Autonomous Vehicles to Evolve to a New Urban Experience

DELIVERABLE

D7.12 Luxembourg Large Scale Pilot Use Case Demonstration report

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Acronyms

ADS	Automated Driving Systems
AI	Artificial Intelligence
AM	Automated Mobility
API	Application Protocol Interface
AV	Automated Vehicle
BM	Bestmile
BMM	Business Modelling Manager
CAV	Connected and Automated 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)
DTU	Technical University of Denmark
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

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, the touristic and busy city surroundings in Pfaffenthal and the main pedestrian road in Esch are leading to different operational experiences. In all use cases, Sales-Lentz (SLA) was able to successfully implement the Automated minibuses into traffic and to gain important experience in their deployment and their operation as well as the preceding administrative preparations. Furthermore, it was possible to identify areas that need further development in order to improve the operation the Automated minibuses.
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 were homologated in the beginning. 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 in the first part of the project. In the end, it was not possible to restart the Pfaffenthal-site after COVID because of delays in the authorization process.
Future concepts for all sites have been analyzed. Pfaffenthal will continue in 2023 for at least two more years. Esch will operate until the end of 2023 with the possibility of extension. Contern can continue if more companies will join the service to lower the costs. 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. Therefore, the further development to an autonomous service without a safety operator on board is necessary for a larger implementation into a city's public transport network or – like in Contern – as a last mile solution.

For the last months of AVENUE, it was possible to cooperate with the Ride-to-Autonomy (R2A) project, because the planned projects could not be implemented. AVENUE can use the lessons learnt from R2A as well as the other way around.

AVENUE has shown that the implementation of a new mobility service can continue after the funding if every stakeholder and the users are convinced that the service is adding more value to the city, expands the mobility options and contributes to a safer, cleaner, quieter and more comfortable environment.

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.

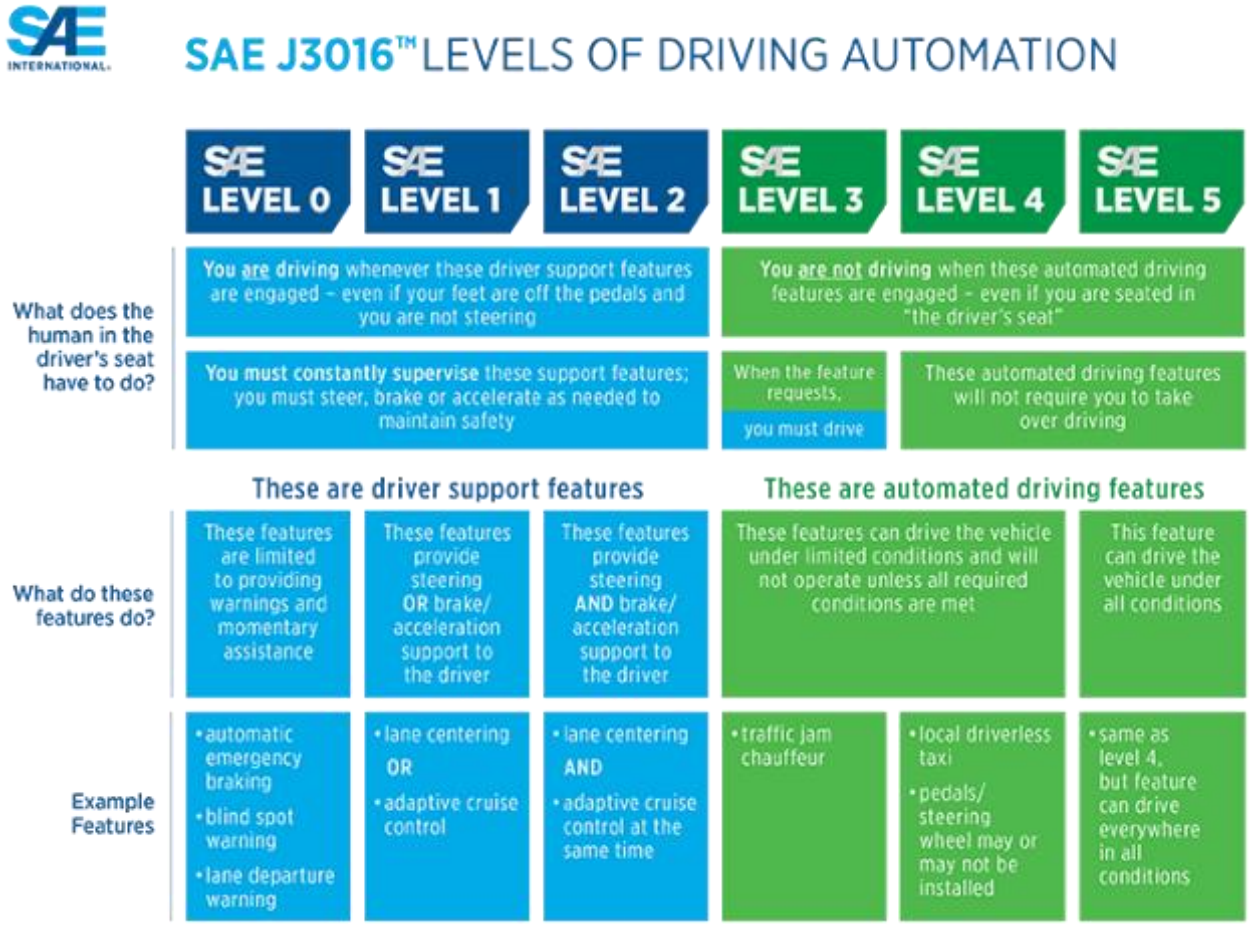


Figure 1: SAE Driving Automation levels (©2020 SAE International)

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 mini-bus is able to bypass a parked car, while it will slow down and follow behind a slowly moving car. The AVENUE mini-buses 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 mini-buses 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. In table 2 provides and overview of the AVENEU sites and OODs.

	Summary of AVENUE operating sites demonstrators						
	TPG		Holo		Keolis	Sales-Lentz	
	Geneva		Copenhagen	Oslo	Lyon	Luxembourg	
Site	Meyrin	Belle-Idée	Nordhavn	Ormøya	ParcOL	Pfaffental	Contern
Funding	TPG	EU + TPG	EU + Holo	EU + Holo	EU + Keolis	EU + SLA	EU + SLA
Start date of project	August 2017	May 2018	May 2017	August 2019	May 2017	June 2018	June 2018
Start date of trial	July 2018	June 2020	September 2020	December 2019	November 2019	September 2018	September 2018
Type of route	Fixed circular line	Area	Fixed circular line	Fixed circular line	Fixed circular line	Fixed circular line	Fixed circular line
Level of on-demand service*	Fixed route / Fixed stops	Flexible route / On-demand stops	Fixed route / Fixed stops	Fixed route / Fixed stops	Fixed route/Fixed stops	Fixed route / Fixed stops	Fixed route / Fixed stops
Route length	2,1 km	38 hectares	1,3 km	1,6 km	1,3 km	1,2 km	2,3 km
Road environment	Open road	Semi-private	Open road	Open road	Open road	Public road	Public road
Type of traffic	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed
Speed limit	30 km/h	30 km/h	30 km/h	30 km/h	8 to 10 km/h	30 km/h	50 km/h
Roundabouts	Yes	Yes	No	No	Yes	No	No
Traffic lights	No	No	No	No	Yes	Yes	Yes
Type of service	Fixed line	On demand	Fixed line	Fixed line	Fixed line	Fixed line	Fixed line
Concession	Line (circular)	Area	Line (circular)	Line (circular)	Line (circular)	Line (circular)	Line (circular)
Number of stops	4	> 35	6	6	2	3	2
Type of bus stop	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Bus stop infrastructure	Yes	Sometimes, mostly not	Yes	Yes	Yes	Yes	Yes
Number of vehicles	1	3-4	1	2	2	2	1
Timetable	Fixed	On demand	Fixed	Fixed	Fixed	Fixed	Fixed
Operation hours	Monday-Friday (5 days)	Sunday-Saturday (7 days)	Monday-Friday (5 days)	Monday-Sunday (7 days)	Monday-Saturday (6 days)	Tuesday & Thursday Saturday, Sunday & every public holiday	Monday - Friday
Timeframe weekdays	06:30 – 08:30 / 16:00 – 18:15	07:00 – 19:00	10:00 – 18:00	7:30 – 21:30	08:30 – 19:30	12:00 – 16h00 & 16h45 – 20h00	7:00 – 9:00 16:00 – 19:00
Timeframe weekends	No service	07:00 – 19:00	No service	9:00 – 18:00	08:30 – 19:30	10:00 – 21:00	No Service
Depot	400 meters distance	On site	800 meters distance	200 meters distance	On site	On site	On site
Driverless service	No	2021	No	No	No	No	No
Drive area type/ODD	B-Roads	Minor roads/parking	B-Roads/minor roads	B-Roads	B-Roads	B-Roads	B-Roads/parking
Drive area geo/ODD	Straight lines/plane	Straight lines/ plane	Straight lines/ plane	Curves/slopes	Straight Lines/ plane	Straight lines/ plane	Straight lines/ plane
Lane specification/ODD	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane
Drive area signs/ODD	Regulatory	Regulatory	Regulatory, Warning	Regulatory	Regulatory	Regulatory	Regulatory
Drive area surface/ODD	Standard surface, Speedbumps	Standard surface, Speedbumps	Standard surface Speedbumps, Roadworks	Frequent Ice, Snow	Standard surface, Potholes	Standard surface	Standard surface

Table 1: Summary of AVENUE operating site (+ODD components)

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 T7.12 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 D7.12, 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 Sales Lentz test sites and replicator site

Within the AVENUE framework, Sales-Lentz runs two test sites (Luxemburg-Pfaffenthal and Contern) and one replicator site (Esch-sur-Alzette).

2.1 General Information

One of the main goals for SLA as a public transport operator is to offer a good service to the people because the AVENUE-funding is public money (besides own financial contributions from SLA) and has to create an added value for the people. The self-understanding of this is not only based on the natural task as a public transport company, but especially because public transport in Luxembourg has been free of charge since 2020 and is 100% financed by the state without any income from ticketing. For new modes of transport, it is even more important than before to convince the local and national politician to see the opportunities and contribute to the financing.

2.1.1 Safety operators related

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

2.1.2 Traveller information

All users of public transport (bus, train, tram, special services) can get travelling information at mobiliteit.lu (former Mobility Center) and at the “Leetstell”.
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.

2.1.3 Way to book an Automated minibus

2.1.3.1 Client Application

This service is not available in Luxembourg and not necessary because public transport has been free for all users since April 2020.
As the public transport is for free in Luxembourg, the Transport Ministry in collaboration with the mobility center wants to draft a procedure concerning the reservations of a service which integrates the use of public transport. The procedure and the way to book a service of a public transport can only be drawn up by the MMTP.
Mobiliteit.lu is the communication platform of the Public Transport Administration of the Ministry of Mobility and Public Works. Travellers can contact the call center about all public transport matters, problems, or complaints or use the application for the public transport.

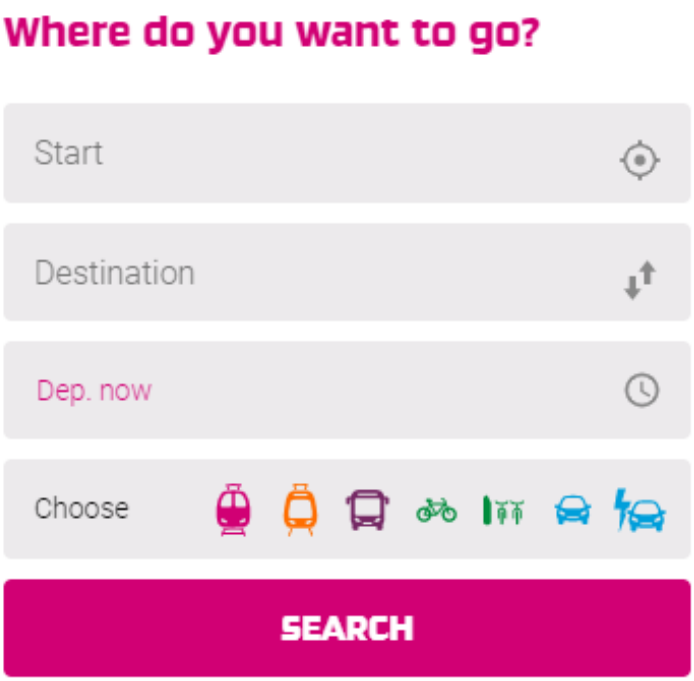


Figure 2: Mobiliteit.lu application

2.1.3.2 Vehicle dispatching

SLA uses the TomTom Webfleet system for geolocation and for the future safety operator's check-in (via Tablet). All drivers are equipped with tablets and they have access to TomTom Webfleet. WebFleet will also be the platform where SLA exports operational data from the Automated minibuses (which is already done with the existing fleet, excluding Automated minibuses).

Figure 3: WebFleet Dashboard

SLA also uses the HOLO-Dashboard with additional information like issues, % of autonomous or manual mode, GNSS-state, battery capacity, passenger counting (with an app) etc. The dashboard was introduced after the service stopped, therefore SLA uses it for Contern and Esch.

Figure 4: HOLO Dashboard

Table 2 gives a general overview of all site-related information.

