AVENUE

Autonomous Vehicles to Evolve to a New Urban Experience

DELIVERABLE 4.3

Final Iteration Transport services

Co-funded by the Horizon 2020 programme of the European Union

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

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Document Information

Grant Agreement Number	**769033**
Full Title	Autonomous Vehicles to Evolve to a New Urban Experience
Acronym	AVENUE
Deliverable	D4.3 Final Iteration Transport services
Due Date	30.04.2022
Work Package	WP4
Lead Partner	TPG
Leading Author	Beukers Jeroen
Dissemination Level	Public

Document History

Version	**Date**	**Author**	**Description of change**
0.1	15.03.2021	Jeroen Beukers	First draft
1.0	15.05.2021	Vedran Vlajki	Composition of PTO information
1.1	15.06.2021	Vedran Vlajki	Addition of PTO information
1.2	18.12.2021	Jeroen Beukers	Review and integration of comments from the European Union
1.3	18.1.2022	Jeroen Beukers	Adaptation revision to reviewers' comments
1.4	28.1.2022	Vedran Vlajki	Final review and adaptation
2.0	30.10.2022	Dimitri Konstantas	Added replicator site data
3.0	18.05.2023	Laurent Helfer	Final version: added Esch, Uvrier sites, added achievements section, adapted descriptions of sites.
3.1	01.09.2023	Maher Ben Moussa	Review and finalisation

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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 test track	Technical University of Denmark test track
EAB	External Advisory Board
EC	European Commission
ECSEL	Electronic Components and Systems for European Leadership
EM	Exploitation Manager
EU	European Union
EUCAD	European Conference on Connected and Automated Driving
F2F	Face to face meeting
FEDRO	(Swiss) Federal Roads Office
FOT	(Swiss) Federal Office of Transport
GDPR	General Data Protection Regulation
GIMS	Geneva International Motor Show
GNSS	Global Navigation Satellite System
HARA	Hazard Analysis and Risk Assessment
IPR	Intellectual Property Rights
IT	Information Technology
ITU	International Telecommunications Union
LA	Leading Author
LIDAR	Light Detection And Ranging
MEM	Monitoring and Evaluation Manager
MT	MobileThinking
OCT	General Transport Directorate of the Canton of Geneva
ODD	Operational Domain Design
OEDR	Object And Event Detection And Response
OFCOM	(Swiss) Federal Office of Communications
PC	Project Coordinator
PEB	Project Executive Board
PGA	Project General Assembly
PRM	Persons with Reduced Mobility
PSA	Group PSA (PSA Peugeot Citroën)
PTO	Public Transportation Operator
PTS	Public Transportation Services
QRM	Quality and Risk Manager
QRMB	Quality and Risk Management Board
RN	Risk Number
SA	Scientific Advisor
SAE Level	Society of Automotive Engineers Level (Vehicle Autonomy Level)
SAN	(Swiss) Cantonal Vehicle Service
SDK	Software Development Kit
SLA	Sales Lentz Autocars
SMB	Site Management Board
SoA	State of the Art
SOTIF	Safety Of The Intended Functionality
SWOT	Strengths, Weaknesses, Opportunities, and Threats.
T7.1	Task 7.1
TM	Technical Manager
TPG	Transport Publics Genevois
UITP	Union Internationale des Transports Publics (International Transport Union)
V2I	Vehicle to Infrastructure communication
WP	Work Package
WPL	Work Package Leader

Executive Summary

This deliverable presents an overview of the deployed AVENUE demonstrator and replicator transport services at the different project sites. To be noted that this deliverable is a Demonstrator deliverable and NOT a report.

This deliverable is a collection of factual information. For more detailed information regarding every demonstrator/replicator site, please consult the WP7 deliverables.

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 based 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**), or as Autonomous Vehicle, is a vehicle that can sense 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.

