AVENUE

Autonomous Vehicles to Evolve to a New Urban Experience

D 2.1

First Gap analysis and recommendations on autonomous vehicles for public service

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Autonomous Mobility

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Abbreviations

- *AV*
  Autonomous vehicle: A vehicle capable of sensing its environment and navigating without human input.

- *ADS*
  Automated Driving Systems

- *SAE*
  Society of Automotive Engineers

- *SoA*
  State-of-the-art

1. Introduction

This Gap analysis is conducted to specify in detail the technological innovation potential for the AVENUE solutions, while proposing innovative and the state-of-art features for the AVENUE project.

It will result in a list of proposed recommendations on autonomous vehicles for public service in order to give further directions for the AVENUE work. Furthermore, the different obstacles e.g. technical, legal and social barriers that can hinder the large-scale adoption and deployment of autonomous vehicles for public transport, will be identified and prioritised.

The analysis is based on the following:

- Existing deployments and pilot projects made by project partners.
- Information about technologies and solutions learned from pilot stage and project under development by non-partners.
- Review of relevant existing guidelines, good practices and standards, coming from European, North American and other international tests and operation of autonomous vehicles for public transport.

1.1 Readers guide

This Gap analysis is structured in 4 sections; AVENUE goals, SoA analysis, The initial gap and Recommendations.

Chapter 1: AVENUE goals
Chapter 1 briefly describes the basis of the AVENUE project, including the project vision and goals.

Chapter 2: SoA analysis
The SoA analysis is conducted with the purpose of illustrating the current technological development of autonomous vehicles and services. This provides a broader understanding of the current knowledge, expertise and experience regarding deployment of autonomous vehicles and services.

In chapter 2, you can read a draft about the technologically scope of the AVENUE project, namely, vehicle and service scope as well as a timeline of NAVYA's Autonom Shuttle deployment.

Chapter 3: The initial gap
Chapter 3 will introduce a description of the gap between the current state (SoA) and the proposed state (Avenue goals). This identified gap will lead to a list of transport and service technological potentials for AVs for public services.

Secondly a description of obstacles that hinder the large-scale adoption and deployment of AVs for public transport will be given and prioritised.

Chapter 4: Recommendations

In chapter 4 a list of recommendations will be proposed to give further directions for the AVENUE project. The recommendations will be based on the learnings from chapter 3.

The relationship between the SoA, the gap analysis, the proposed AVENUE goals (after 4 years) and the recommendations is visualised in Figure 1.