	Pfaffenthal	Contern	Esch-sur-Alzette
City	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
Date of Service	19.09.2018 – 31.01.2020 No restart in 2022 but for sure from April 2023 for 2 years	19.09. – 30.12.2018 01.01. – 16.03.2020 01.10.- 18.12.2020 04.04.– 15.07.2022 12.09.– 31.12.2022	17.09.2021 – 31.12.2022 Service for 2023 is nearly fixed, maybe beyond
Type of route	Fixed circular line	Fixed circular line	Fixed circular line
Distance (one way)	1.2 [km]	2.3 [km]	1 [km]
Road	Open road	Open road	Open road / pedestrian zone
Type of traffic	Mixed	Mixed	Mixed
Speed limit	30 – 50 [km/h]	50 [km/h]	20 [km/h]
Peak speed	18 [km/h]	18 [km/h]	5.4 [km/h]
Roundabout	No	No	No
Traffic lights	No	No	No
Type of service	Traditional busline	Traditional busline	Traditional busline / On Demand since 12.09.22
Concession	Line	Line	Line
Number of bus stops	3	2	5 (+4 on demand)
Type of bus stop	Fixed	Fixed	Fixed (+4 virtual)
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: 10h00 – 21h00	Monday – Friday 07h20 – 09h10 & 15h50 – 18h35	Monday – Saturday 11h00 – 18h00 18h00 – 21h00 (on demand)
Depot	On site	On site	On site
Driverless service	No	No	No
KM driven in total	9.000	4.040	4.700
Total passenger	25.060	850	11.600
autonomous mode	~85%	~50%	~60%

Table 2: Sales-Lentz demonstrator site comparison

2.2 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 is a showcase to see how an autonomous vehicle can be integrated in such a diverse environment.

2.2.1 Partners

Project partners

- Ville de Luxembourg (VDL) > https://www.vdl.lu/fr
- Autobus de la Ville de Luxembourg (AVL) > https://www.vdl.lu/en/the-city/city-departments-at-your-service/service-autobus
- L'Administration des ponts et chaussées > https://pch.gouvernement.lu/fr.html

2.2.2 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 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 Automated minibuses in Pfaffenthal are operated under subcontract for AVL by SLA.

2.2.3 Site description

Pfaffenthal is a small urban living area located in Luxembourg City, the capital of Luxembourg. This urban area with around 1.300 inhabitants is based in a valley between the historical center of Luxembourg City and Kirchberg, the business district of Luxembourg City, home of the European Investment Bank and the Court of Justice of the European Union.
Pfaffenthal is connected to the city center via a public elevator and to Kirchberg via a funicular. Several bus connections are available in the surroundings of the elevators entrance at the city center level. 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 on top, a tram connection and additional bus stops are 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.

2.2.3.1 Use cases

During the day, residents, employees and a vast number of tourists are using the multimodal station in combination with the elevator 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 a 5-10 minute walking distance.

2.2.3.2 Site Data

To connect the public elevator, the multimodal station and the residential area with each other, the following route for the Automated minibuses has been selected. The traffic in the residential area is low because the valley of Pfaffenthal is far away from the main roads leading to the city.

Figure 5: Route and Automated minibuses stops

Figure 6: traffic map Pfaffenthal

2.2.3.3 Automated minibus stops

The Pfaffenthal route includes four fixed Automated minibus stops.

Automated minibus stop 1	Panorama Lift
Automated minibus stop 2	Funiculaire-Gare
Automated minibus stop 3	Sichenhaff
Automated minibus stop 4	Funiculaire

Table 3: Fixed Automated minibuses stops Pfaffenthal

2.2.3.4 Route (fixed)

Driving direction	Clockwise
Route length	1.2 [km]
Speed limit all traffic	30 – 50 [km/h] (30 during the test-phase with the shuttle)
Road	Public road

Table 4: Route Pfaffenthal

2.2.3.5 Current public transport status

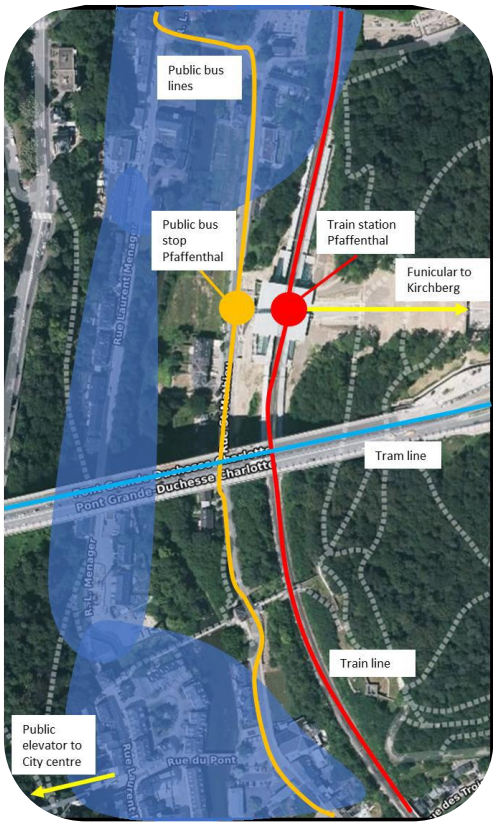


Figure 7: Several public transport stops Pfaffenthal

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)

Table 5: Bus Lines (public transport) near Pfaffenthal

2.2.3.6 Road network and environmental conditions

Based on the Operational design domain (ODD) standard the following list describes shortly the complexity of the road network and the environmental conditions of the test site. Only the most important parts of the ODD will be described.

- There are no special zones.
- The traffic area consists of a short minor road and a long major road inside a quiet residential are.
- The drivable area geometry consists of straight planes and one curve from/to the main road without any noteworthy radiuses or slopes. The planes are undivided but with oncoming traffic. Partially there are pavements.
- The lane dimensions are normal, the small minor road has a speed limit of 30 km/h and is a little narrow. There are no other lanes as for cars and trucks, but the main road is shared with a public bus. It is one per direction of driving. The markings are continuous.
- There are signs on every junction.
- Mostly there are curbs on the roadside but on the last part there is a shared space right before the elevator.
- The surface of the main road is uniform with no road damage. The surface of the minor road are cobblestones.
- There are several intersections. There is one small bridge over a little river. There are no streetlights.
- We have no data for the weather and particulates. The main road has artificial illumination, the minor road has not.

2.2.3.7 Vehicle depot

At the beginning there was an unused area close to the route at the end of residential street (fig. 6). This area is to be developed. An alternative arises at the other end of the route (top of fig. 2) which can be used after the restart of the service in 2023.

2.2.3.7.1 Route to vehicle depot

Figure 8: Vehicle Depot Pfaffenthal

2.2.3.7.2 GNSS base antenna

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

Figure 9: GNSS base antenna Pfaffenthal

2.2.4 Operations

Operational experience Pfaffenthal

- 25.060 passengers since 24.09.2018 (until 16.03.2020)
- 9.000 km driven with both vehicles since 24.09.2018 (until 16.03.2020)
- Instantaneous consumption (kwh) per hour > 0.58
- Instantaneous consumption(kwh) per kms > 0.51

2.2.4.1 Main issues Pfaffenthal trial

- Obstacles on the Automated minibuses 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)

2.2.4.2 Timetable

SLA assured the following service:

- Tuesday & Thursday: 12h00-16h00 &16h45-20h00
- Saturday, Sunday & on holidays: 10h00 – 21h00

2.2.4.3 Operational Costs

Here below you will find an updated table of the estimated costs based on D8.4 (“4.3 Preliminary results from the AVENUE demonstrators’ sites"). The CAPEX (Capital Expenditures) has not the Amortization and Depreciation integrated.

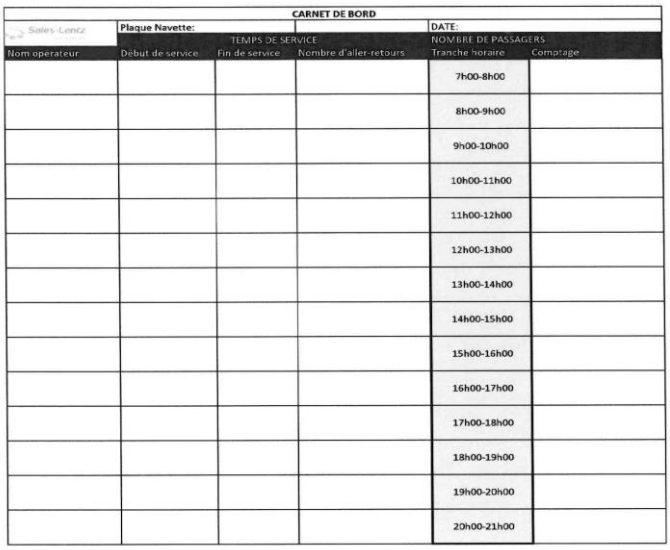
	Luxembourg (Sales-Lentz)		
	Pfaffenthal	Contern	Esch
CAPEX			
Single shuttle	346.250,00 €	346.250,00 €	346.250,00 €
Fleet total	626.950,00 €	346.250,00 €	346.250,00 €
OPEX			
Single shuttle	123.685,00 €	123.685,00 €	137.185,00 €
Fleet total	242.070,00 €	123.685,00 €	137.185,00 €
KPIs**			
Cost passenger/km	0,90 €	2,23 €	1,83 €
Cost shuttle/km	13,45 €	33,43 €	27,44 €

Table 6: CAPEX and OPEX Pfaffenthal

2.2.5 Reporting

2.2.5.1 Safety operator

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



CARNET DE BORD

Sales-Lentz | Plaque Navette: | | | DATE:

Nom operateur	TEMPS DE SERVICE Debut de service	Fin de service	Nombre d'aller-retours	NOMBRE DE PASSAGERS Tranche horaire	Comptage
				7h00-8h00	
				8h00-9h00	
				9h00-10h00	
				10h00-11h00	
				11h00-12h00	
				12h00-13h00	
				13h00-14h00	
				14h00-15h00	
				15h00-16h00	
				16h00-17h00	
				17h00-18h00	
				18h00-19h00	
				19h00-20h00	
				20h00-21h00	

Figure 10: Safety operators report

2.2.5.2 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”.

2.2.5.3 Authorities

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

- Daily distance of the two Automated minibuses (distance per day)

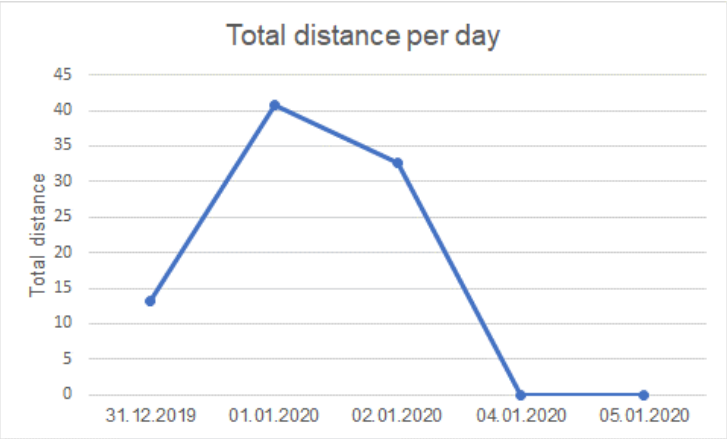


Figure 11: Daily distance graphic

- 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**

Figure 12: Number of passengers report

- If there were any anomalies during the week

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

Figure 13: Wild parking Pfaffenthal

2.2.6 Deployment

There were no issues with the deployment at all. Everything went as expected. The shuttle was driven on a trailer to the location, the GNSS-antenna was set up, the charging point was installed and after a few test runs over a couple of days with NAVYA, the service started.

2.2.7 Evaluation

During the last months of 2019, SLA encountered the following issues:

- Obstacles on the Automated minibuses 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 14: Obstacles on the Automated minibuses path Pfaffenthal

After the restrictions because of COVID were eased the parking for the shuttle was no longer usable. The search for a new parking close to the route was very difficult, because of the density and high land prices in Luxemburg. Several options were declined by the city. One alternative could not be uses because there was no electricity nearby and road work needed to be done. The coordination between the different departments of the city for authorizations was difficult, too. A last option was found 800m away from the route and the shuttle needed to cross a national road. During the authorization-process the city offered us a new parking space close to the route with the request to write an offer for a two-year-service. The service will finally continue in April 2022.

For more general information see also point 2.5 Recommendations.

2.2.7.1 Operations related

It was possible for travellers to find information like the timetable, the objective of the project and the advantages on the page of the City of Luxemburg but since the service stopped, the page is offline. (https://www.vdl.lu/en/getting-around/bus/routes-and-maps/city-shuttle)

For more see also point 2.2.4

2.2.7.2 Vehicle related

The Automated minibuses have been victims of vandalism. On two different dates, unknow people broke several windows of the Automated minibuses. After these incidents, the City of Luxemburg installed a fence around the shuttles at the parking lot and no other destruction happened again.

09.01.2019

Figure 15: Vandalism January

13.02.2019

Figure 16: Vandalism February

2.2.7.3 Infrastructure related

No special occurrences

2.2.7.4 COVID related

The following protective and preventive measures had to be observed until the service stopped at the beginning of 2020 by all operators and users of public transport to minimize 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 Automated minibuses a 2-meter distance cannot be respected. The drivers should wear his mask non-stop.