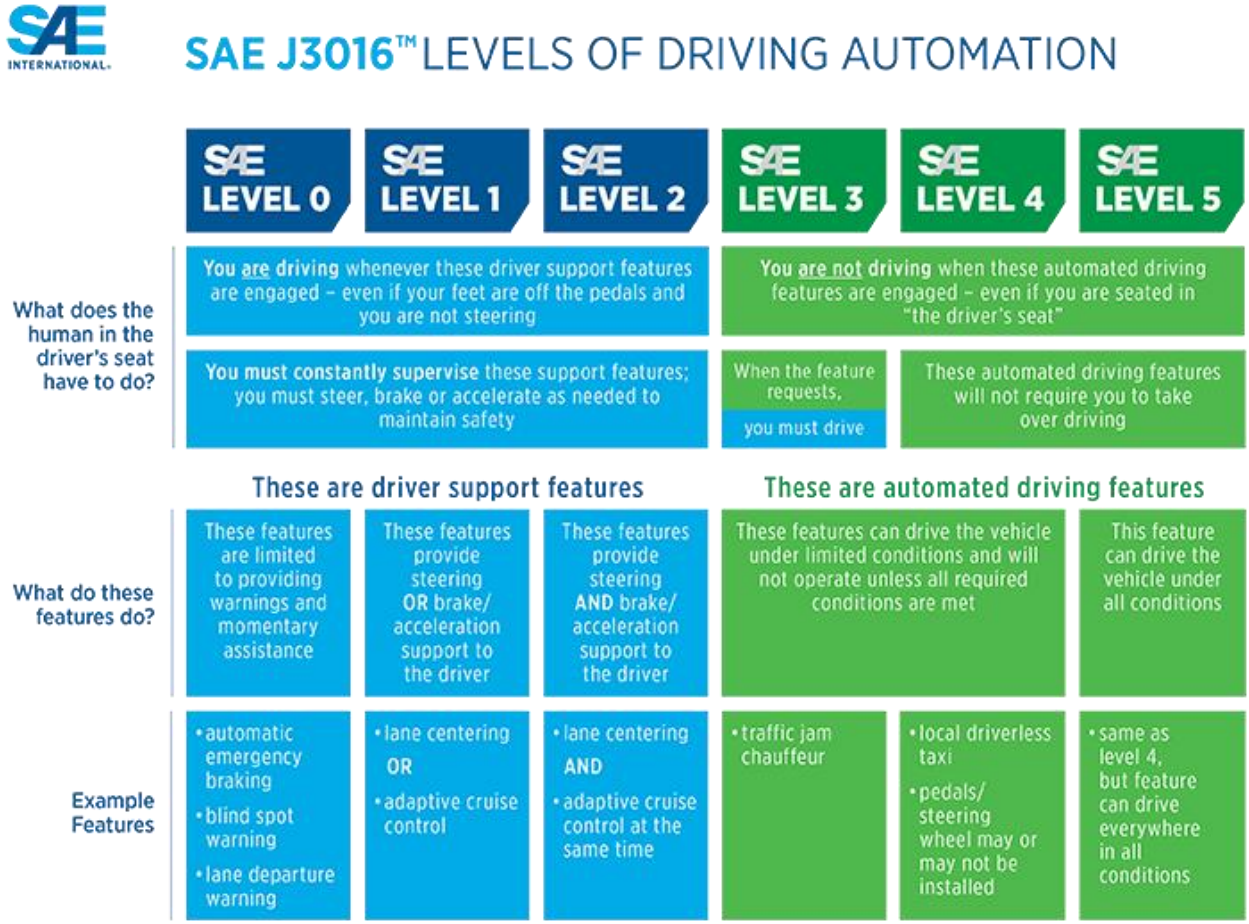

Table 1: SAE Driving Automation levels (©2020 SAE International)

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 of 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 considers 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 or wait behind them, based on the defined policies. For example, with small changes in its route the AVENUE minibus 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 minibuses 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 minibuses. Table 2 provides an overview of the AVENEU sites and ODDs.

	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	Esch sur Alzette
Funding	TPG	EU + TPG	EU + Holo	EU + Holo	EU + Keolis	EU + SLA	EU + SLA	EU + SLA
Start date of project	August 2017	May 2018	May 2017	August 2019	May 2017	June 2018	June 2018	February 2022
Start date of trial	July 2018	June 2020	September 2020	December 2019	November 2019	September 2018	September 2018	April 2022
Type of route	Fixed circular line	Area	Fixed circular line	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	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	1 km
Road environment	Open road	Semi-private	Open road	Open road	Open road	Public road	Public road	Main pedestrian road
Type of traffic	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Pedestrians, bicycles, delivery cars
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	20 km/h
Roundabouts	Yes	Yes	No	No	Yes	No	No	No
Traffic lights	No	No	No	No	Yes	Yes	Yes	No
Type of service	Fixed line	On-demand	Fixed line	Fixed line	Fixed line	Fixed line	Fixed line	On Demand
Concession	Line (circular)	Area	Line (circular)	Line (circular)	Line (circular)	Line (circular)	Line (circular)	Line (circular)
Number of stops	4	> 35	6	6	2	4	2	3
Type of bus stop	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Bus stop infrastructure	Yes	Sometimes, mostly not	Yes	Yes	Yes	Yes	Yes	Yes
Number of vehicles	1	3-4	1	2	2	2	1	1
Timetable	Fixed	On-demand	Fixed	Fixed	Fixed	Fixed	Fixed	On-demand
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	Monday – Saturday
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 – 20h00	7:00 – 9:00 16:00 – 19:00	11:00 – 18:00 11:00 – 18:00
Timeframe weekends	No service	07:00 – 19:00	No service	9:00 – 18:00	08:30 – 19:30	10:00 – 21:00	No Service	On Suterday only
Depot	400 meters distance	On site	800 meters distance	200 meters distance	On site	On site	On site	500 m distance
Driverless service	No	2021	No	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	Straight lines / plane
Lane specification/ODD	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Open area
Drive area signs/ODD	Regulatory	Regulatory	Regulatory, Warning	Regulatory	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	Standard Surrface

