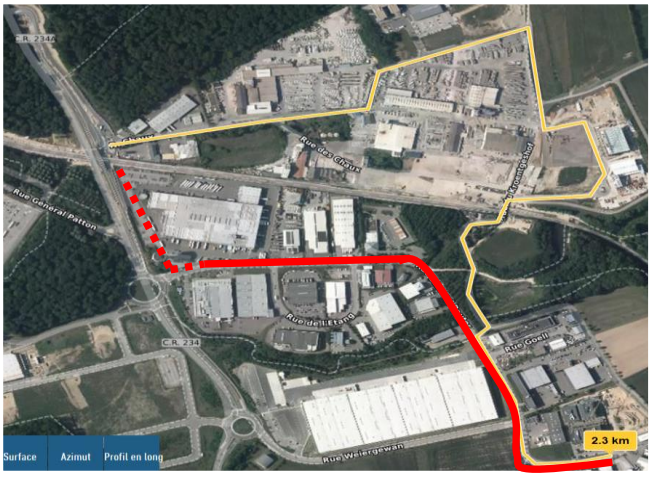
2.2.3 Site description

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 was entering the industrial zone of Contern. No transportation solution from the public transport stops to the different companies was available.

2.2.3.2 Use cases

The vast majority of the company’s employees was using their private car for their work commute as well as for transfers inside the zone.

2.2.3.3 Site Data



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

2.2.3.4 Route

Driving direction	Clock-wise
Route length	1.2 [km]
Speed limit all traffic	30-50 [km/h] area
Road	Public road