During the peak of COVID in 2020 SLA asked the City of Luxembourg to give permission to drive with the measures put in place by SLA, but because of the confinement the request had been rejected. At the end of 2021 SLA tried to restart the service after most of the restrictions ran out. There was a huge problem in finding a new parking lot, because the former one was going to be developed. To get the permission from every authority (and the two months break during the summer vacation) was so much time consuming that in the end it was not possible to restart the service until the end of the AVENUE project. But SLA was asked in September 2022 to plan the restart of the service from April 2023 on for at least two years.

2.2.7.5 Intended future situation

During the time of the AVENUE project there were plans to expand the route 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, a retirement home (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. An emerging factor is providing accessibility to different users where transportation is scarce.

The city of Luxembourg wanted to get a few months of experience with the original route before giving the authorizations for an on demand and door to door service. Due to COVID and the full stop of the service until the end of the project, the extension has never been realised but is still a possible option in the future.

Figure 17: Future Stops Pfaffenthal

2.2.8 Future developments

In the near future the City of Luxembourg is willing to restart the service from April 2023 on for at least two years. SLA can implement the on-demand-option because Esch has shown that this service can be implemented. The restart along the existing route and with enough time to get all authorizations is a good way to get back to the service after a three-year break. Afterwards the extension or implementation of

other options and routes can be done, if needed. It is a very good sign that this service was so successful that the stakeholders want to continue after a long break and without EU funding!

The vision for the trial in Pfaffenthal is to deploy more routes within Luxembourg City to establish a network and an on-Demand service of Automated minibuses that are linked to each other, to the different parts of Luxembourg City and to the public transport of the city.

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

Figure 188 shows a map of Luxembourg City center with existing public transport lines and the potential future routes for Automated minibuses to establish an Automated minibuses network.

The yellow lines (numbered 1,2,3 and 4) are the Automated minibuses routes and the different colored lines are current bus lines. The yellow line with number 1 is representing the current Automated minibuses route with a slight modification.

This network will only be authorized when an automated vehicle reaches a speed of at least 40 km/h. A drop in speed on several roads in town will not be approve from “Administration des Ponts et Chaussées”. In a controlled area it would be possible to reach a speed of 30-40km/h. But in an open road, where people and vehicle have to live and interact with each other, it’s difficult to raise the speed above 18-20km/h.

Any risk has to be avoided and to achieve a zero-risk level, it’s difficult to raise the speed with today’s standards, like the resolution of the LIDAR-sensors and its limited range resulting in a lower reaction time. In a controlled area, where people are aware of the existence of the shuttle and where the path is clearly delineated, the operational speed of the vehicle can be raised. But this is only possible in a private road, where the number of users is limited and informed about the existence of the automated shuttle.

Today it isn’t possible raising the speed to 30-40km/h on a public road, for safety reasons.

Figure 18: Bus Network Pfaffenthal

2.3 Test site Contern

2.3.1 Partners

Contern partners:

- Campus Contern s.à.r.l.→ https://www.campuscontern.lu/en
- Administration Communale de Contern → https://contern.lu/
- L'Administration des Ponts et Chaussées → https://pch.gouvernement.lu/fr.html

2.3.2 Objectives

The core objective was to dispatch people arriving by public transport at the train station to the different companies in the industrial zone and to provide a mobility solution within the zone. In this first phase the Automated minibus was operating between a real estate development company called “Campus Contern” with more than 300 employees and the train station as shown in the top left in Figure 19.
The trial in the industrial zone of Contern was chosen for its different 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.

2.3.3 Site description

Contern is a city located around 10 km south-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. There are several other stops within the zone but no direct connection exists from the train station to Campus Contern.

2.3.3.1 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. The shuttle is a good alternative because it closes the last-mile-gap from the train station during the rush hour. The traffic in the industrial zone is frequent with heavy vehicles all day long and commuters during peak hours.

2.3.3.2 Site Data

Figure 19: Route Contern

Figure 20: traffic map Contern

2.3.3.3 Automated minibus stops

The Contern route includes three fixed Automated minibus stops.

Shuttle Stop 1	Campus Contern
Shuttle Stop 2	Gare Sandweiler-Contern

Table 7: fixed Automated minibuses stops Contern

2.3.3.4 Route

Driving direction	Clockwise
Route length	2.3 [km]
Speed limit all traffic	50 [km/h] area
Road	Public road

Table 8: Route Contern

2.3.3.5 road network and environmental conditions

Based on the Operational design domain (ODD) standard the following list describes shortly the complexity of the road network and the environmental conditions of the test site. Only the most important parts of the ODD will be described.

- There are no special zones.
- The roads are minor roads inside the industrial zone.
- The drivable area geometry consists of straight planes and curves without any noteworthy radiuses or slopes. The planes are undivided but with oncoming traffic. Partially there are pavements.
- The lane dimensions are wide because of the heavy vehicles driving inside the industrial zone. There are no other lanes then for cars and trucks and it is one per direction of driving. The markings are continuous.
- There are signs on every junction.
- For the most part there are curbs, fences and hedges on the roadside but for a short section there is only grass.
- The surface is uniform with no road damage.
- There are several intersections.
- There is one automated access controlled are in the middle of the route, shortly before there is a bridge too.
- There is one streetlight right before a curve and close to a driveway of a company to give heavy vehicles more and safe space to drive.
- There is no data for the weather and particulates. The whole industrial zone has artificial illumination.

2.3.3.6 Current public transport status

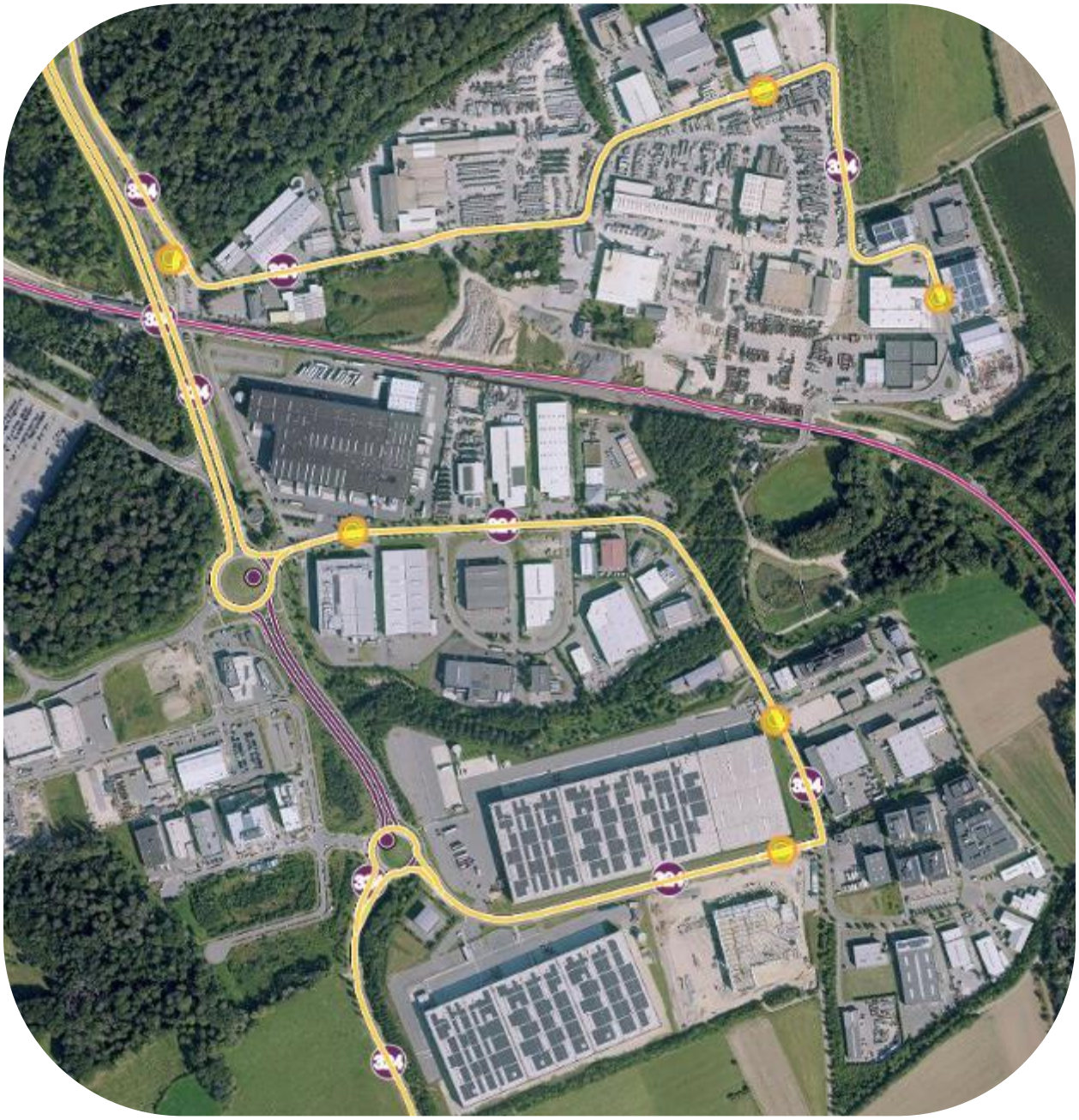


Figure 21: Several public transport stops Contern

Bus lines near Campus

Line 324	RGTR

Table 9: Bus lines

2.3.3.7 Vehicle depot

Campus Contern provided an underground depot for the Automated minibuses.

Figure 22: Vehicle Depot Contern

2.3.3.7.1 Route to vehicle depot

The Depot is the parking at Campus Contern, so there is no special route to show.

2.3.3.7.2 GNSS base antenna

The GNSS antenna is installed on the highest building in the region, “the water tower”.

Figure 23: GNSS base antenna Contern

2.3.4 Operations

- 850 passengers between 19.09. - 30.12.2018, 01.01. - 16.03.2020, 01.10. - 18.12.2020 and 04.04. – 31.12.2022 (with a two month break during the summer vacation)
- 4.040 km driven at the same time

2.3.4.1 Main issues Contern trial

- Traffic in the industrial zone consists more of industrial vehicles, trucks and individual cars and less cyclists and pedestrians. The driver attitudes could be different and hazardous situations might occur because the other vehicles might react different to passenger cars.
- Obstacles on the Automated minibuses path (mainly wrongly parked vehicles on the side of the road or partially reaching into the minibuses path)

Figure 24: Obstacles on the Automated minibuses path Contern

2.3.4.2 Timetable

An automated minibus is running during the peak rush hours between Campus Contern and the train station Sandweiler-Contern.

Monday - Friday	07h00 – 09h30 & 16h00 – 19h00

Table 10: Timetable Contern

2.3.4.3 Operational Costs

Here below you will find an updated table of the estimated costs based on D8.4 (“4.3 Preliminary results from the AVENUE demonstrators’ sites"). The CAPEX (Capital Expenditures) has not the Amortization and Depreciation integrated.
The costs for passenger/km should be 0,86€ and for vehicle/km 12,95€ for Contern, if we would have driven as planned. As SLA only could drive 3.700 km and the long route has only two stops, the real costs are 2,23€ for passenger/km and 33,43€ for vehicle/km.

	Luxembourg (Sales-Lentz)		
	Pfaffenthal	Contern	Esch
CAPEX			
Single shuttle	346.250,00 €	**346.250,00 €**	346.250,00 €
Fleet total	626.950,00 €	**346.250,00 €**	346.250,00 €
OPEX			
Single shuttle	123.685,00 €	**123.685,00 €**	137.185,00 €
Fleet total	242.070,00 €	**123.685,00 €**	137.185,00 €
KPIs**			
Cost passenger/km	0,90 €	**2,23 €**	1,83 €
Cost shuttle/km	13,45 €	**33,43 €**	27,44 €

Table 11: CAPEX and OPEX Contern

2.3.5 Reporting

2.3.5.1 Safety Operator

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

2.3.5.2 Clients

As subcontractor, all contact with passengers must go through the ordering parties; Campus Contern.

2.3.5.3 Authorities

No reporting to authorities is necessary.

2.3.6 Deployment

At the beginning of the Contern trial it was not possible to deploy the automated minibus on the extended route because of heavy construction works on a specific part of this route. The company “Campus Contern” agreed that the Automated minibus had to run in a first phase on a shortened route to the railway station and in a second phase, when the construction works will have been finished, on the extended route as planned. Besides that, everything else went as expected. The shuttle was driven on a trailer to the location, the GNSS-antenna was set up, the charging point was installed and after a few test runs over a couple of days with NAVYA, the service started.

2.3.7 Evaluation

As the Automated minibus was operating exclusively for “Campus Contern”, the total costs were paid by this company. On this extended route the Automated minibus is passing in front of several other companies and thus could connect more of them to the railway station. Companies along the Automated minibuses 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 entities. The extended route could not be deployed due to delays of the construction works. After four months of operation in Contern, while the extension of the route was still not possible due to the ongoing construction works, “Campus Contern” decided not to renew the contract because it was not willing to pay the high costs linked to the operation of the Automated minibuses alone until the extension of the Automated minibus route will be possible. The construction works that prevented the extension of the longer Automated minibus road were finished in 2020, but new works are going on other parts of the road until 2023 to transform the small industrial zone to a big one.