Table 2: Summary of AVENUE operating site (+ODD components)

1.3 Preamble

Working Group 4 (WP4) aims to develop, adapt and integrate passenger transport and in- and out- of vehicle services, and to design, develop, adapt and integrate services to support users of autonomous vehicles before the trip, during the trip, and at the end of the trip. The main objective of this working package is to provide services in order to demonstrate that the user experience can be seamless and secure, and that people embrace this new technology. Hence, we included the following services:

- Adapt and integrate existing transport services.
- Develop autonomous vehicle specific services.
- Provide services that foster the acceptance of driverless vehicles by both passengers and people interacting with the automated minibuses.
- Introduce safety related services.

The target of task T4.1 is to define and validate the transport services of the operators. Deliverable 4.2 is a demonstrator of the developed and operated transport services and D4.3 is the final iteration of this document. We present in the following the deployed services and details for each site.

2 Overview of the deployments

During the AVENUE project, we deployed some automated vehicle-based services in various European cities following an incremental complexity scheme. Although the overall target is the same, each of the deployment sites had its own special issues and challenges. To be noted that in none of the sites any special indications were installed regarding the presence of automated vehicles on the street.

Here is a list of the AVENUE deployments:

- The Meyrin (section 3.1.1), Nordhavn (3.2.1) and Pfaffenthal (3.3.1) sites, where simple, fixed-route, fixed-stop services have been introduced. These sites were the first to be deployed at the start of the project and allowed the operators to gain knowledge about the issues related to autonomous vehicles. They also contributed to raising the public awareness about the future automated vehicle public transportation.
- The Belle-Idée site (3.1.2) that hosts the most advanced deployment in the project, providing fully automated On-demand and Door-to-door services, with no intervention from the on-board operator.
- The Slagelse site (3.2.2) where the first deployment fully integrated into the existing PTO network and information system was carried. Here, the automated vehicles itineraries have been integrated into the overall PT service. Due to legal challenges in Denmark, another site has been implemented in Ormøya, near Oslo (3.2.3).
- The Contern site (3.3.2) has been implemented in a heavily mixed road environment, with complex road conditions: narrow roads, many parked cars on the side of the roads, sharing the road with heavy vehicles.
- The Lyon Parc OL site (3.4), where V2X infrastructure has been integrated to allow the vehicles to control barriers and traffic lights. The site also includes a very complex roundabout, shared with high-speed vehicles.
- In a second phase, two replicator sites were introduced in Esch-sur-Alzette (3.5) and in Uvrier (3.6).

2.1 Linked deliverables

This document provides a factual snapshot of the deployments, which constitute the actual deliverable. It is not meant to provide details and explanations on issues faced and solutions provided. These are given to the related report deliverables. In the table below we provide the list of related report deliverables where the related information can be found.

Content and information	Related Deliverables
Detailed description of the deployments and statics	D7.2, D7.5, D7.8, D7.11
Detailed description of use cases, including ODD components (Table 30)	D2.8
In and out of vehicle services	D4.5, D4.8

3 AVENUE Deployments

3.1 Geneva demonstrator

3.1.1 Meyrin

The Xa-Line at Meyrin/Geneva was the first deployment with fixed bus-stop and fixed itinerary transport service. It provided a traditional public transport service using fully automated vehicles, connecting the train station to the tram line in the centre of Meyrin.

The objective of this public transport solution is to start offering a simple transport service for the inhabitants of a residential area where there was no public transport before.

Project details	
Start date project	01.08.2017
Start date trial	02.07.2018
End date trial	31.02.2020
Demonstrator Layout	
Type of route	Fixed circular line
Route length	2.1 [km]
Bidirectional route sections	0
Roads	Public road
Type of roads	Mixed: double lane, speed bumps
Type of traffic	Mixed: cars, buses, trucks, bicycles
Speed limit	30 [km/h]
Roundabout	Yes: between track and depot
Traffic lights	No
Number of bus stops	4
Type of bus stops	Predefined points
Bus stops with infrastructure	4
Virtual bus stops	0
Vehicle depot	At 400 [m] distance
Vehicle depot : entrance/exit vehicles	Manually
Transport Services	
Number of vehicles	1 (+ 1 reserve)