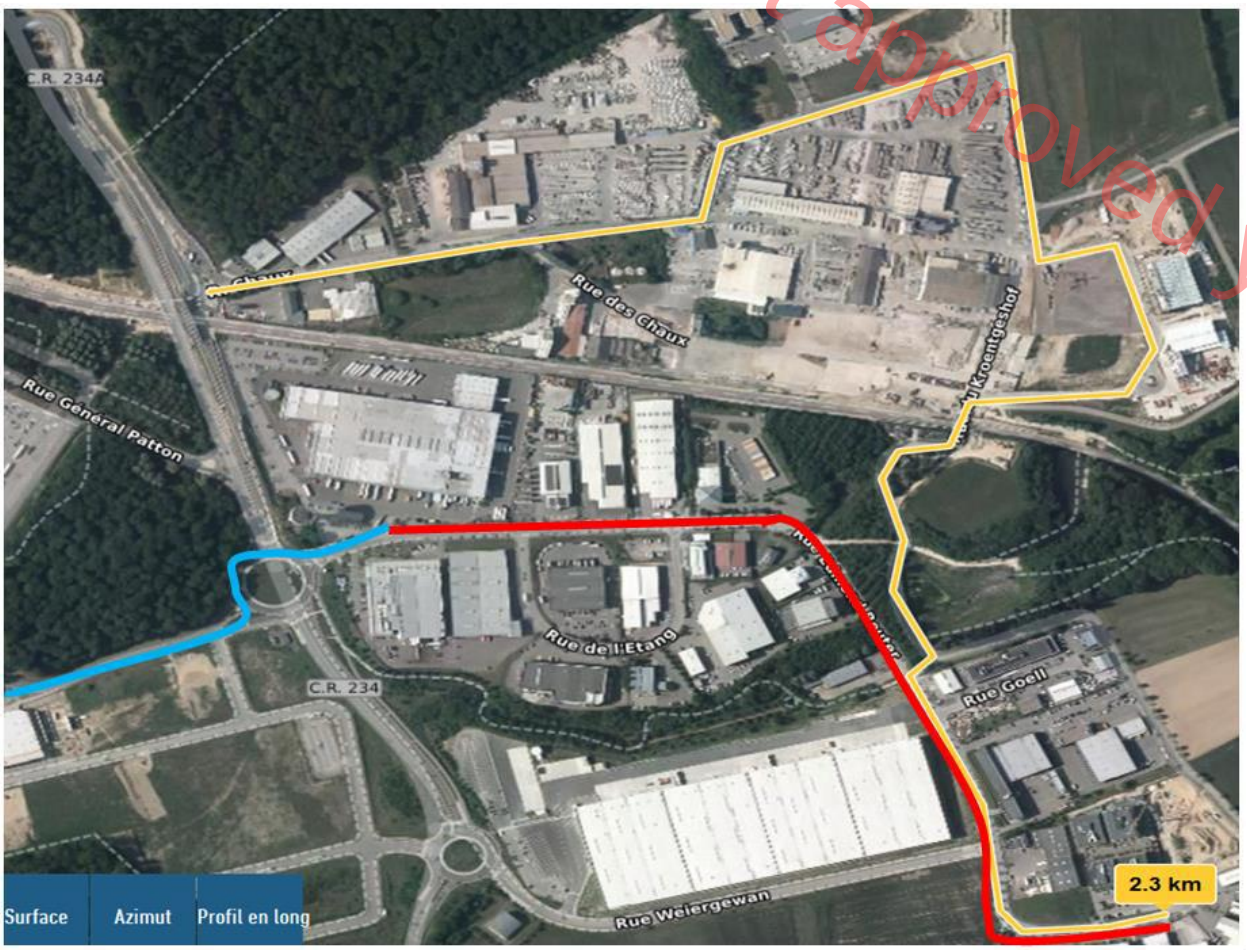
2.2.3.5 Current public transport status

Bus lines near Campus Contern

Line 142	RGTR

2.2.3.6 Future situation

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.



2.2.3.7 Depot

Campus Contern provided an underground depot for the shuttle.

2.2.3.8 GNSS base antenna

The Gnss antenna is installed on the highest builind in the region. “the water tower”

2.2.3.9 Operationas

- 650 passengers between 24.09.2018-01.01.2020
- 1900 km driven

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)

2.2.3.10 Timetable

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

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

2.2.4 Way to book a shuttle

See point 2.15,

2.2.5 Reporting

2.2.5.1 Safety driver

Safety drivers have to fill-in a report with findings and interventions during every service.

2.2.5.2 Clients

As subcontractor, all contact with passengers must go through the ordering parties in this case Campus Contern

2.2.5.3 Covid 19 related

As mentioned in point 2.1.9.5 Covid 19 unfortunately upset the evolution of the project in Contern.

Due to government restrictions, and the new law that allows employees to do Home office, only 10% comes to work at Campus Contern, and by car.

A few weeks before its expiry at the end of March, the law agreement with Luxembourg was once again extended. Cross-borders commuters will thus be able to continue with the Home office without impact until June 30, 2020.

https://guichet.public.lu/en/actualites/2020/mars/19-teletravail-frontaliers.html

2.2.3.7 Financial related

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 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.

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 Authorities

Luxembourgish Ministry of Mobility and Public, MMTP
https://mmtp.gouvernement.lu/fr.html

National Society of Automotive Traffic (société nationale de circulation automobile -SNCA)
https://snca.public.lu/fr.html

Administration des Ponts et Chaussées
https://pch.gouvernement.lu/fr.html/

3.2 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.

3.3 Test site homologation

For every test site an authorization of the Luxembourgish Ministry of Mobility and Public works is needed. This authorization 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 authorization is valid for one year. A new authorization can be requested afterwards.
The following terms are linked to the authorization:

- No other vehicles than the ones stated in the authorization are allowed on the route.
- No other route than the one documented in the authorization 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 authorization.
- An operator with a bus driving license (license 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 and in Contern was 50 km/h. For this reason, an authorization 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 authorization was granted by the Luxembourgish National Roads Authority (Administration des Ponts et Chaussées).

3.3.1 Concessions

3.3.1.1 Telecommunications

3.3.1.2 Passenger transport concession

Virtual bus stops etc

3.3.2 Application process

3.3.2.1 Timetable

3.3.2.2 Costs

3.3.2.3 Issues

4 Vehicles *(per type if more then 1)*

4.1 *Operator name (vehicle owned)*

Type	ID	Type	Funded by	Project	Covering
Navya Arma DL4	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	Esch	TBD