Nevertheless, all stakeholders have looked together to see when safe traffic is guaranteed. After the service could restart in the beginning of 2020, COVID came to Europe and stopped the service again. There was an attempt to restart again in the end of 2020, where the shuttle drove for some month. But even after the COVID-restrictions were eased the companies didn’t change their homeoffice-policies and a lot of employees worked from home. SLA was in very close contact to Campus Contern and regularly evaluated the number of possible passengers. After the return of enough employees, the service restarted in April 2022 and the contract was made up to the end of 2022. In the beginning there were some problems with the GNSS-antenna because the power was cut off, and the vegetation, because it was not cut off and the shuttle detected it as obstacles. The continuation of the contract depends on other companies to join the service and to lower the costs for the participants. Another possibility would be a safety-operator that is not on board anymore but monitors multiple shuttles from an office. This can lower the costs per shuttle and make the service more affordable for companies.

It is very important to notice that the operation of the Automated minibuses is linked to very high costs – as long as a safety operator is on board and not supervising several shuttles from a central office. 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.

2.3.7.1 Operations related

No special occurrences

For more see also point 2.3.4

2.3.7.2 Vehicle related

Whenever the shuttle had a major problem, the driver used the small camionette with which he arrived from the SLA main depot, so the service was nearly never interrupted.

2.3.7.3 Infrastructure related

No special occurrences

2.3.7.4 COVID related

As mentioned in point 2.2.7.4 COVID unfortunately upset the evolution of the project in Contern.

Due to government restrictions and a law that allows employees to do home-office, only 10% came to work at Campus Contern and doing this by car.

A few weeks before its expiry at the end of March 2020, 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. After the situation got better, the people returned over the time to the offices and the service could restart in April 2022 until the end of the year.

2.3.7.5 Intended Future situation

The industrial zone in Contern was seen as 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 request for the Automated minibuses is mainly made between the train station and the different companies. Outside of these peak hours, the demand switches more to the interior side of 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 22, were imagined as well as adding more stops in front of other companies that want to use the service, too. Due to the stop of the service during COVID and the slow return of the employees back from the home-office, there were too few passengers to justify the (expensive) extension of the existing service. But other companies are still interested.

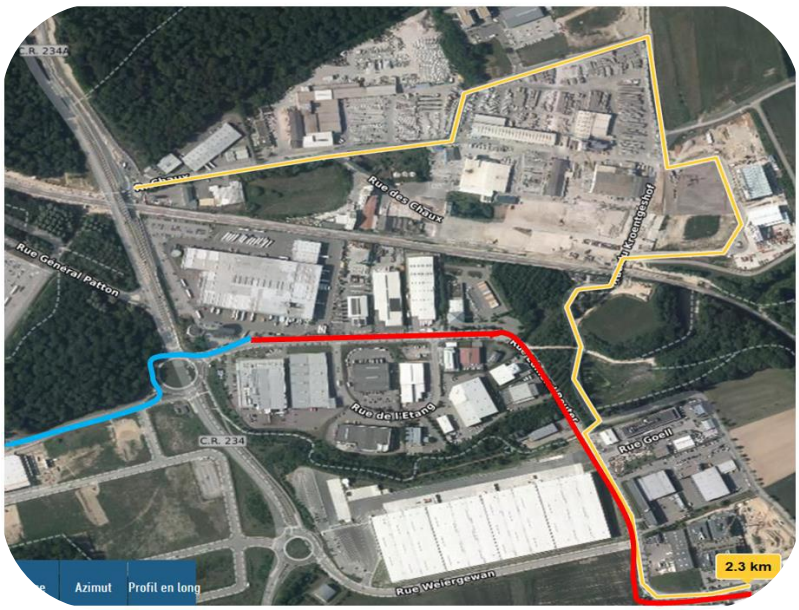


Figure 25: Future situation Contern

2.3.8 Future developments

The vision for Contern is to establish a system of autonomous vehicles connected to the bus network and other shared transport modes like carsharing, establish the on-demand system and implemented the shuttles into the public transport information system. This can make it possible to match up the shuttle with the train even in case of delays.
Numerous shuttles could be available for the different parts of the industrial zone, which can be ordered on-demand. This will provide to close the last mile between train/bus-stop and the destination of the workers.
As the costs are too high for one company, SLA applied for another EU-project. An alternative can be the cooperation with more companies in the industrial zone to finance the operation of the shuttle.

2.4 Replicator site Esch-sur-Alzette

Esch-sur-Alzette is carrying the title “European Capital of Culture 2022”. Eleven municipalities (known as the ProSud alliance) and 8 municipalities (CCPHVA, Communité de communes du Pays Haut Val d’Alzette) from the French border are also involved in the “European Capital of Culture 2022”. There is also a cooperation with the city of Kaunas in Lithuania.

2.4.1 Partners

- City of Esch-sur-Alzette
- Ministère de la Mobilité et des Travaux publics
- Board of promotion of European Capital of Culture Esch 2022
- Transport intercommunal de personnes dans le canton d’Esch-sur-Alzette (TICE)

2.4.2 Objectives

In September 2021 the service started in the main pedestrian/shopping street. In this part of the city, no public transport can be provided but the mobility of the people can be optimized, especially elderly, wheelchairs, strollers or people with heavy shopping bags by providing the shuttle-service. On rainy days the shuttle-service can get people dry from one spot of the shopping street to another.

In September 2022 the planned on-demand-service went live and provides longer service hours not only from 11h00 to 18h00 but to 21h00. The shops are closed after 18h00 but the cafés and restaurants are still open. A moving shuttle in the evenings quieter street can even create a safer environment for people, as the shuttle gives some movement and light in the street.

The long-term vision is an autonomous based, door-to-door service in Esch-sur-Alzette. The objective is to start first trials of an automated minibus with dynamic routing in a geographically defined area, without fixed bus lines or predefined timetables like in TPG’s project at “Belle Idée” in Geneva.

2.4.3 Site description

Esch-sur-Alzette with 35.000 inhabitants from more than 120 nationalities 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. Esch-sur-Alzette has a lively past with the development of the steel industry in Luxembourg. Today the shuttle is running in the longest shopping street of the country and can help revitalizing it with the new service of mobility. The shuttle ends on one side near a bus stop while at the other end there is no public transport. In this way the shuttle closes the gap between the public transport stop and the inner city.

2.4.3.1 Use cases

During the day, residents, visitors/tourists and people that want to go shopping are coming to the street in which the shuttle operates and use it a lot. In the evening hours, the shuttle provides a service for the visitors of the restaurants and cafés along the road.

2.4.3.2 Site Data

The shuttle is driving along the 1km distance on the street Rue de l'Alzette with several stops at the crossings with other streets. Only Pedestrians and bikes are allowed in the street. Before 11h00 and after 18h00 delivery traffic is allowed, too. The on-demand-service startet on 12th September 2022, extended the service hours to 21h00, added four virtual stops and is serving the same road.

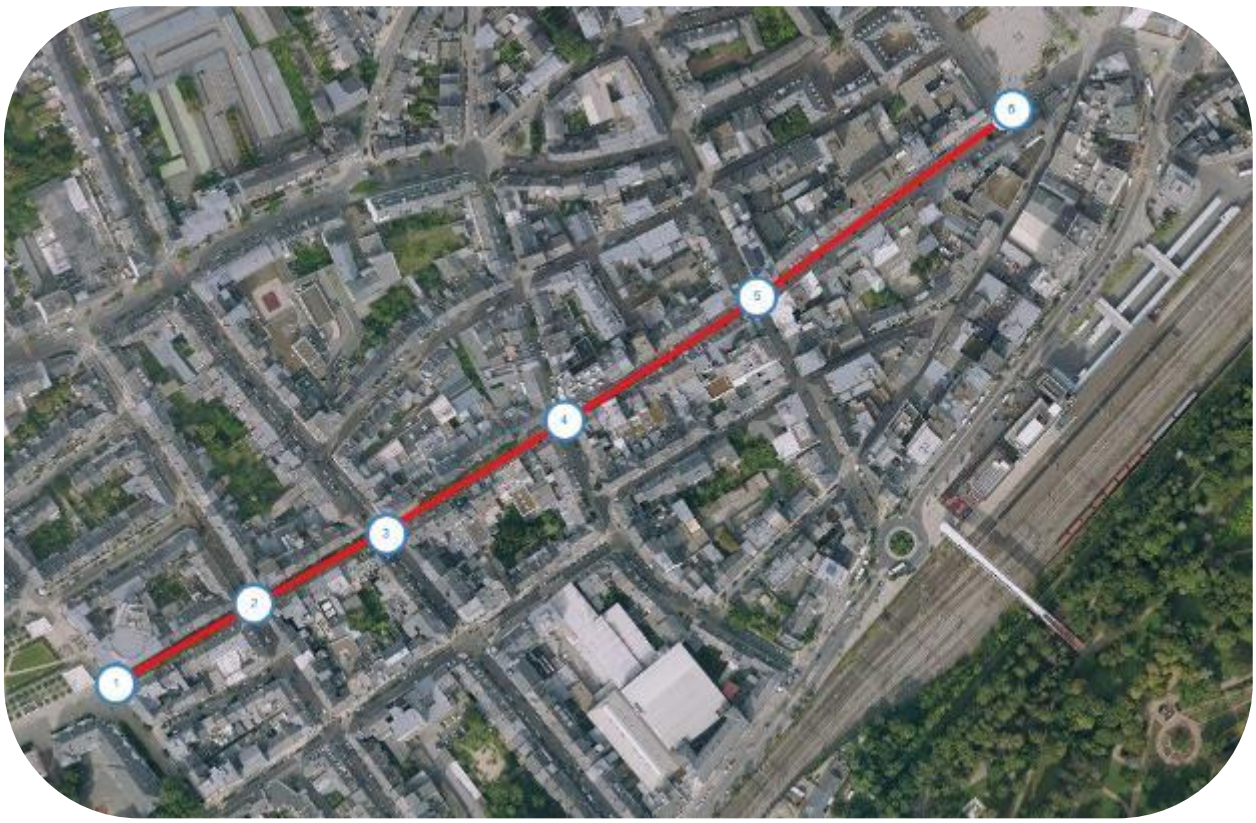


Figure 26: Route of the Automated minibus

2.4.3.3 Automated minibus stops

The Esch route includes six fixed Automated minibus stops. Between 1 and 5 there are 4 virtual stops for the on demand service.

Automated minibus stop 1	Alzette 1
Automated minibus stop 2	Alzette 2
Automated minibus stop 3	Alzette 3
Automated minibus stop 4	Alzette 4
Automated minibus stop 5	Alzette 5
Automated minibus stop 6	Alzette 6

Table 12: Fixed Automated minibuses stops Esch

2.4.3.4 Route (fixed)

Driving direction	Clockwise
Route length	1.2 [km]
Speed limit all traffic	20 [km/h]
Road	Pedestrian road

Table 13: Route Esch

2.4.3.5 Current public transport status

Figure 27: Several public transport stops Esch

Bus lines (Public transport) stops in Esch

Line 1	TICE (the PTA of the southern Cities)
Line 2	
Line 3	
Line 4	
Line 7	
Line 12	
Line 13	
Line 17	
Line 603	RGTR (national bus network)
Line 641	
Line 641	
Line 650	
Line 60	CFL (national train operator)

Table 14: Bus Lines (public transport) in Esch

2.4.3.6 road network and environmental conditions

Based on the Operational design domain (ODD) standard the following list describes shortly the complexity of the road network and the environmental conditions of the test site. Only the most important parts of the ODD will be described.

- There are no special zones.
- The road is pedestrian road.
- The drivable area geometry consists of straight planes, no curves and without any noteworthy radiuses or slopes. The planes are undivided but with traffic from the side roads. There are no pavements.
- The lane dimensions are normal, the road has a speed limit of 20 km/h and is a little narrow due to signs of shops, fences of a construction side and chairs/tables from restaurants. There are no other lanes as for cars and trucks, but the road is shared with pedestrians.
- There are signs on every junction.
- The surface of the road is uniform with no road damage.
- There are several intersections. There are no streetlights.
- We have no data for the weather and particulates. The road has artificial illumination.

2.4.3.7 Vehicle depot

The depot is in the top left corner of fig. 28 and the safety operator must drive around 500m in manual mode to the starting point of the service.

Figure 28: vehicle depot Esch

2.4.4 Operations

- Around 12.000 passengers between 17.09.2021 - 31.10.2022
- 4.700 km driven at the same time
- More than 100 passengers used the on-demand-service, which started at September 12th and is operating between 18h00 and 21h00

2.4.4.1 Main issues Esch trial

The street is wide enough for one vehicle but with a lot of pedestrians, bicycles, maintenance cars, events and construction sites, it can be difficult for the shuttle to drive all the time in autonomous mode. A lot of communication with the City of Esch is necessary, to solve these problems but it's working out very well. One of the biggest problems are people testing the shuttles reactions on purpose by stopping or running in front of it and force it to stop. No accident has happened because the systems and algorithms are very good as well.

Besides that, the smaller technical problems that occur during a scientific test are forcing SLA to contact NAVYA very often around the week: Doors not closing, missing GNSS-connection that forced a switch to NTRIP, Router problems (Hardware + Software) or PC problems (had to be replaced) consume more time for the safety operator on board and the technical team in the back-office than expected. Some problems got solved, some problems keep popping up.

Figure 29: narrow street with obstacles on the Automated minibuses path Esch

2.4.4.2 Timetable

An automated minibus is running in the main pedestrian road in Esch from the late morning until the late evening.

Monday - Saturday	11h00 – 21h00 (on demand 18h00 – 21h00)

Table 15: Timetable Esch

2.4.4.3 Operational Costs

Below is an updated table of the estimated costs based on D8.4 ("4.3 Preliminary results from the AVENUE demonstrators' sites"). The CAPEX (Capital Expenditures) has not the Amortization and Depreciation integrated.