On-demand	No
Door-to-door	No
Dynamic routing	No
Ride pooling	Yes
Connected to existing network	Yes: 1 bus/tram hub and 1 bus/train hub
Supervision @ distance	No
Safety operator actions	Yes: vehicle control and selection of destination
Fully driverless (no safety operator onboard)	No
Passenger services	
Timetable	Fixed
Operation hours	Monday-Friday (5 days)
Timeframe weekdays	06:30 - 08:30 / 16:00 - 18 :15
Timeframe weekend / holidays	No service (from June 2019)
Ticketing	TPG standard ticketing policy

3.1.2 Thônex (Belle-Idée)

The Belle-Idée/Geneva site is the 2nd deployment site in Geneva, and it has been offering On-demand, Door-to-door services. The deployment provides transport services for the employees, patients and visitors of the hospital site. The transport services cover parking to building transport (used by personnel and visitors), building to building (for personnel mainly) and bus-stop to building (for visitors).
The objective of this public transport solution was to start offering a state-of-the-art On-demand transport service for different types of users of a hospital area connected to the existing public transport network.

Project details	
Start date project	01.05.2018
Start date trial	01.07.2020 (9 months project deployment)
End date trial	Continues after Avenue
Demonstrator Layout	
Type of route	Area (Geographical Zone)
Route length	38 [hectare] 9.6 [km] of routes
Bidirectional route sections	6
Roads	Semi Public road
Type of roads	Mixed: one lane, double lane
Type of traffic	Mixed: cars, buses, trucks, bicycles, pedestrians
Speed limit	30 [km/h]

Roundabout	Yes
Traffic lights	No
Number of bus stops	75
Type of bus stops	Predefined points
Bus stops with infrastructure	5
Virtual bus stops	70
Depot	On site
Depot vehicle entrance/exit	100% Automated
Transport Services	
Number of vehicles	3 (+ 1 reserve)
On-demand	Yes
Door-to-door	Yes
Dynamic routing	Yes
Ride pooling	Yes
Connected to existing network	Yes, 5 bus hubs
Supervision @ distance	Yes on site
Safety operator actions	No: vehicle and On-demand 100% automated
Fully driverless (no safety operator onboard)	No
Passenger services	
Timetable	On-demand only
Operation hours	Monday-Sunday (7 days)
Timeframe weekdays	08:00 – 22:00
Timeframe weekend / holidays	06:00 – 19:00 (from 09.2021)
Ticketing	Free of charge

3.2 Copenhagen demonstrator (+Ormøya)

3.2.1 Nordhavn

Nordhavn was the first deployment site in Copenhagen. The objective of this public transport solution was to start offering a simple transport service in a residential area where there was no public transport before. The transport services offered, due to Danish legislation restrictions were fixed itinerary and fixed bus stop services with fully automated buses for the region's residents. The service was interrupted due to heavy works and the complex procedure for changing itineraries.

Project details	

Start date project	01.04.2018
Start date trial	04.08.2020
End date trial	28.02.2021
Demonstrator Layout	
Type of route	Fixed circular line
Route length	2 [km]
Bidirectional route sections	0
Roads	Public road
Type of roads	Mixed: double lanes, bicycle and pedestrian lanes
Type of traffic	Mixed: cars, buses, trucks, bicycles, pedestrians
Speed limit	30 [km/h]
Roundabout	No
Traffic lights	No
Number of bus stops	6
Type of bus stops	Predefined points
Bus stops with infrastructure	6
Virtual bus stops	0
Vehicle depot	At 800 [m] distance
Vehicle depot : entrance/exit vehicles	Manually
Transport Services	
Number of vehicles	2
On-demand	No
Door-to-door	No
Dynamic routing	No
Ride pooling	Yes
Connected to existing network	Yes: 1 metro (200 meters distance)
Supervision @ distance	Yes
Safety operator actions	Yes: Vehicle control (manual) + safety mitigations
Fully driverless (no safety operator onboard)	No
Passenger services	
Timetable	Fixed
Operation hours	Monday-Friday (5 days)
Timeframe weekdays	10:00-13:00, 14:00-17:00
Timeframe weekend / holidays	No service
Ticketing	Standard ticketing policy

3.2.2 Slagelse

Slagelse was the 2nd deployment site in Copenhagen, within a hospital area. The objective of this public transport solution was to start offering a state-of-the-art On-demand transport service for different types

of users of the hospital area. The transport services are provided to patients, employees and visitors, linked to the backbone transportation services, and fully connected to the regional transport services (ticketing, reservations, routes).