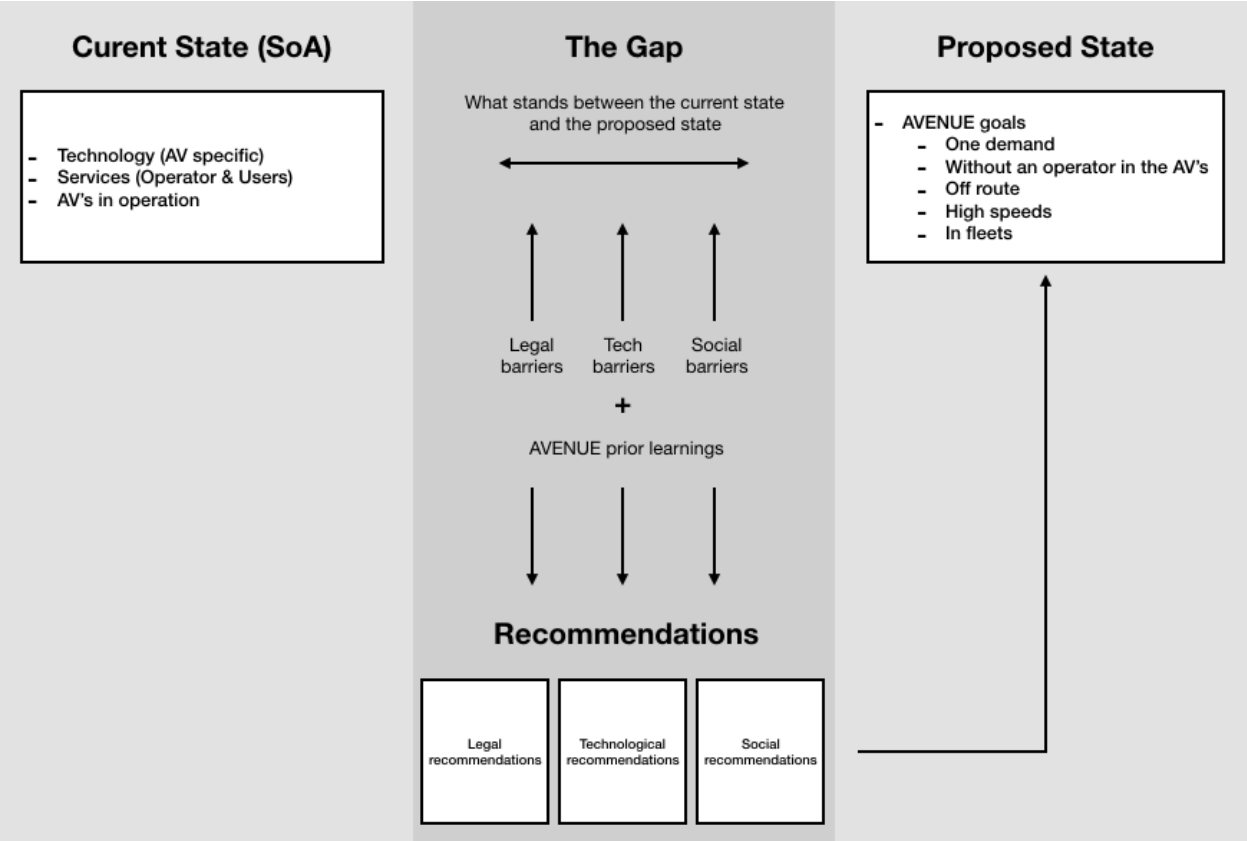


Figure 1 - The gap visualised

In figure 1, the gap is defined as the "space" between the proposed state and the current state - meaning the barriers and obstacles that stand between the current state and the AVENUE goals. The barriers and obstacles can be defined in three categories: Legal, Social and Technical barriers. Furthermore, the gap feeds the recommendations including the AVENUE prior learnings from the deployment of autonomous vehicles. The recommendations then represent the actions that needs to be initiated in order to reach the proposed state.

2. AVENUE goals

The proposed state (the goals of the AVENUE project) is defined.

2.1 Proposed state

The purpose of the AVENUE project is to demonstrate and pilot the adaptability and efficiency of the deployment of small and medium autonomous vehicles (AV's) in Lyon, Luxembourg, Geneva, Copenhagen and 2-3 replicator cities as of the 3d year of the project. The AVENUE vision for future public transport in urban and suburban areas, is that autonomous vehicles will ensure safe, rapid, economic, sustainable[1] and personalised transport of passengers, while minimising vehicle changes. The goal is to provide door to door autonomous transport allowing commuters to benefit from autonomous vehicles.

At the end of the AVENUE project - 4 year period - the mission is to have demonstrated that autonomous vehicles will become the future solution for public transport. The AVENUE project will demonstrate the economic, environmental and social potential of autonomous vehicles - for both companies and public commuters - while assessing the vehicle road behavior safety.

To summarise the AVENUE goals can be defined as follows in figure 6.