	Luxembourg (Sales-Lentz)		
	Pfaffenthal	Contern	Esch
CAPEX			
Single shuttle	346.250,00 €	346.250,00 €	**346.250,00 €**
Fleet total	626.950,00 €	346.250,00 €	**346.250,00 €**
OPEX			
Single shuttle	123.685,00 €	123.685,00 €	**137.185,00 €**
Fleet total	242.070,00 €	123.685,00 €	**137.185,00 €**
KPIs**			
Cost passenger/km	0,90 €	2,23 €	**1,83 €**
Cost shuttle/km	13,45 €	33,43 €	**27,44 €**

Table 16: CAPEX and OPEX Esch

2.4.4.4 On-Demand-Service (ODS)

The ODS started at September 12th 2022, extended the service hours to 21h00 and added four virtual stops to the six existing ones. An app is required to book the shuttle for the desired time. The user can't see the stops in the app but the service area. The user can choose the pick-up and drop-off-location freely within the area but is guided to one of the 10 stops. Theses stops are very close to each other, so the user doesn't need to walk more than one minute. This is just a very small restriction but gives the user the feeling to book wherever he/she wants to. For today it is not possible to create the service area with "unbookable" spots or areas. This can be important in larger areas with different service times for certain spots or areas during the day. Ioki is working on that and can implement it in the near future.

2.4.5 Reporting

2.4.5.1 Safety Operator

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

2.4.5.2 Clients

As subcontractor, all contact with passengers must go through the ordering parties; the City of Esch.

2.4.5.3 Authorities

The City of Esch asks frequently for the numbers of passengers.

2.4.6 Deployment

There were no issues with the deployment at all. Everything went as expected and there was a press conference close to the shuttle with the major of Esch, George Mischo and his team. The shuttle was driven on a trailer to the location, the GNSS-antenna was set up, the charging point was installed and after a few test runs over a couple of days with NAVYA, the service started.

2.4.7 Evaluation

Esch is a success-story because more than 12.000 users took the shuttle in the first year, the service hours were extended with the implementation of the on-demand-service and the major praised the service at the press-conference right before the start of the on-demand-service. It is planned to continue in 2023 and it is possible to extend the route as well as the service hours.

2.4.7.1 Operations related

There was two weeks break in the summer of 2022 because of technical difficulties. After the break the passenger numbers were as high as before. This is a very good sign because people got used to the shuttle and use it even after a longer break again. The on-demand-service had more than 100 requests in the 1.5

month until the end of the project, which is very good. Unfortunately, nobody used the app but everybody booked via telephone.

For more see also point 2.3.4

2.4.7.2 Vehicle related

A pedestrian mode was successfully tested with NAVYA but unfortunately the software-version of the pedestrian mode does not work with the on-demand-system. To establish the on-demand-service the shuttle needed a software-update. To get sure that the service was not interrupted because of technical difficulties, a second shuttle (one of the shuttles from Pfaffenthal) was brought to Esch. From there on one shuttle drove the first shift from 11h00 to 18h00 and the shuttle with the software-update for the on-demand-service drove the second shift. This is also necessary because the capacity of the battery is not high enough to run the whole service with only one shuttle during the hot summertime. The exchange of the shuttle takes some minutes, therefore around 18h00 there is no service for some minutes.

2.4.7.3 Infrastructure related

No special occurrences

2.4.7.4 COVID related

The start of the service was delayed but there are no further restrictions since then.

2.4.7.5 Intended Future situation

The long-term vision for an autonomous based, door-to-door service in Esch-sur-Alzette:
In the fourth quarter of 2021, the objective is to start the operation of an Automated minibus with dynamic routing in a geographically defined area, without fixed bus lines or predefined timetables. In a first phase predefined bus stops will be foreseen to board and alight passengers (phase 3). After validation of the Automated minibuses operation, the aim is to switch to a real on-demand, door-to-door operation mode without fixed bus stops (phase 4). The planned network for dynamic routing will be deployed inside a geofenced area in the residential area in the center of Esch-sur-Alzette. Figure 22 shows the boundaries of the planned site.

Phase	Name of Phase	Start	End
Phase 1	Permissions / authorizations	01.01.2020	30.04.2022
Phase 2	Autonomous Network	01.06.2021	30.06.2021
Phase 3	Autonomous Network fixed stops	30.06.2021	30.12.2021
Phase 4	Autonomous Network Door-to-door	01.12.2022	30.10.2022
Phase 5	Official mobility partner Esch 2022 European Capital of Culture	01.01.2022	30.10.2022

Table 17: Project evolution Esch-sur-Alzette

Figure 30: future Door-to-door area for the service in Esch-sur-Alzette

Because of COVID the whole schedule delayed very much. The start was over one and a half years later than planned and it was soon very obvious that for a service area like shown above, much more shuttles are needed to provide a useable service – like it is done within the ULTIMO project from 2023 on. For Esch the steps need to be smaller but nevertheless is the described plan still a desirable one.

2.4.8 Future developments

The service should continue in 2023. If the on-demand-service is used often enough, it could also be part of the extension. The same goes for longer service hours. If people use the shuttle starting at 6pm often and get used to it, it will show that the shuttle is part of their mobility and can maybe even drive until 22h00 – with or without the on-demand-service. Another option is to add another street at the end of the existing route where a lot of restaurants are, so their customers are even closer to the shuttle service. The shuttle itself is not only another mobility option but plays a role in revitalizing the city center, make it safer, cleaner and more livable.

2.5 Recommandations

The following table is from the lessons learnt of the Ride-to-Autonomy project (R2A). There is a cooperation between R2A and AVENUE because no project from R2A could be implemented in Luxemburg. The cooperation is about sharing data and findings. The table includes general information valid for every project site.

Phase	**Topics**	**Guiding questions**	**Challenges & obstacles**	**Success factors & opportunities**	**Weaknesses & gaps**
PREPARATION AND PLANNING	*Feasibility / risk assessment study*	*What studies needed to be undertaken?* *What recommenda-tions can you provide?*	Feasibility of the route	Good video and pictures guarantee a successful preparation	Changes between first recordings and final programming can be problematic
	Route and technical definition: infrastructure, connectivity, supervision	*Please consider route selection and preparation, and all the technical set up plans and operational requirements*	No problems with route selection with the partners Infrastructure has to be set up once, connectivity was given (4G and GNSS for a better GPS signal), supervision via NAVYA and an own dashboard with the KPI	Looking out for possible problems for the authorization (e.g. roads with a speed limit above 50 km/h should be avoided. 30 km/h would be perfect. Avoid national roads because road authority needs long time for authorization)	finding a location for the GNSS antenna could be difficult Changes for the route afterwards generate extra costs for remapping Temporary changes can affect the mapping (vegetation, construction sites)
	Local commitment / responsibilities Financial planning	*Were there challenges in assuring local commitment? Why?* *How did you assign responsibilities/tasks among involved actors?*	Convincing cities/companies to invest money for a project that might not operate every day and where one cannot foresee the success	Road safety, zero emission etc. Can convince them and be part of testing the technology of the future	One city quit the R2A-project before the start because they had to put up warnings signs and reduce the speed limit to 30 km/h. It was too much work for them.

PROCUREMENT AND LEGAL REGULATIONS	*Vehicle and operation procurement*	*How did you handle the vehicle and operation procurement?*	Sales-Lentz already had shuttles from another project. 2 were paid via AVENUE, 2 were bought from NAVYA. Operation The general homologation of the vehicle took about one year but only has to be done once.		Everything depends on the manufacturer because without it, the shuttles are not running. Software problems need to be solved by the manufacturer and can delay or stop the local service of the shuttle (this time cannot be invoiced to the customer)
	Legal requirements, permits	*Were there any unexpected requirements?* *What were the main challenges to consider?*	Authorization from different parties (ministry, city, road authority) can take a lot of time and mostly are handled one after the other and not at the same time	Start ASAP to ask for authorization, even before contract signing with partners	The authorization of the Ministry has to be done every year, as long as the vehicles are not approved for "normal" road traffic. Bring EVERY authority and partner at a round table and discuss the timeline and prioritize the authorization!
CITIZEN AND STAKEHOLDER PARTICIPATION	*Stakeholder mapping and engagement*	*How did the stakeholder identification and engagement work?*	Cities and Companies are more partners than stakeholders because they are actively participating in improving the service not only for themselves but for the employees/inhabitants/guests/tourist		NAVYA is more an investor as a stakeholder because it seems they are not interested in working together with but just for the owner of the shuttles. Every operator is providing a lot of data with the running shuttles but has to pay for every little service.

	Citizen outreach/public acceptance	*How did you reach out to citizens? What feedback did you receive?*	As long as a safety operator is needed on board, he can also explain the shuttle, technic etc. to the passengers which is very helpful for the acceptance	Via the AVENUE-survey the project got way more detailed answers as from personal conversation	
	Communication channels/strategy	*Which channels and dissemination strategies did you use?*	Sharing events , news and videos via Social media (LinkedIn, facebook, twitter, youtube)		
PILOT IMPLEMEN-TATION AND OPERATION	*Physical and Digital Infrastructure set up and operation*	*Final infrastructure set up and its operation.*	See above (Route and technical definition: infrastructure, connectivity, supervision)		
	Vehicle operation and safety	*How did the pilot operation go? (usage, speed, safety, etc.) Key take aways.*	Depends on the situation Esch: main pedestrian road, used more by elderly or persons with reduced mobility, 5km/h, successfully testing out the “pedestrian mode” of the NAVYA to reduce harsh breakings Contern: industrial zone, long route from the train station to an office complex but people used the service, less than in Esch or Pfaffenthal but the situation is very different because they are only going to the office in the morning and to the train in the afternoon. Implementation of an OnDemandService is planned for mid of September to see, if there is more to do Pfaffenthal: 25.000 passengers in 15 month before COVID. Very touristic route between to elevators in a valley No accidents at any site, for problems see “Vehicle and operation procurement” and “Stakeholder mapping and engagement”		
	Maintenance / Repairs *Storage / Charging*	*How did you handle the vehicle’s maintenance/repair needs?* *Where was it stored and charged?*	Sales-Lentz has a maintenance contract with NAVYA to do all Level 1-3 repairs (including storage of parts) in the main depot in		Repairs are sometimes not prioritized, so the partnership seems very one-sided

			Luxemburg. Only for Level4/5-actions NAVYA has to help out. This saves cost and time		
CCAM STRATEGY (BUSINESS MODELS, SERVICE DESIGN)	*Mobility service and CCAM strategy*	*How did the mobility service provided perform? What conclusions did you derive for the site's CCAM strategy?*	See AVENUE-survey, from the view of Sales-Lentz all the sites were successful in their own way (because of the different environment the passenger numbers are not comparable). Esch will continue in 2023, Contern is possible because other companies are interested in the service – which is a mentionable success of the whole project because the service convinced others to be part of it even if it is still a scientific test Pfaffenthal did not restart in 2022 but the city knows about the number of passengers wants to continue the service from April 2023 on for at least two years		
	How were users identified, targeted and engaged with the pilot?			*In Esch and Pfaffenthal the shuttle was very visible to everybody and via social media it attracted even tourist to try it out* *In Contern the communication inside and between the local companies is very good to let everybody know there is a shuttle running*	
	How did the integration with public transport and other modes work?			*Very well, in case the stops of the autonomous shuttle and PT are nearby*	The integration in the mobility app is not possible for today – as long as the service is temporarily/need a yearly approval from the ministry
	User experience evaluation	*How did you assess user experience?*	see AVENUE-survey		

EVALUATION AND MONITORING	*Stakeholder evaluation*	*Which stakeholders were consulted? How?*		Just the cities/companies involved and they are more than happy with the service. Signed contracts longer than the project is running.	Companies seem to be more price-sensitive but can easily combined if they are close to each other/the route in the same area, which lowers the costs for everybody
	Operational metrics, data collection and analysis	*What data was collected? What restrictions did you face?*	See KPIs		
OTHER	*Main conclusions and take aways to highlight (as messages to quote*	*What are your main take aways?* *What was the biggest success?*	One year is not enough to start a service AND have it running to collect a good amount of data. Combination with existing routes in another EU-project. Both benefit from each other		
		Which challenge didn't you expect? *What would you have done differently?*	Authorization takes more time than expected. Start ASAP with the process. Every other detail with the manufacturer of the shuttle or the local partner can be handled in the mean-time.		

Table 18: Lessons Learnt

(source: Ride-to-Autonomy project with the same project sites as for AVENUE in Luxemburg)

2.6 Demos

Before AVENUE started and during the project, Sales-Lentz had several other demos to present the autonomous vehicles at different sites.

2.6.1 Bascharage

A lot of ministers and institutions from Luxemburg as well as partners from Europe visited the main depot of Sales-Lentz in Bascharage to see and drive with the shuttles.

Figure 31: Depot Bascharage

2.6.2 LuxExpo 2017

In 2017, a NAVYA-Shuttle was presented as the next big thing for Sales-Lentz and even some members of the Royal Familiy were on board of the shuttle. It was also the Birthday of the Grand Duchess and a special day for every visitor in many ways.

Figure 32: LuxExpo 2017

2.6.3 Automotive Day Colmar-Berg 2018

In 2018 it was the first time that an autonomous shuttle drove in Luxemburg. Sales-Lentz was present at the Automotive Day some month before the service in Pfaffenthal started.