Project details	
Start date project	01.06.2019
Start date trial	01.08.2021
End date trial	01.08.2022
Demonstrator Layout	
Type of route	Hospital area
Route length	5,5 kms of road
Bidirectional route sections	1
Roads	Public roads
Type of roads	Mixed: double lanes, bicycle and pedestrian lanes
Type of traffic	Mixed: cars, buses, trucks, bicycles, pedestrians
Speed limit	30 [km/h]
Roundabout	No
Traffic lights	No
Number of bus stops	7
Type of bus stops	Predefined points
Bus stops with infrastructure	7
Virtual bus stops	0
Depot	On site
Depot vehicle entrance/exit	Manually
Transport Services	
Number of vehicles	2 (1 AVENUE + 1 SHOW)
On-demand	Yes
Door-to-door	Yes (department to department)
Dynamic routing	Yes (to some extend)
Ride pooling	Yes
Connected to existing network	Yes, 2 bus hubs and 2 taxi hubs
Supervision @ distance	Yes
Safety operator actions	Yes: Vehicle control (manual) + safety mitigations
Fully driverless (no safety operator onboard)	No
Passenger services	
Timetable	On-demand (via touch screen in the area)
Operation hours	Monday-Friday (5 days)

Timeframe weekdays	07:00 - 16:00
Timeframe weekend / holidays	No service
Ticketing	Free operation

3.2.3 Ormøya

The third HOLO site was situated on the little inhabited island of Ormøya in the municipality of Oslo. A small bridge allows the inhabitants to go there to enjoy beaches, parks and a marina. This deployment consisted of a 1.6km public road route including 6 bus stops (called 85b line). Thanks to this deployment, users had the opportunity to commute between Malmøya and Mosseveien, where express buses are going to and from Oslo. This service provided a convenient access to a school and to the marina. The major challenges there were environmental, both vegetation and snowfall were interpreted as obstacles and were also obstructions to the GSS signal.

Project details	
Start date project	01.12.2019
Start date trial	01.12.2019
End date trial	01.12.2020
Demonstrator Layout	
Type of route	Fixed line
Route length	4 kms of road
Bidirectional route sections	Yes
Roads	Public roads
Type of roads	Mixed: double lanes, bicycle and pedestrian lanes
Type of traffic	Mixed: cars, buses, trucks, bicycles, pedestrians
Speed limit	30 [km/h]
Roundabout	No
Traffic lights	No
Number of bus stops	10
Type of bus stops	Predefined points
Bus stops with infrastructure	2
Virtual bus stops	8
Depot	On site [200m distance]
Depot vehicle entrance/exit	Manually
Transport Services	
Number of vehicles	4
On-demand	No
Door-to-door	No
Dynamic routing	No

Ride pooling	Yes
Connected to existing network	Yes
Supervision @ distance	No
Safety operator actions	Yes: Vehicle control (manual) + safety mitigations
Fully driverless (no safety operator onboard)	No
Passenger services	
Timetable	Yes
Operation hours	Monday-Sunday
Timeframe weekdays	08:00 - 22:00
Timeframe weekend	09:00 - 18:00
Ticketing	Free operation

3.3 Luxembourg demonstrator

3.3.1 Pfaffenthal

The Pfaffenthal automated minibuses connected two major transport hubs in Luxembourg, offering a service that did not existed before, and allowing citizens an easier access to the back-bone transport services. The service was on a fixed itinerary with fixed bus stops.

Project details	
Start date project	01.07.2018
Start date trial	19.09.2018
End date trial	01.01.2020
Demonstrator Layout	
Type of route	Fixed Circular line
Route length	1.2 km
Bidirectional route sections	All the route
Roads	Public roads
Type of roads	Mixed: double lanes, bicycle and pedestrian lanes
Type of traffic	Mixed: cars, buses, trucks, bicycles, pedestrians
Speed limit	35 [km/h]
Roundabout	No
Traffic lights	No
Number of bus stops	3
Type of bus stops	Fixed predefined
Bus stops with infrastructure	Yes
Virtual bus stops	0

Depot	On site
Depot vehicle entrance/exit	Manually
Transport Services	
Number of vehicles	1
On-demand	No
Door-to-door	No
Dynamic routing	No
Ride pooling	Yes
Connected to existing network	Yes
Supervision @ distance	Yes
Safety operator actions	Yes: Vehicle control (manual) + safety mitigations
Fully driverless (no safety operator onboard)	No
Passenger services	
Timetable	Fixed
Operation hours	12:00 - 16:00 & 16:45 – 20:00
Timeframe weekend / holidays	Yes
Ticketing	Free operation

3.3.2 Contern

Contern was the 2nd deployment site in Luxembourg, aiming for fully automated, Door-to-door, On-demand transport services, for the employees of the under development industrial and office area. The transport services offered included: parking to office, office to office and office to restaurant services.