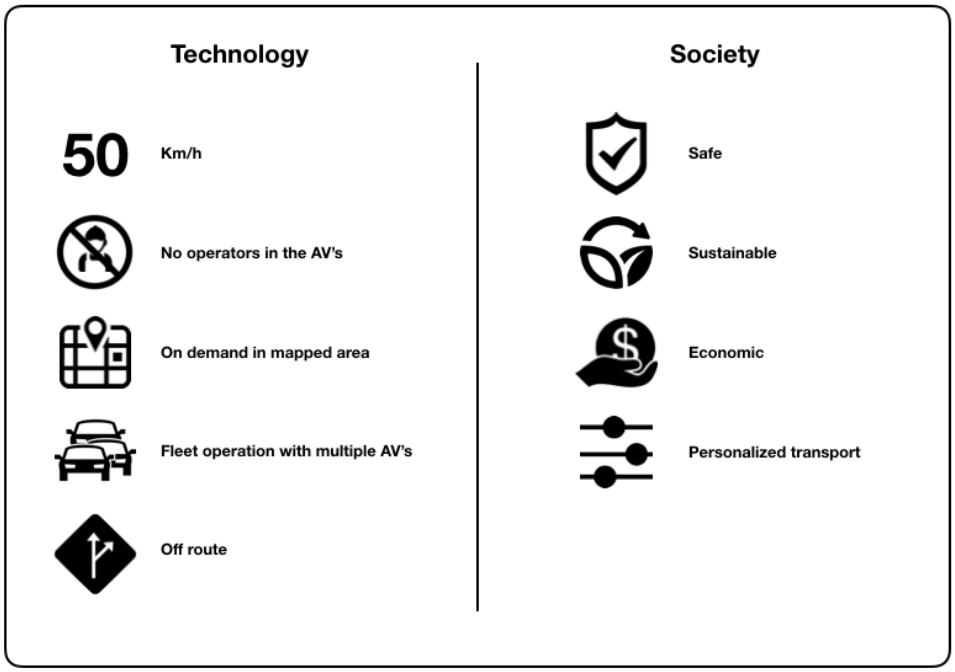


Figure 6 - AVENUE goals

[1] Within urban transportation sustainable most often refers to electric vehicles.

3. SoA analysis

The SoA analysis looks into the current state of the AV development - AV's and services connected to autonomous driving. The SoA looks into the pilot experience and knowledge within the consortium and outside the consortium.

3.1 Current state

Many new vehicles have integrated automated technology that assists drivers to increase the safety of driving by helping them to avoid unsafe lane changes, warn them that vehicles are approaching or break automatically if obstacles appear in front of the vehicle. These safety technologies use a combination of software and hardware (cameras, lidars, radar and sensors) to assist the vehicle in identifying certain safety risks and act accordingly to avoid collisions.

As a part of the autonomous vehicle technology, Automated Driving Systems (ADS) are used to increase the safety. The technology was first introduced in 1950, and has been developed rapidly since. Table 1, shows the Evolution of Automated Safety Technologies.

1950 - 2000	2000 - 2010	2010 - 2016	2016 - 2025	2025 +
Safety /Convenience Features • Cruise Control • Seat Belts • Antilock Brakes	Advanced Safety Features • Electronic Stability Control • Blind Spot Detection • Forward Collision Warning • Lane Departure Warning	Advanced Driver Assistance Features • Rearview Video Systems • Automatic Emergency Braking • Pedestrian Automatic Emergency Braking • Rear Automatic Emergency Braking • Rear Cross Traffic Alert • Lane Centering Assist	Partially Automated Safety Features • Lane keeping assist • Adaptive cruise control • Traffic jam assist • Self-park	Fully Automated Safety Features • Highway autopilot

Table 1 - AV safety development[2]

[2] https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety

In continuation of the evolution of the automated safety technologies, the SAE driving levels are illustrated to indicate the development of autonomous vehicles and to determine the scope of the vehicles involved in the AVENUE project. The SAE has determined 5 autonomous driving levels as described in Table 2 below.

0 **No automation**	The vehicle is being fully human and manually controlled
1 **Driving assistance**	The vehicle is controlled by the driver, but there are some features assisting the driver
2 **Some automation**	The vehicle has some automated functions like acceleration and steering, but the driver must be engaged with the driving tasks and monitor the road at all times.
3 **Conditional automation**	The vehicle can safely control aspects of driving in mapped areas. The driver is necessary but does not have to monitor the road at all times.
4 **High automation**	The vehicle can perform all driving tasks in mapped areas. The driver have the option of controlling the vehicle. No steering wheel or pedals.
5 **Full automation**	The vehicle is capable of driving under all conditions. The driver have the option of controlling the vehicle. No steering wheel or pedals.