Figure 33:Automotive Day 2018
(source: https://paperjam.lu/article/news-a-bord-de-la-navette-autonome-de-sales-lentz)

2.6.4 European Union in Brussels 2019

A public demonstration of the autonomous vehicle was organised in front of the Berlmont building. The shuttle from Sales-Lentz was part of another EU project (Ride2Autonomy) and was placed at the airport of Charleroi at that time.

Figure 34: European Union in Brussels 1
Figure 35: European Union in Brussels 1

2.6.5 Knauf 2019

Knauf is a large shopping center in the western part of Luxemburg. The shuttle there operated between the two parts of the center devided by a large national road and a roundabout. It was a project that ended because of COVID and ran before Esch became a replicator site.

Figure 36: Knauf 1
Figure 37: Knauf 2

Figure 38: Knauf 3
Figure 39: Knauf 4

2.6.6 Autoworld Brussels 2019

The project manager of AVENUE, Dimitri Konstantas, presented the AVENUE project at the Autoworld in Brussels and Sales-Lentz provided the shuttle.

Figure 40: Autoworld Burssels 1
Figure 41: Autoworld Burssels 2

2.6.7 Other

Sales-Lentz also visited other events with the autonomous shuttle to present it. In Mondorf the shuttle was shown at the Fleet Awards.
The second visit at the LuxExpo Sales-Lentz developed together with Navya a technical presentation with simulations of zebra crossings, different stops and also darker and narrower places along the "excursion". At that time the Grand Duke rode for the first time with the shuttle, too.
Since 2017 Luxemburg has again a tram. During the opening of the new Depot „Tramshapp“ the autonomous shuttle was also presented and the Prime Minister drove with it the first time.

3 Project homologation

Luxembourgish authorities have 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").

LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère du Développement durable
et des Infrastructures

Département des transports

Ci/let/2018/12923/pp

Sales-Lentz S.A.
Monsieur Georges HILBERT
B.P. 39
L-4901 Bascharage

Concerne : Votre demande du 26 janvier 2018 concernant une autorisation ministérielle pour des essais scientifiques avec trois véhicules autonomes

Monsieur,

Conformément au paragraphe F) de l'article 49 de l'arrêté grand-ducal modifié du 23 novembre 1955 portant règlement de la circulation sur toutes les voies publiques (communément appelé « Code de la Route »), je marque mon accord, avec la mise en circulation de trois véhicules Navya, numéros d'immatriculation SL 8001, SL 8002 et SL 8003, numéros de châssis VG9A2CB2CIV019080, VG9A2CB2CIV019093 et VG9A2CB2CIV019106, équipés d'une technologie permettant la conduite autonome sous le couvert d'essai scientifique sur les voies publiques luxembourgeoises.

Les véhicules concernés, qui sont conçus suivant de nouvelles technologies, seront immatriculés sous le couvert d'une réception nationale individuelle conformément à l'article 3, paragraphe 1er, point b, 1er tiret, de l'arrêté grand-ducal précité du 23 novembre 1955.

Cependant, l'immatriculation initiale va se réaliser en tant qu'immatriculation provisoire sur base de l'article 7, paragraphe 8 du règlement grand-ducal modifié du 26 janvier 2016 relatif à la réception et l'immatriculation des véhicules routiers, étant donné qu'actuellement les derniers documents obligatoires pour l'immatriculation des véhicules sont encore sous revue par la SNCA.

La présente autorisation est soumise aux conditions suivantes:

1. L'autorisation est uniquement valable pendant la période du 19 septembre 2018 au 30 septembre 2019 inclus sur le territoire de la Ville de Luxembourg pour les véhicules VG9A2CB2CIV019093 (SL 8002) et VG9A2CB2CIV019106 (SL8003), ainsi que du 19 septembre 2018 au 31 mars 2019 inclus sur le territoire de la Commune de Contern pour le véhicule VG9A2CB2CIV019080 (SL 8001).

Figure 42: MMTP authorisation

Figure 43: registration certificate

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 Automated minibuses is mandatory. This approval includes a technical inspection of the vehicle as well as full technical documentation of the vehicles from Navya.

SNCT
SOCIÉTÉ NATIONALE DE CONTRÔLE TECHNIQUE
Partenaire de votre sécurité

9) **Société Nationale de Contrôle Technique**
BP 23
L-5201 Sandweiler

Page 1/1

2) Numéro d'immatriculation: **SL8801**

5) Catégorie du véhicule: **M2**	1) Numéro d'identification du véhicule: **VG9A2CB2C1V019080**
Marque: **NAVYA**	4) Kilomètres/Miles/Heures: **657**

Certificat de contrôle valable jusqu'au: 8) 18.09.2020

sous réserve des dispositions de l'article 4bis modifié de la loi du 14 février 1955 concernant la réglementation de la circulation sur toutes les voies publiques

3) Contrôle technique effectué à **Sandweiler (L-5230) le 29.08.2019**

6) **Défectuosités et non-conformités constatées**

Mineures: - défectuosité(s) requérant une réparation / mise en conformité sans requérir un contrôle complémentaire du véhicule

Néant

Majeures: - défectuosité(s) requérant une réparation / mise en conformité et en outre un contrôle complémentaire du véhicule

Néant

Critiques: - défectuosité(s) requérant une réparation / mise en conformité et en outre un contrôle complémentaire du véhicule

Néant

7) Résultat du contrôle technique: **Le véhicule sus-visé est accepté.**

10) Autres informations:

9) Identification de l'inspecteur technique responsable : 59

Merci pour votre visite et bonne route en toute sécurité!

ACCREDITATION NUMBER: 3/007 ISO/IEC 17020

Le présent certificat correspond à l'état du véhicule au moment du contrôle visé ci-dessus et ne présume nullement de son évolution ultérieure.

www.snct.lu
catalogue des sanctions

Figure 44: SNCT report

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 authorization is free of charge. The hole process has a duration of at least five to 7 months.
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 automated minibus stops)
- Admission by the National Society of Automotive Traffic
- A sign with “scientific research” (“essai scientifiques”) needs to be installed visible on every Automated minibus.
- Automated minibuses need a valid insurance for the duration of the authorization.
- An operator with a bus driving license (license D1) needs to be inside the Automated minibus 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 Automated minibuses 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).

4 Vehicles

4.1 Sales Lentz Vehicles

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	Esch	UELZECHT MOBIL

Table 19: Vehicles – Sales Lentz Fleet

4.2 Technical data

See appendix A

4.3 Options

4.3.1 General

- Air conditioning
- In all Automated minibuses the seats are equipped with seatbelts

4.3.2 Wheelchair ramp

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

4.4 Covering

SLA

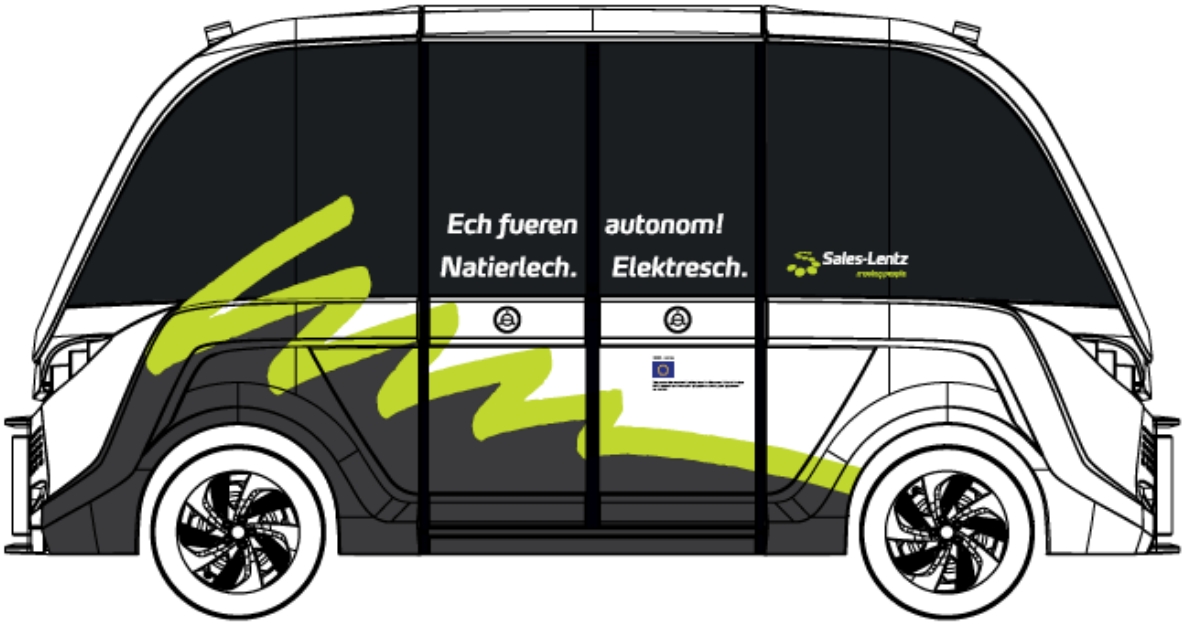


Figure 45: SLA Covering

AVL-Multiplicity

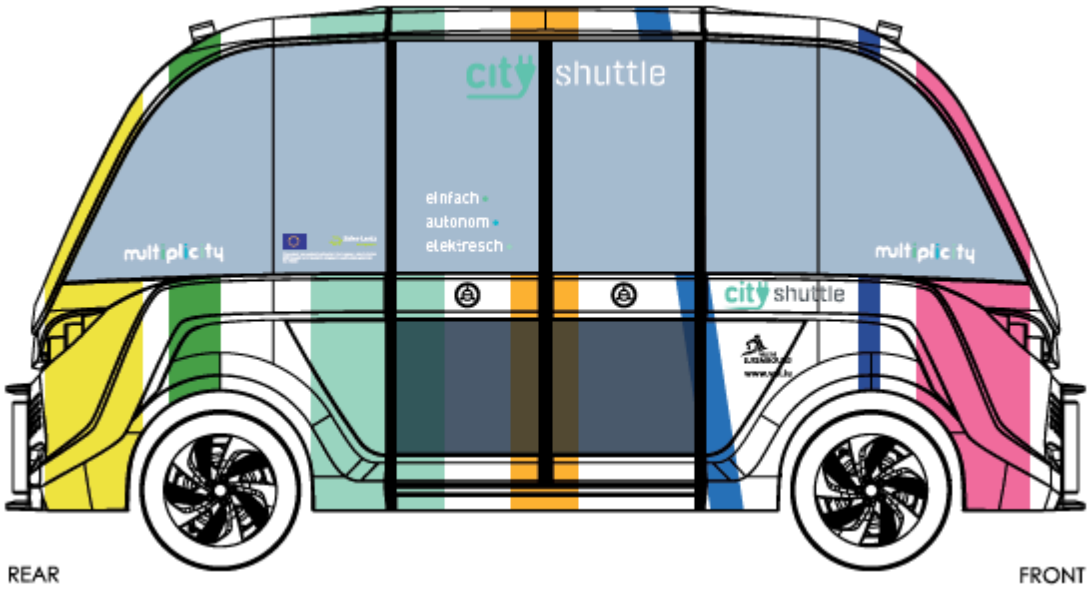


Figure 46: AVL Covering

Campus Contern

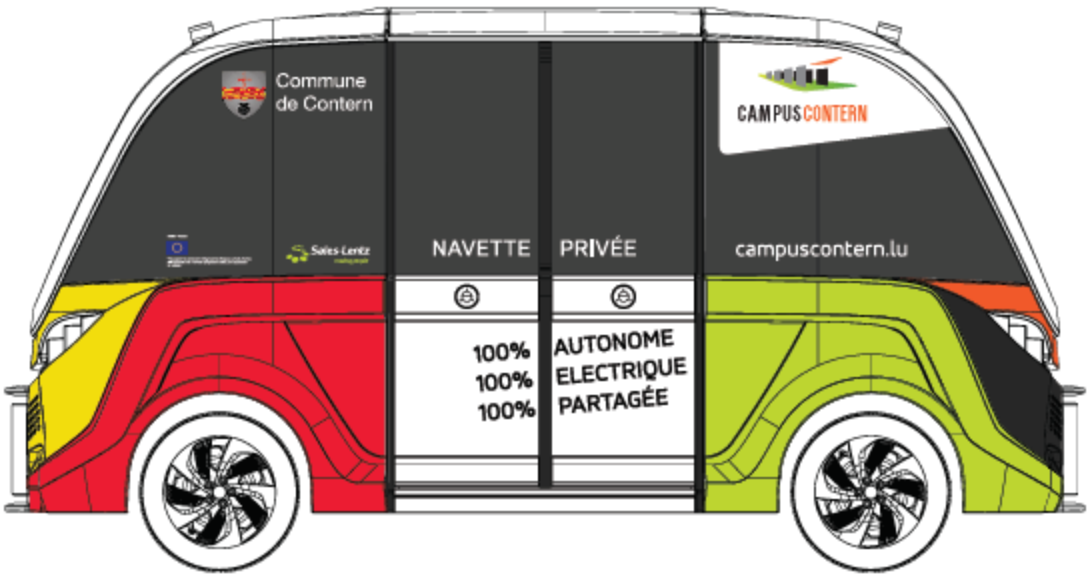


Figure 47: Contern Covering

Figure 48: Esch Covering

4.4.1 AVENUE EU Logo

4.4.1.1 French

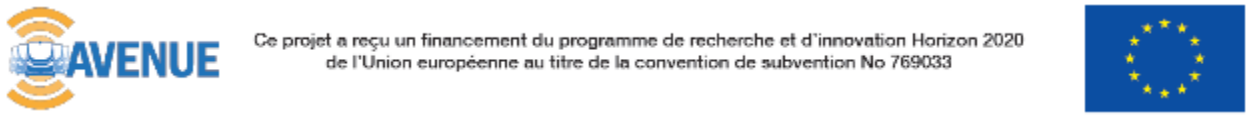


Figure 49: Avenue Logo French

4.4.1.2 English

Figure 50: Avenue Logo English

4.4.1.3 On vehicle example

Figure 51: Example on vehicle

4.5 Vehicle inspection

The Navya Automated minibuses 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

The technicians have been trained by Navya to do in-house maintenance work on SLA's 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 Automated minibuses, the safety operator can instantly contact the technical department of Navya via a phone number, a Whatsapp group or the Automated minibuses intercom. This way Navya's technicians can actively assist the safety operator in solving all kind of issues that can occur during the operation of the automated minibus. During the operation of the Automated minibuses this possibility has proved to be very effective at finding promptly a solution.
There is a special procedure in case of a safety related incident for the bus drivers which can be adopted to the shuttle drivers. They are aware of these procedures because they are bus drivers with a special training (see point 5).