Project details	
Start date project	01.07.2018
Start date trial	01.08.2019
End date trial	01.12.2022
Demonstrator Layout	
Type of route	Industrial area
Route length	3 kms of road
Bidirectional route sections	1
Roads	Public roads
Type of roads	Mixed: double lanes, bicycle and pedestrian lanes
Type of traffic	Mixed: cars, buses, trucks, bicycles, pedestrians
Speed limit	50 [km/h]
Roundabout	No
Traffic lights	No

Number of bus stops	2
Type of bus stops	Predefined points
Bus stops with infrastructure	Yes
Virtual bus stops	0
Depot	On site
Depot vehicle entrance/exit	Manually
Transport Services	
Number of vehicles	1
On-demand	No
Door-to-door	Yes (department to department)
Dynamic routing	Yes (to some extend)
Ride pooling	Yes
Connected to existing network	No
Supervision @ distance	Yes
Safety operator actions	Yes: Vehicle control (manual) + safety mitigations
Fully driverless (no safety operator onboard)	No
Passenger services	
Timetable	On-demand (some timetable slots)
Operation hours	Monday-Friday (5 days)
Timeframe weekdays	07:20 - 18:35
Timeframe weekend / holidays	No service
Ticketing	Free operation

3.4 Lyon demonstrator

The Lyon Parc OL site is an office and activity site. Autonomous buses have supported the development of this area, which aims to become a major centre of activity in Lyon. The deployment offered On-demand, services transport in mixed traffic and pedestrian area.

Project details	
Start date project	01.06.2018
Start date trial	01.11.2019
End date trial	01.10.2022
Demonstrator Layout	
Type of route	Circular route
Route length	3.5 kms of road
Bidirectional route sections	1
Roads	Public roads

Type of roads	Mixed: double lanes, bicycle and pedestrian lanes
Type of traffic	Mixed: cars, buses, trucks, bicycles, pedestrians
Speed limit	30 [km/h]
Roundabout	Yes (2)
Traffic lights	Yes (4)
Number of bus stops	14
Type of bus stops	Predefined points
Bus stops with infrastructure	2
Virtual bus stops	0
Depot	On site
Depot vehicle entrance/exit	Manually
Transport Services	
Number of vehicles	2
On-demand	Yes
Door-to-door	No
Dynamic routing	No
Ride pooling	Yes
Connected to existing network	Yes, bus hubs and metro hubs
Supervision @ distance	Yes
Safety operator actions	Yes: Vehicle control (manual) + safety mitigations
Fully driverless (no safety operator onboard)	No
Passenger services	
Timetable	On-demand (some timetable slots)
Operation hours	Thuesday-Saturday (5 days)
Timeframe weekdays	12:00 - 20:00
Timeframe weekend / holidays	No service on Sunday
Ticketing	Free operation

3.5 Esch-sur-Alzette replicator

The Esch-sur-Alzette replication site aimed to solve the mobility issues in the city centre of Luxembourg by deploying an automated minibus in the main shopping street. The work conducted by Sales-Lentz (SLA) as an AVENUE demonstrator allowed the Esch-sur-Alzette replicator site to benefit from this anterior legal work to get the necessary authorizations to operate some NAVYA ARMA vehicles.

Project details	
Start date project	01.08.2021

Start date trial	01.08.2021
End date trial	01.12.2022
Demonstrator Layout	
Type of route	Linear route
Route length	1.2 [km]
Bidirectional route sections	0
Roads	Pedestrian roads
Type of roads	High pedestrian frequentation
Type of traffic	Pedestrians, Bicycles
Speed limit	Pedestrian zone
Roundabout	No
Traffic lights	No
Number of bus stops	10
Type of bus stops	Predefined points
Bus stops with infrastructure	6
Virtual bus stops	4
Vehicle depot	On site
Vehicle depot : entrance/exit vehicles	Manually
Transport Services	
Number of vehicles	1
On-demand	Yes
Door-to-door	No
Dynamic routing	No
Ride pooling	Yes
Connected to existing network	Yes: railway, bus-stops
Supervision @ distance	No
Safety operator actions	Yes: vehicle control and selection of destination
Fully driverless (no safety operator onboard)	No
Passenger services	
Timetable	On Demand: via app or call
Operation hours	Monday-Saturday (6 days)
Timeframe weekdays	11:00 – 21:00
Timeframe weekend / holidays	No operation on Sunday

Ticketing	Free operation

3.6 Uvrier replicator

This replication site, operated by Post-auto was specifically inspired by the Belle-idée (TPG) demonstration and, just like its counterpart, offered On-demand and Door-to-door services. The project took place in the village of Uvrier, near Sion, and served low-density residential areas. The aim was to provide every resident with a stop close to their home, so that they could reach strategic points such as the village's school and shopping centre, as well as the railway station, enabling workers to commute to Sion. No fixed routes were established, with each user being able to determine his point of departure and arrival (dynamic vehicle routing).