Table 2: Vehicles – Operator Fleet

4.2 Technical data

See appendix A

4.3 Options

4.3.1 General

- Air conditioning

4.3.2 Seat-belts

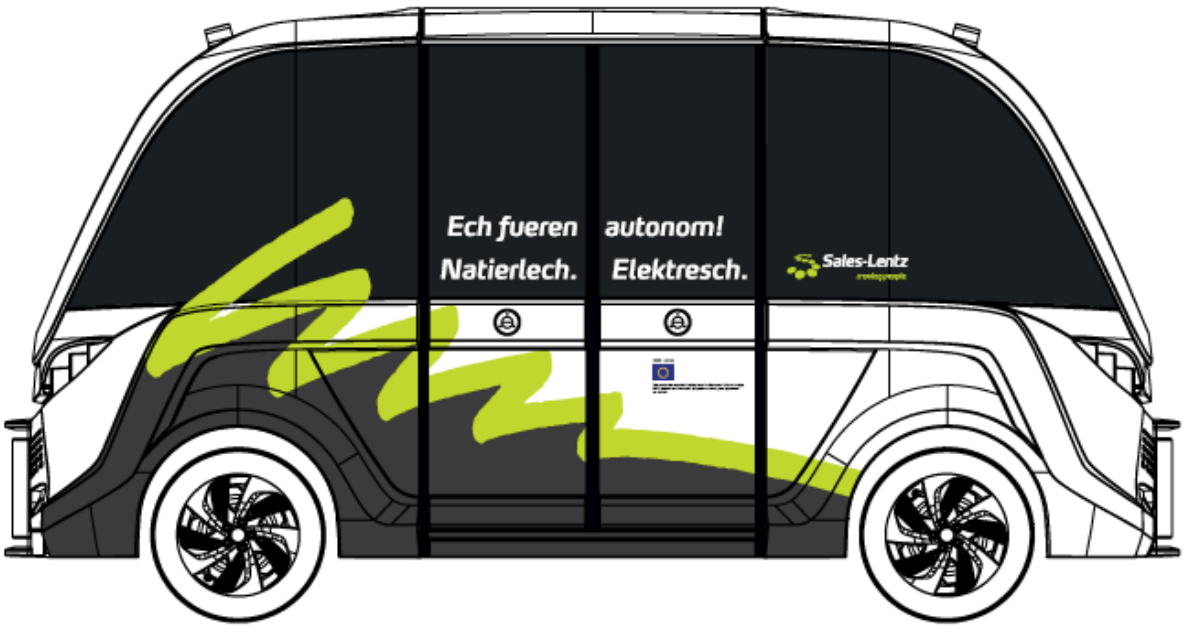
In all our shuttles the seats are equipped with seatbelts.

4.3.3 Wheelchair ramp

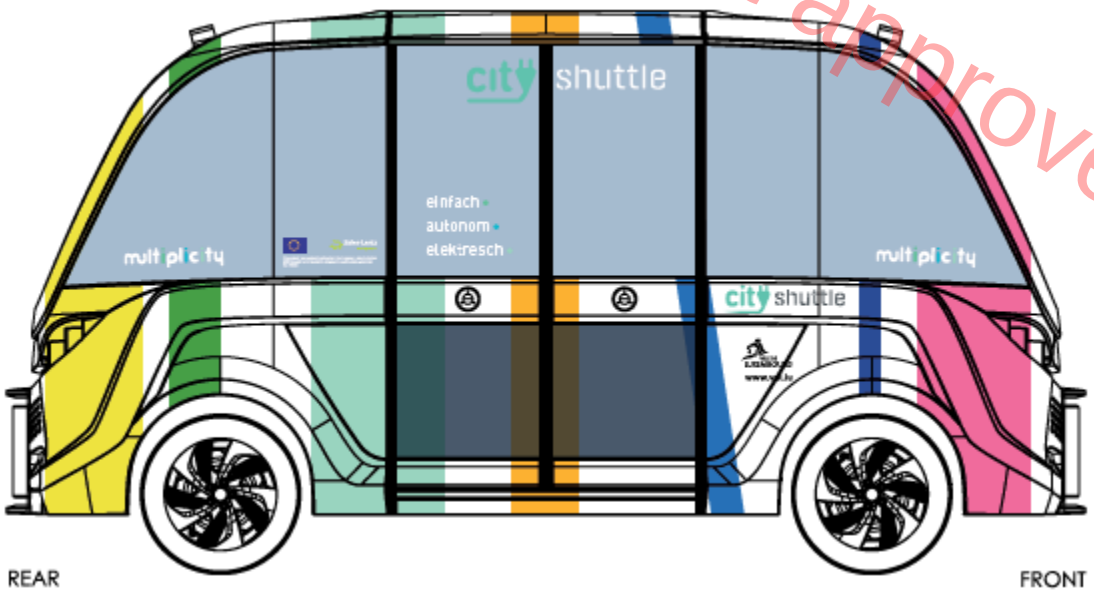
For all buses that are driving for AVL, a PMR is mandatory. SLA took the decision to equip all their NAVYA shuttles with a PMR ramp. The first shuttle P80 acquired by SLA is equipped with a manual ramp for PMR since an automatic ramp was not available at the moment of the shuttle acquisition. The shuttles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