"Procedure in the event of a breakdown on national or departmental roads
In the event of a breakdown or accident, you must always keep in mind the three following actions:
PROTECT - ALERT - RESCUE.

- Turn on your hazard lights.
- If the condition of your vehicle allows it, try to park the vehicle in completely safe.
- If necessary, call the emergency services at the emergency number 112 or 113 at Luxembourg.
- Put on your yellow safety vest before getting out of your vehicle. If you judge that the passengers are in danger inside the vehicle, make the exit on the right if possible.
- Get as far away from traffic as possible.
- Contact the 24/7 operation desk and notify them of the breakdown or accident."

For the shuttle-drivers it is possible to contact NAVYA too. After an incident a report needs to be filled out.

5 Personnel

5.1 Supervisor

The ***Tower*** team oversees all Sales Lentz operations, 24/7, the activity never stops. Teams can monitor all transport operations in real time to ensure the best possible service and react to all solutions.
SLA's Tower team is composed of 30 people.

5.2 Safety operators

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	X				
Pedro	x		x		x
Philippe			x		x
Adelakun		x			
ANISIO		x			
El Fassi		x			
Tesor		x			
Michel		x			

Table 20: Sales Lentz current people involved in the day-to-day

There is a special job posting for the drivers. They also receive training including a test to ensure the safety of passengers, other road users and the vehicle.
Profile sought (m / f / d):

- You must have a D license;
- Be able to manage the autonomous operation of the shuttle and be able to drive it manually;
- Be responsible for the comfort and safety of passengers;
- Have an interest in technology and computers. You are brought to understand how the shuttle works and will be able to act effectively on the IT part in the event of a complication;
- Be autonomous and adaptable: many situations mixing technical management and customer reception are to be expected;
- Have a sense of service: you will have to explain to passengers how the shuttle works and ensure them the best possible quality of service.

Operator-attendant training

- days of basic training
- 1 review
- 1 day of specific trip training

6 Conclusion

6.1.1 Conclusions for the three sites

The three different trials in Contern, Pfaffenthal and Esch showed that Automated minibuses could successfully be integrated into traffic and the number of travelers shows that passengers are ready to step into an automated minibus. SLA was also able to identify areas that still need development to improve the operation of Automated minibuses.

The different environments 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 SLA did not encounter this problem seen in Pfaffenthal. There is less traffic in the industrial zone of Contern compared to Pfaffenthal, so the Automated minibuses encountered less overtaking. The main issue encountered where vehicles parked illegally on the Automated minibuses path. From the view of the other road users the autonomous shuttle is driving comparatively slow. This can result in less acceptance to have the AV's as a new kind of road user and on the other hand in using the shuttle itself, as long as they are driving slow(er than the own car).

In Pfaffenthal the traffic situation is very different. The Automated minibuses 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 Automated minibuses encounters numerous overtaking which cause harsh breakings of the Automated minibus. Complex traffic situations around the Automated minibuses cause a rough driving behavior. The Automated minibuses needs to identify other traffic and not only detect it. The Automated minibuses 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 Automated minibuses out of the morning peak hours to prevent the Automated minibuses from slowing down traffic. With more than 25.000 passengers in around 18 Month, Pfaffenthal is the most successful site of AVENUE regarding the users.

Esch is a very different environment for the AV, too. The very dense and narrow shopping street is only used by pedestrians and sometimes bikes and scooters. Some people want to test the "reflexes" of the shuttles' systems and others are not paying attention even if the AV rings the bell. From time to time there are chairs from restaurants or the fence of a long-term construction site in the path of the AV and the safety operators or SLA itself must talk to the owners or the city of Esch. The testing and further development of the pedestrian mode resulted in less harsh breakings and the implementation of the on-demand resulted in longer services ours and a demand-orientated service for the users. With around 12.000 passengers in 12 months the site in Esch is nearly as successful as Pfaffenthal.

The future operation in two of the three sites beyond European funding shows, that the initial investment was well used to implement this new mobility option, the acceptance of the users shows that they take it for granted and the cities of Luxemburg and Pfaffenthal are convinced to continue on their own.

6.1.2 Mainly required technical and legal developments

There were main technical areas of the Automated minibuses identified that need to be improved.

With a higher operational speed (30 or 40 km/h), the AV's can integrate in the flow of the traffic and are no longer an obstacle for other road users. In addition, they were not longer noticed as slow public transport vehicles but as an alternative to the own car (depending on the deployed area).

A better object identification (and not only object detection) can prevent unnecessary and harsh breakings, which will lead to higher safety inside and outside the shuttles. Also driving around small obstacles in autonomous mode is important for two things.

First, to improve the time driven in autonomous mode. The three test sites in Luxembourg were never close to 90%, because:

- In Contern the train arrives every 30 minutes and the route (there and back again) takes 30 minutes. One obstacle or unplanned stop was enough to create a delay and the operator had to go the way back (without passengers on board) in manual mode.
- In Pfaffenthal there were small obstacles or car coming very fast from behind. They were then detected as an obstacle and the shuttle made a full stop. Driving fast would solve this problem.
- In Esch the mentioned construction site results in an area, where the operator nearly every day needs to switch to manual mode and drive around the fence, which just is 10 cm in the path of the shuttle.

Second, it is needed as the next step towards fully automated driving without an operator on board. This must be the main focus in the development to lower costs for customers and make the service as a whole affordable for private companies (especially in industrial zones as a last mile solution) and for not-so-rich cities (especially in the rural areas with a lower quality of public transport in the mornings, evenings and weekends). The safety operator can then supervise several shuttles at once from the office. To put the safety operator outside of the shuttle can lower the costs in Luxemburg to around 50%.

It is important to implement the developments made during the AVENUE project, like the in-vehicle-services and observations of dangerous situations (like stealing, falling, violence etc.). In Luxemburg those were not implemented, because after the development was ready to use:

- Contern stopped and started to often to assure a steady testing of the technology and normally there are only one or two persons at the same time in the vehicle.
- Esch had to implement the on-demand-service
- Pfaffenthal already stopped with the beginning of COVID and could not restart until the end of the project

SLA's 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 Automated minibuses 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.

6.1.3 Learnings from the partner-project Ride2Autonomy

Besides the table in “2.5 Recommandations” there are more learnings from the projects that could not be realized for the “Ride2Autonomy” (R2A) project. R2A started in May 2021 and ended November 2022, including a 7-month prolongation. There were three planned project sites for Sales-Lentz.

6.1.3.1 Vianden

Vianden is a very touristic, small city in the east of Luxembourg with around 2.000 inhabitants. The route was planned from the parking for caravans near the walkway along the river to a hotspot with cafés and restaurants. The route is one way 850 meters. Nearly everything was ready to start at the end of October 2021 but then the national road authority (Ponts et Chaussées) needed longer for the last permission that expected. In the end they asked Vianden to put up warning signs for pedestrians (because of a silent shuttle driving around) and signs for cars along the street to lower the speed limit from 50 of 30 km/h. It was also said that the first run should be declared as a test period. SLA wanted to use the Easter Holidays 2022 for that to get afterwards the permission for the whole time the service was there. Out of nowhere on March 10th Vianden quit the project and the whole cooperation with very few sentences. The effort was to much for such a small administration. No one is to blame but the requirements have to be clear from the beginning on and should not overwhelm the partners.

Figure 52: Shuttle in Vianden
Figure 53: Route Vianden

6.1.3.2 Differdange

With around 28.000 inhabitants, Differdange is the third largest City in Luxembourg after the capital and Esch. The first route planned was from a parking to the new museum but constructions at the parking and later the conversion of the roundabout to an intersection with traffic lights made it impossible to realize the project here. The second route was from a P&R, past a small cultural spot used for promoting Esch 2022 to the town hall, but the city stopped the renovation and expansion of the town hall, so there was no need for a shuttle anymore. But more important was the fact, that the route crosses a railway and NAVYA said no to this option because of safety issues. The last alternative was from the P&R to the parking of the first route with a planned stop at the back side of the cultural spot. But this would have crossed a national main road and needed the authorization of the national road authority which would have taken too much time. There are more ideas existing and as one of the 100 climate neutral and smart cities and part of a consortium of another EU project, Differdange and SLA are going for another try with new

options. It is possible to connect existing bus lines through residential areas and extend the public transport service or to close streets around schools in the morning and provide a new service for the pupils/students. Below are the first three planned routes that were never realized.
It is important to have a partner (here the city of Differdange) that doesn't give up easily, has the flexibility to find alternatives together, brings in own ideas and is aware of the advantages of the AV.

Figure 54: alternative routes Differdange

6.1.3.3 Charleroi

The airport Charleroi is 50 km south of Brussels and the second largest airport in Belgium. The peculiarity of the airport is the need for transit passengers changing the Terminals, to check-out and check-in again. The AV should have operated airside between the two Terminals and the passengers then don’t need to check-out/-in. The first test with the AV was made in September 2019 and everything went as expected until COVID hit and the aviation industry was one of the most affected. As a result, Terminal 2 was closed and the AV needed a new route. Two ideas came up. The first was an “employee-shuttle” from one parking to Terminal 1 and the second one was a “passenger-shuttle” from another parking to Terminal 1. But there weren’t enough passengers and at a certain point the project was stopped.

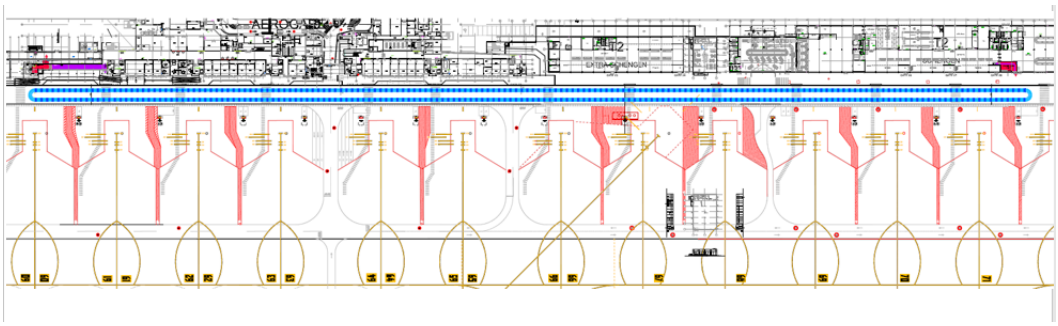


Figure 55: Route Charleroi airport

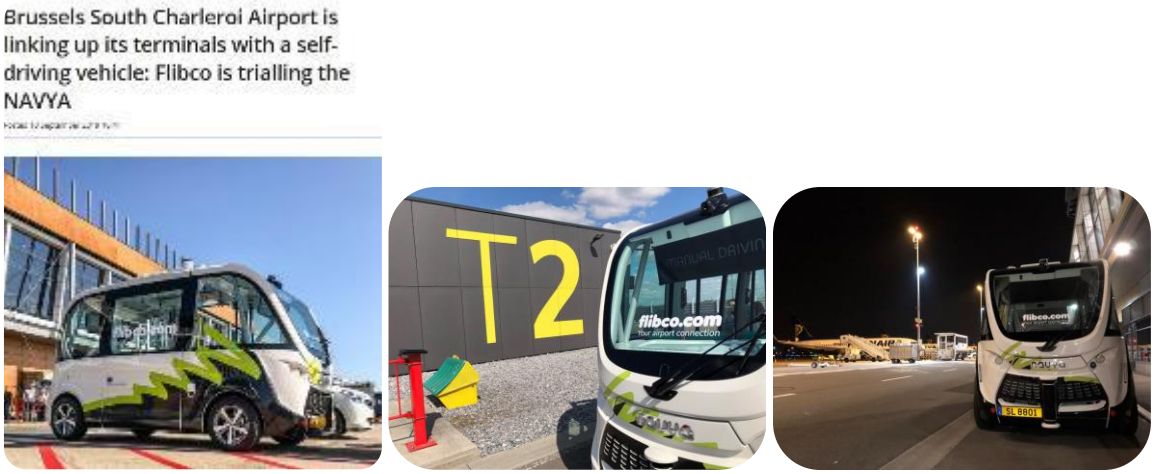


Figure 56: Shuttle at the airport Charleroi

The closest alternative in terms of space and similarity was the Airport Zaventem (Brussels). Luckily they are part of the STARGATE-project and want to implement an AV in 2023 or 2024 and R2A could have been a good test-run. The route was also planned airside and connecting different gates as a customers service. Unfortunately the time was running out and the end of R2A was to close to invest the needed amount of money, just to “maybe” drive.