Project details	
Start date project	01.12.2019
Start date trial	12.04.2021
End date trial	31.10.2021
Demonstrator Layout	
Type of route	Whole area
Route length	3.0 [km]
Bidirectional route sections	Yes
Roads	Public road
Type of roads	Mixed: double lane, speed bumps
Type of traffic	Mixed: cars, buses, trucks, bicycles
Speed limit	30, 50, 60 [km/h]
Roundabout	Yes
Traffic lights	No
Number of bus stops	16
Type of bus stops	Predefined points
Bus stops with infrastructure	4
Virtual bus stops	12
Vehicle depot	On site (Uvrier)
Vehicle depot : entrance/exit vehicles	Manually
Transport Services	
Number of vehicles	2
On-demand	Yes

Door-to-door	Almost (numerous virtual stops)
Dynamic routing	Yes
Ride pooling	Yes
Connected to existing network	Yes: bus-stop (15 and 412 line), train-station
Supervision @ distance	Yes
Safety operator actions	Yes
Fully driverless (no safety operator onboard)	No
Passenger services	
Timetable	No: reservation via app/fixed terminal/phone
Operation hours	Monday-Friday (5 days)
Timeframe weekdays	07:00 - 18:00
Timeframe weekend / holidays	No Week-end operation
Ticketing	Free operation

4 Project learnings, achievements and successes

First of all, the AVENUE project became the first to offer some autonomous On-demand and Door-to-door PT services on public roads at such a large scale and has therefore met its major objective. The project has also achieved all the other goals that were set, and this despite the COVID-19 crisis. All the planned demonstration and replication deployments were successfully implemented and this within the planned timeframe; the project's 18 automated minibuses transported 58,000 passengers over 75,000 km all across Europe, providing a great service to local communities by operating in areas that were previously underserved, and facilitating the access to the various transport hubs (this integration into the PT network was also part of the set targets). The AVENUE teams also demonstrated the suitability of AMPTs for a wide range of conditions, from crowded pedestrian-only streets, to busy city centres, through industrial zone b-roads, and the perfect management of traffic signals and other road infrastructures (high-speed roundabouts, stops, traffic lights, etc.), proving that this technology can provide a reliable day-to-day service and improve the population's daily life.

As our teams set out to do, the project also verified the reliability and safety of the AMPT technology, with no accidents occurring during our long periods of intensive testing. The project also contributed to the improvement of AMPT technology. Indeed, the extensive tests across all the AVENUE demonstration and replication sites and associated data and feedbacks also helped Navya© to further refine the functioning of the automated minibus technology (braking algorithms or obstacle detection improvements for example).

As we had also targeted to, the AVENUE project teams focused on the development of a client-oriented/user-centric environment model (MaaS integration, ergonomic mobile phone reservation app taking into account the needs of everyone, etc.) that can be replicated on a very large scale. The AVENUE project also contributed to the evolution of the autonomous driving legislation of various European states with the most important advances in Germany and Switzerland.

The AVENUE pioneering deployments offered a unique opportunity to perform a large-scale social assessment on AMPT users for the first time, enabling research into the social impact of this technology and the degree of acceptance toward it. As also set out in our goals, operating and running costs were estimated more precisely, enabling us to validate the economic viability of the model. As also planned, we also estimated the environmental impact of the AMPT advent.

Another AVENUE goal was the consideration of the needs of people with reduced mobility (PRMs); it has been at the centre of the project teams' attention, which has strived to create the most inclusive environment possible. Our surveys also confirmed that automated minibuses were seen by PRMs as a viable solution to their mobility problems. Furthermore, the AVENUE project's AMs have enabled many PRMs to move around freely, particularly at the Belle-idée site in Switzerland and at the Slagelse hospital in Denmark.

Thanks to our various communication and dissemination activities, the AVENUE project also enjoyed a significant amount of visibility via the various social networks dedicated to the project and those of the various partners, via the AVENUE website and mailing lists as well as various events across Europe and the world. Some Youtubers also came on-site and shared videos dedicated to the project that reached hundreds of thousands of people. This also allowed to inform the public about the very existence of AMPT technology and of the On-demand and Door-to-door services.

5 Site learnings & achievements

The project has also allowed a number of achievements, success and learnings specific to different demonstrator/replicator deployments.

5.1 Copenhagen demonstration

This demonstration was composed of three deployment sites, Nordhavn, Slagelse and Ormøya where AMPTs services have been transporting 9,975 passengers over 31,267km. The 8 vehicles were confronted with a wide range of situations, from driving in a busy city area with many obstacles such as delivery trucks, bicycles and e-scooters, to driving on faster country roads and in residential areas, as well as operating in a hospital and faced difficult weather conditions, such as heavy snowfalls.