Table 2 - Autonomous SAE driving levels[3]

3.2 Autonomous technology (AV specific)

In order to set the framework of the SoA, regarding the autonomous vehicle technology, it is necessary to define the vehicle scope - vehicles that have the functions and capabilities to be included in the AVENUE project. The vehicle scope defines in 5 points the minimal vehicle requirements as shown in Figure 2 below. Besides the 5 main vehicle requirements, the vehicles have to be electrically driven.

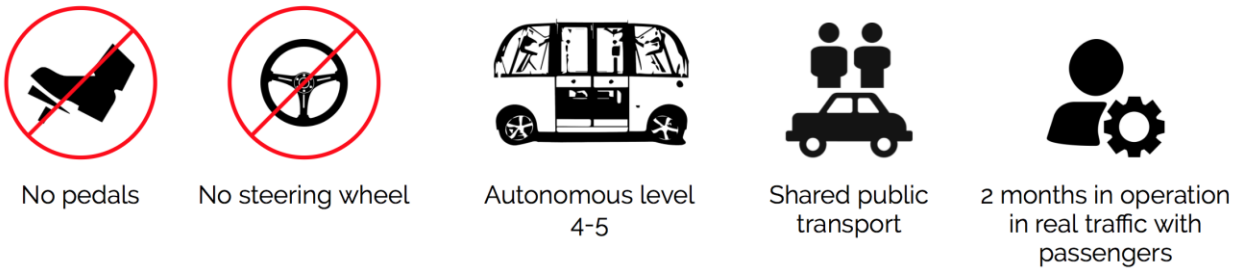


Figure 2 - AVENUE AV scope

[3] https://medium.com/field-of-view/against-the-odds-why-the-av-industry-should-probably-focus-on-just-the-even-numbered-sae-autonomy-ed4510633dcf

Based on the autonomous vehicle scope, desk research on autonomous vehicles and shuttles was conducted with the purpose of establishing an overview of the current autonomous technology and vehicle industry. The vehicle systems are illustrated in Figure 3 below.