The key takeaway here was that it is important to look for alternatives, but don't rush into a new project only to realize that it will end up costing more than it brings.

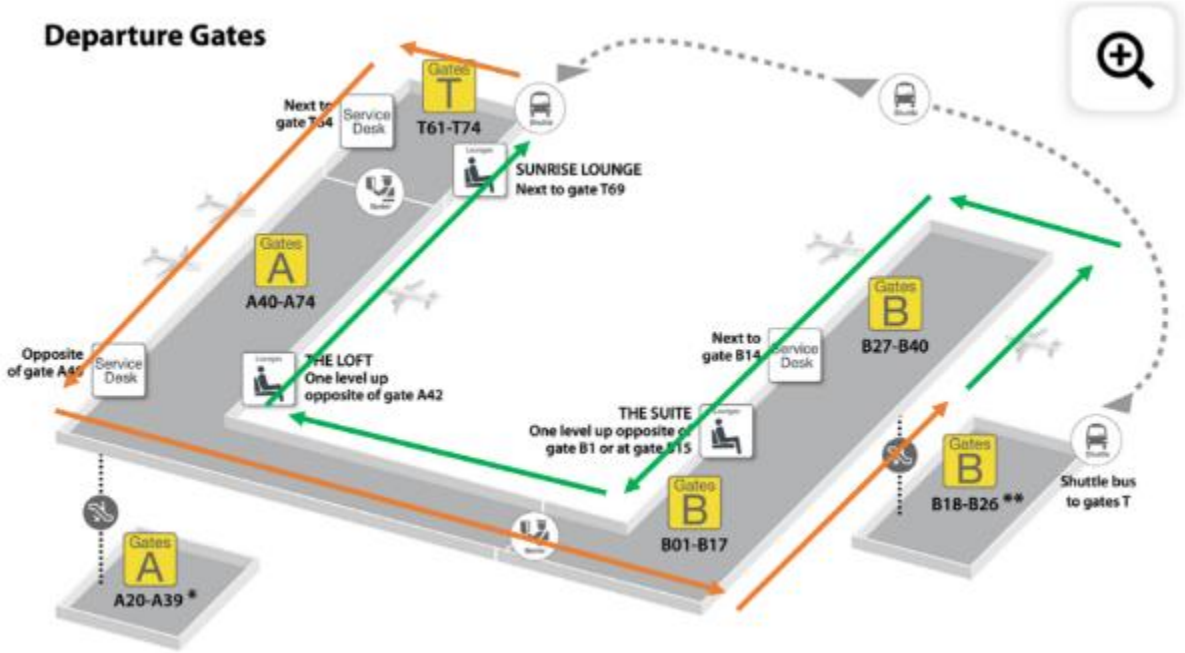


Figure 57: Route Zaventem airport

6.1.4 CCAM readyness study for Luxembourg

In spring 2022 the „CCAM Readyness Study" for Luxembourg was publish and SLA was part of the working group. The main results are the following ones while the whole study can be provided by SLA on request:

The structures in Austria, France and Germany were examined and evaluated in order to draw suitable conclusions for Luxembourg. All the countries examined have a well-developed strategy for automated driving that is accompanied by legal measures. […] The basis of the developments in the sample countries was a great political will to deal with CCAM and to create the necessary framework conditions. This will has not yet been formally declared in Luxembourg.

The approval procedures based on international agreements have been described in detail for Luxembourg and show scope for action for the approval of experimental vehicles. […] To increase the attractiveness of Luxembourg for automated driving, it is therefore of significant importance to ensure process reliability. This can be established through a comprehensible, reliable and consistent process flow as well as designated contact persons. One form of this contact can be a SPC, which supports Luxembourg in structuring and communicating its activities on CCAM.

Luxembourg's geographic location makes it dependent on European standards for infrastructure and data, which have not yet been entirely developed but are necessary for the long-term deployment of interoperable communication. Therefore, a unified concept for an extended Open Data Portal or Mobility Data Space offers benefits for local companies and creates economic value for Luxembourg. […] As a fast follower, Luxembourg should monitor European research initiatives to be able to identify technological trends and evaluate them in advance for Luxembourg.

Overall, practical testing of use cases is always necessary in order to identify problems and get new insights into automated driving and to take them into account in development before the vehicle receives regular approval. While the aspect of extraordinary approval for test purposes has already been addressed, the practical use cases also play a major role in ascertaining the degree of technical maturity as well as acceptance by the future users. […] Through this study, the necessary awareness for the topic of CCAM will be created among the active stakeholders at local and national level.

Based on examples from relevant reference countries of the European Union, administrative structures can be critically examined and necessary process improvements can be initiated. […] Based on this study, a process may be initiated to develop a national strategy for CCAM that takes into account and recognizes the interests of the various stakeholders at the administrative level as well as in research and development and in industry.

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]
Tires	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	25 [km/h]
Operating speed	18 [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 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

Table 21: Technical data Navya Arma-DL4

Appendix B

Esch was one of the European Capitals of Culture in 2022. One artist asked the operator of SLA on a day in June 2022, if he could draw him and the shuttle. Here is the result:

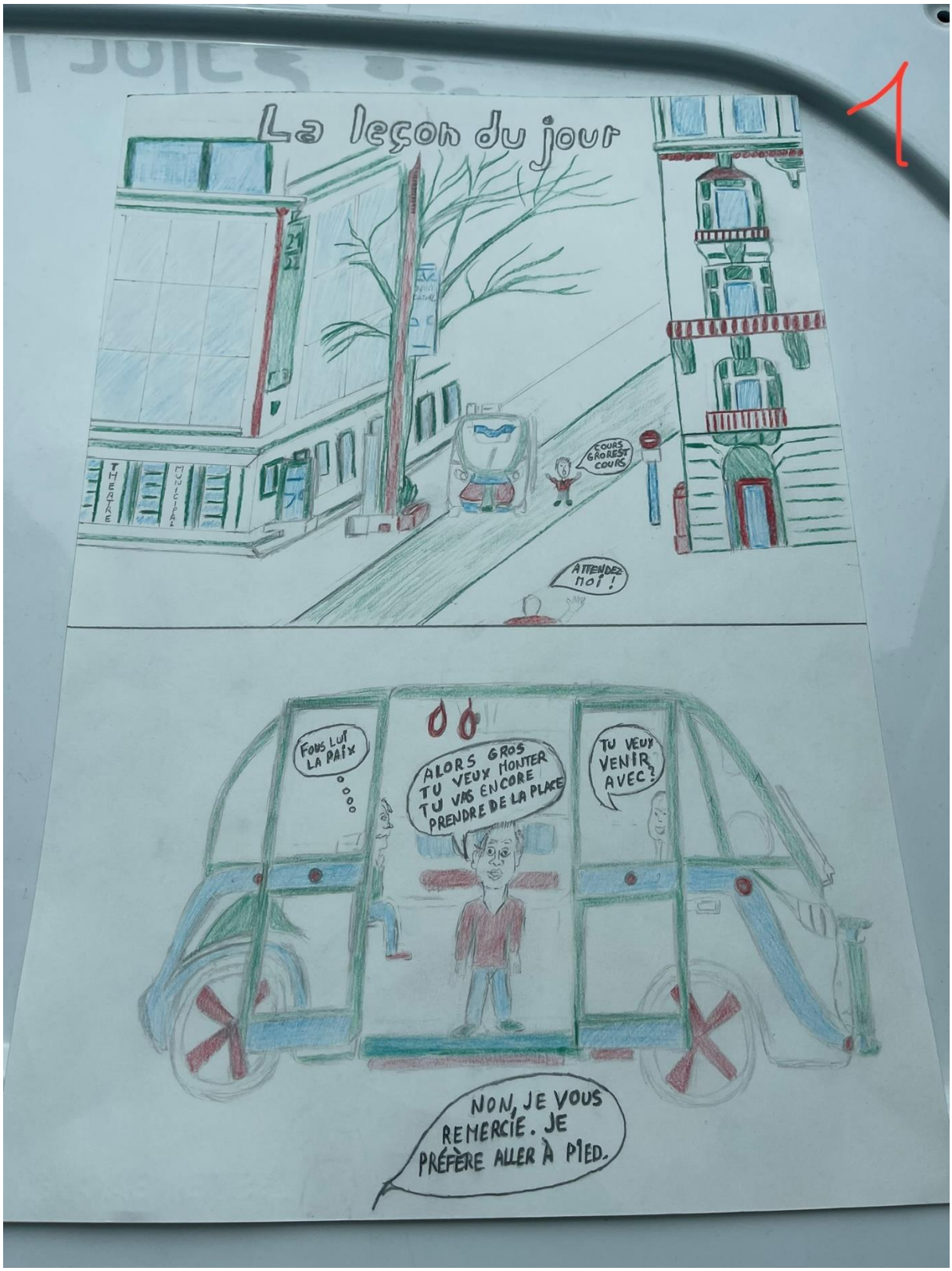


Figure 58: drawing of the shuttle Esch2022 part 1/3

Figure 59: drawing of the shuttle Esch2022 part 2/3

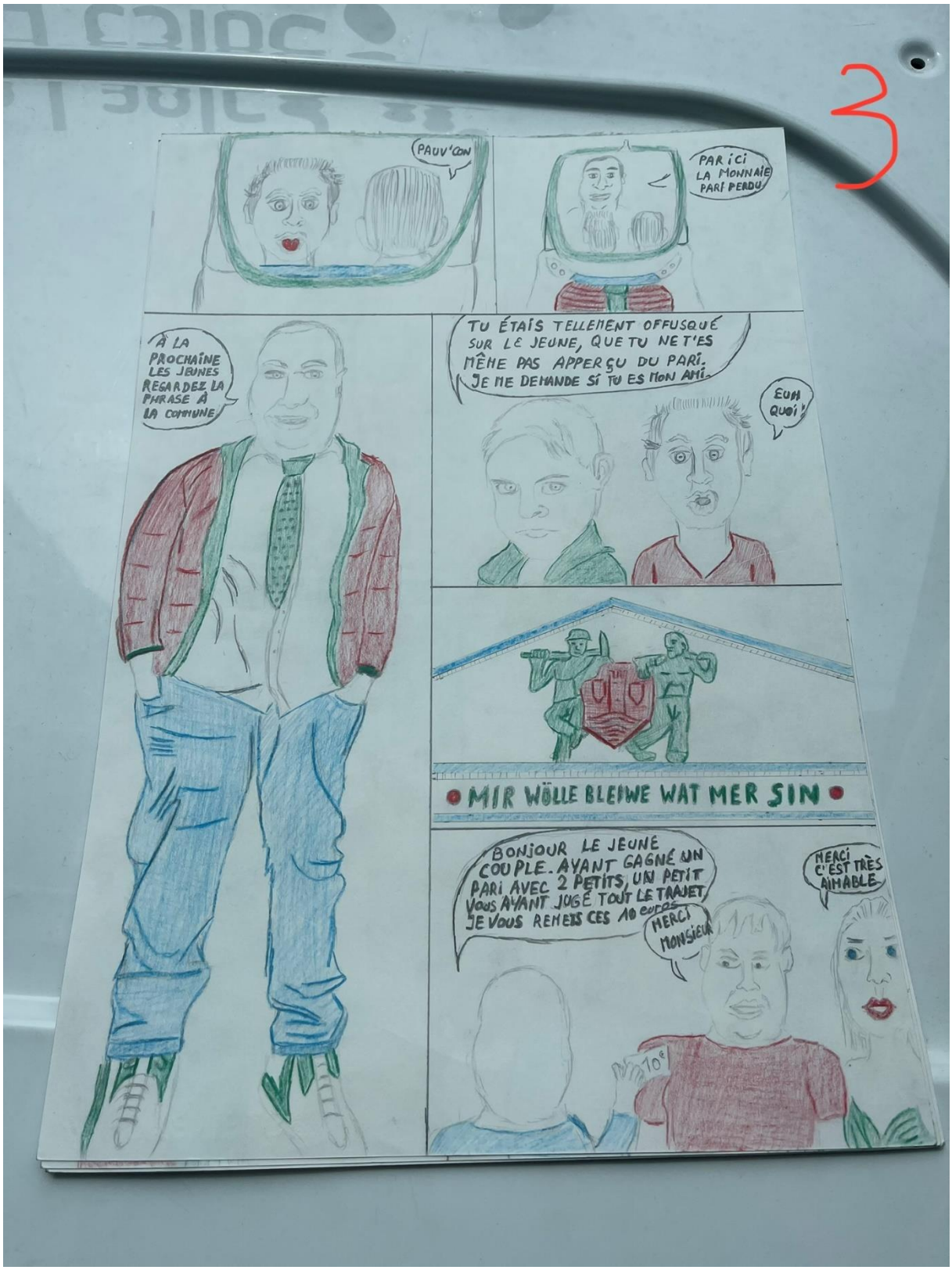


Figure 60: drawing of the shuttle Esch2022 part 3/3