The Copenhagen demonstration led to the following achievements and learnings:

- Operating On-demand (+ordering via public transport interface)
- Allowing the first Danish approval
- Operating on high-complexity roads in the city centre
- Operating in an urban city centre
- Operating in busy areas with many obstacles
- Integrating AMPTs within the PT network
- Helping the hospital patients, relatives and the hospital staff
- Learning about braking algorithms for carrying fragile passengers
- Driving in snowy and heavy rain conditions
- Helping local communities

5.2 Lyon demonstration

The first deployment in Lyon took place in the Confluence district, a densely populated area in the heart of the city, where the AMPTs provided a great support to the population. The operations were then refocused on a new site in the Groupama stadium area situated in Décines, a commune of the Lyon metropolitan area experiencing a heavy traffic, that hosts hotels, medical centres, recreation centres, and office buildings. In this context, AMPT services enabled the transport of 51,000 passengers over 78,000km and supported the economic development of the district by proposing a new mobility offer integrated to the public transport network.

The Lyon demonstration led to the following achievements:

- Showcasing the world's first public road automated minibus experiment
- Operating on a roundabout passage with 45,000 vehicles per day
- Operating the first On-demand service without the intervention of a safety driver
- Integrating the automated minibuses in a difficult social environment
- Developing new V2X functionalities
- Supporting the economic development of a new district
- Proposing a new mobility offer integrated into the public transport network
- Helping to establish the basis for the future French regulation
- Simulating difficulties on a test site
- Conducting some social surveys

5.3 Luxembourg demonstration

In Contern, AVENUE's AMPTs commuted passengers between the train station and the Campus Contern, dispatched people arriving by public transport directly to their work and provided a mobility solution within this industrial zone. The 2.3km journey was strewn with industrial vehicles, trucks and individual cars. The Pfaffenthal deployment, connected a residential area with the train and funicular station as well as with the panoramic elevator, that goes up to the city of Luxembourg. This deployment has provided a valuable convenience to the population by creating a connection between the different means of transportation arriving in different points of the area. Here, the automated minibuses have allowed the mobility of local residents, commuters and tourists from all age groups in an environment with multiple traffic situations, in a busy inner-city area full of cyclists and pedestrians. Within these sites the project's AMPTs covered almost 13,040 km and carried more than 25,910 passengers.

Luxembourg's deployment sites have led to a number of achievements:

- Driving in touristic site, industrial zone and pedestrian zone
- Overcoming different kinds of obstacles
- Allowing the first Luxembourgish approval for public roads
- Operating On-demand
- Integrating AMs into the public transit network

5.4 Geneva demonstration

After more than four years of operation, the Geneva demonstration automated vehicles have travelled a total of 9,825km and carried 1,787 passengers. After a phase with regular customers on a fixed-route, fixed-schedule itinerary in Meyrin, a commune on the outskirts of Geneva (Xa-Line), 3 autonomous mini-buses were deployed in Belle-idée, an area accessible to everyone where a medical complex is located. This deployment offered the world's first large-scale On-demand and Door-to-door service on a 38-hectare estate where cars, buses, scooters and bicycles converge, as well as a large number of patients who were able to take advantage of these services.

Among the achievements of the Geneva site, we can mention:

- Operating seamlessly in urban environments and on complex itineraries
- Operating on busy public roads with many obstacles and heavy traffic
- Implementing a dynamic routing system
- Integrating AMs within the existing public transport network
- Allowing the first Swiss AM vehicle homologation
- Contributing to the Swiss autonomous driving legislation evolution
- Transporting regular customers' base
- Helping many mobility impaired persons within the Belle-idée domain
- Testing long-term operation with a very high level of safety and reliability
- Participating in the improvement of obstacle and vegetation detection

5.5 Uvrier replication site

This replicator site was located in Uvrier**,** a small residential town and aimed to solve a real mobility problem in this sparsely populated region. Two automated vehicles have thus crisscrossed the streets of the municipality to respond to user requests (On-demand services) made via the *SmartShuttle* application or by simple phone call request.

The Uvrier replicator permitted multiple achievements:

- Proving that the demonstrators' model can be replicated
- Implementing the automated trip planning suggestions (algorithm-based trip planning)
- Implementing the trip planning via call centres (conventional trip planning for people without smartphones)
- Implementing digital or human information points
- Implementing help requests and visualization in real time of the path/destination
- Developing of V2I communication to ensure the passage of intersections
- Providing one of the first On-demand service with autonomous vehicles
- Providing the opportunity to try out various booking options, including a virtual avatar

5.6 Esch-sur-Alzette replication site

The Esch-sur-Alzette demonstration took place along a 1.2km route crowded with pedestrians. This deployment offered an On-demand service linking the existing public transport lines that provided a consistent service to the local population which was particularly helpful during the European Capital of Culture Esch 2022. The Esch-sur-Alzette automated minibus covered more than 4,800km and carried more than 11,600 passengers.

The Esch-sur-Alzette's deployment site has led to many achievements:

- Confirming the replicability of the demonstrators' sites
- Driving on small streets full of pedestrians
- Filling the existing gap in public transport in the centre of Esch-sur-Alzette
- Proving the feasibility of driving in high pedestrian density environments