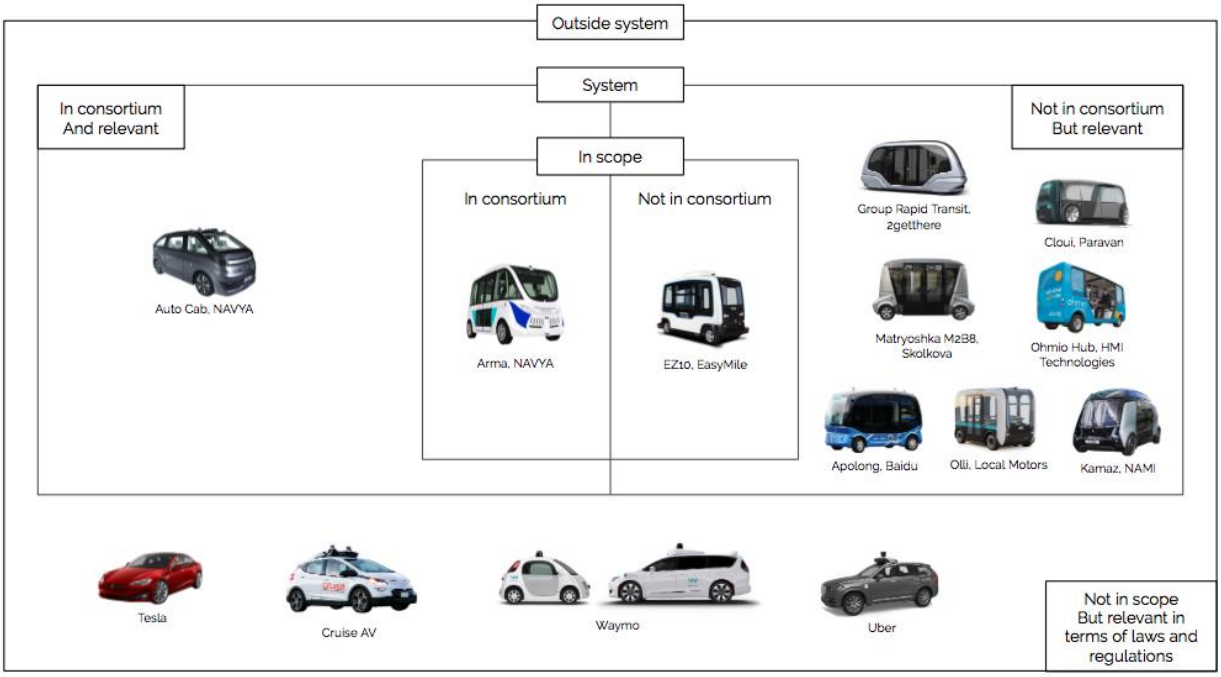


Figure 3 - Vehicle system

Figure 3 defines the vehicle systems - within and without the project vehicle scope - all relevant for the AVENUE system. The AVENUE system is vehicles, services and experience within or outside the consortium. There are three levels in the system:

- **In scope**
  There are currently two vehicles that fit the AVENUE AV scope; NAVYA's Autonom Shuttle and EasyMile's EZ10. As Consortium partner, Autonom Shuttle is within the consortium, while EZ10 is outside the consortium.

- **System**
  There are multiple autonomous vehicles under development, which potentially could fit within the timeframe of the AVENUE project. E.g. NAVYA's Autonom Cab, might be piloted in real trafic[4] with real passengers during the project, hence over time fit within the AV scope. All the vehicles illustrated in figure 3 in the "system", technologically work differently, but are viewed as very relevant since they all face the same barriers and obstacles for their commercial deployment.

- **Outside system**

[4] Real traffic conditions - also referred to as mixed traffic - means vehicle, pedestrian and bicycle traffic in city areas with e.g. intersections, roundabouts and traffic in both directions.

Vehicles that do not fit the vehicle scope of the project are placed outside the system, because they, for example, have steering wheels and pedals. Nonetheless, these vehicles are perceived as relevant in terms of laws and regulations, since they have the same barriers and obstacles regarding deployment of autonomous vehicles.

3.3 In the vehicle scope

For now, Autonom Shuttle and EZ10 are considered to fit the AV scope defined earlier for the AVENUE project. The two vehicles are shortly described in this paragraph, including major learnings.

NAVYA's Autonom Shuttle (previously known as Arma)		
Details	**Development (as of June 2018)**	**Use cases**
Official launch: October 2015 Capacity: 14 passengers Durability: 8 hours of driving Engine: 100 % electric Recharging: 5 hours (0-99 %) Self-driving, no steering wheel and pedals	More than 100 vehicles produced 87 vehicles sold worldwide Operating in 16 countries Carried more than 275.000 passengers since 2016	Accessible to people with reduced mobility Navigation indoors and outdoors In house fleet management system - Navya Lead
		

EasyMile's EZ10		
Details	**Development (as of June 2018)**	**Use cases**
Official launch: April 2015 Capacity: 12 passengers Durability: 14 hours of driving Engine: 100 % electric Recharging: 5 hours (0-99 %) Self-driving, no steering wheel and pedals	80 vehicles produced 200 autonomous deployments since launch First autonomous shuttle to ride in mixed traffic environment Demonstrated in 22 countries	Passengers and goods Accessible to people with reduced mobility Navigation indoors and outdoors or in woodlands No dedicated infrastructure needed In house agnostic fleet management system
		

3.4 Services (operators and end-users)

Besides getting to know the autonomous vehicles and the technology development behind the vehicles, it is necessary to understand the services that are used to manage and monetize the vehicles when they are deployed - as well as services developed for end-users using the AV's.

3.4.1 Operators

The service scope - related to fleet management of the autonomous vehicles - is displayed in Figure 4, indicating the services that are considered in the AVENUE project. The services are divided like the vehicles scope - within and outside the consortium.

As this is the draft, only the major service providers of autonomous fleet and operation management is mentioned and as the AVENUE project develops, the services scope will expand to include user-oriented services versus operator-oriented services.