4.4 Covering

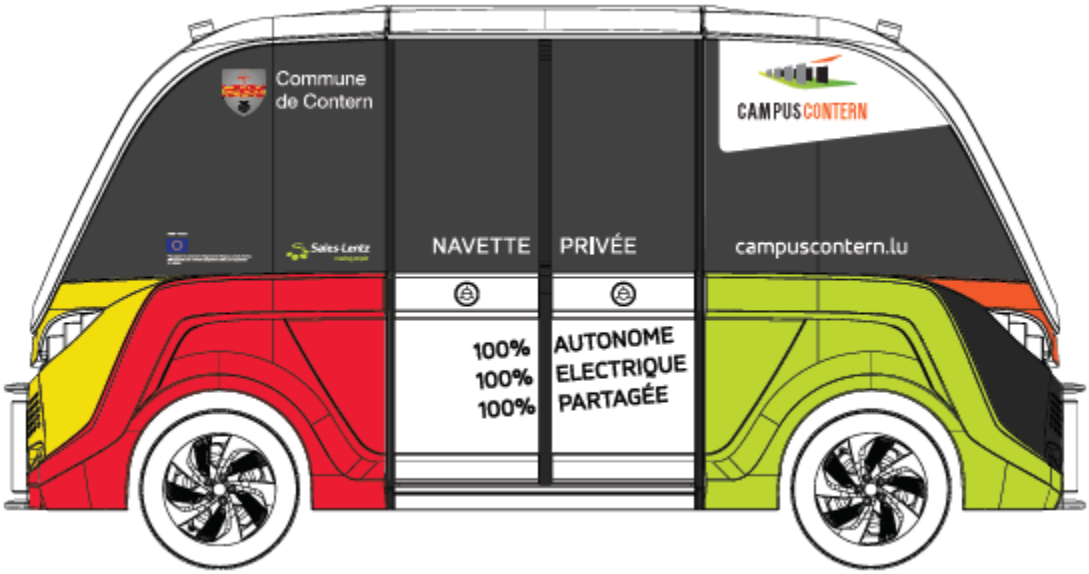
SLA



AVL-Multiplicity



Campus Contern



4.4.1 AVENUE EU Logo

4.4.1.1 French

Ce projet a reçu un financement du programme de recherche et d'innovation Horizon 2020
de l'Union européenne au titre de la convention de subvention No 769033

4.4.1.2 English

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

4.4.1.3 On vehicle example

4.5 Vehicle inspection

The Navya shuttles must undergo a yearly technical inspection. This inspection focusses on the mechanical parts. The autonomous system will not be part of this inspection.

4.6 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.

4.7 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 Personnel

5.1 Supervisor

5.2 Safety driver

Current pole of people who are involved in the day-to-day operations of the autonomous vehicles.

Name	Expert	Operator	Super Operator	Tech Operator	Trainer
Georges HILBERT	X				
Christian WEINTZ	X				
Steve MARRAFA	X				
Gaby KLOPFENSTEIN	X				

Pedro DA SILVA GOMES	x		x		x
Philippe DIEDERICH			x		x
Adelakun STANLEY		x			
Da Cruz ANISIO		x			
El Fassi MUSTAPHA		x			
Tesor DAMIEN		x			
Michel SEGUINI		x			

6 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 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 did not 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 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 30 km/h
- Object identification (and not only object detection) to prevent unnecessary and harsh breakings.

These two improvements will lead to:

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

Our government experts' team who travels around the world and who has as objective to test all the new technologies concerning public transport, advised us, that a new model of shuttles already exist on the

market and that exceed 30 km/h and the obstacle detection is done via a camera system and not Lidar sensors.

This means that a new authorization to lower speed on public roads will be more difficult to obtain.

7 Footnote

Appendix A

Technical data Navya Arma-DL4

Description	value
Capacity	
Passengers	15
Sitting	11
Standing	Not homologated in Switzerland
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 hour
Charge duration for 90 %	8 hour 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
Wheel chair access	Manuel ramp

Localization & object detection	
Lidar 1	Two 360° multi-layer lidars
Lidar 2	Six mono-layer 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