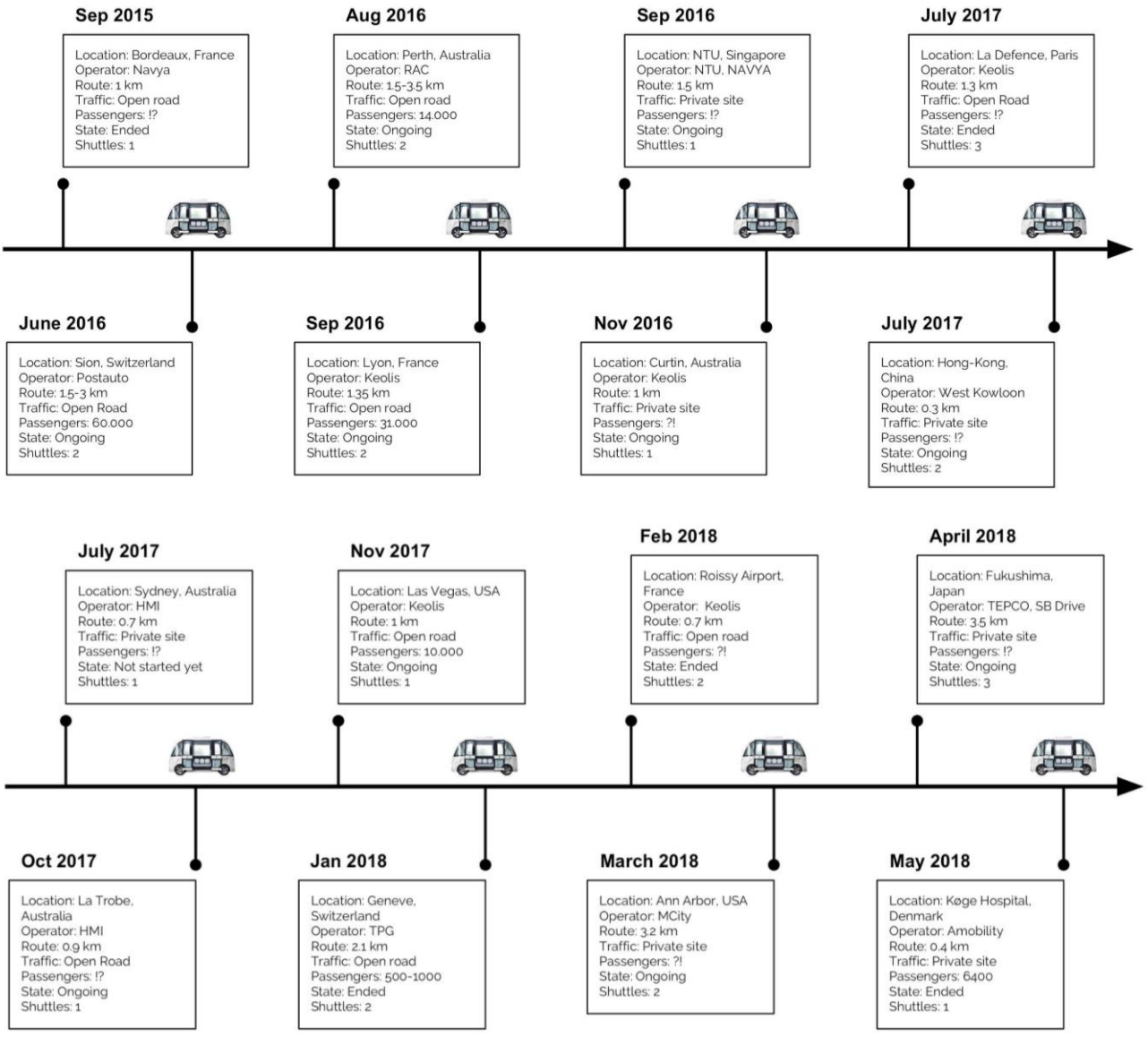
Figure 4 - Service scope

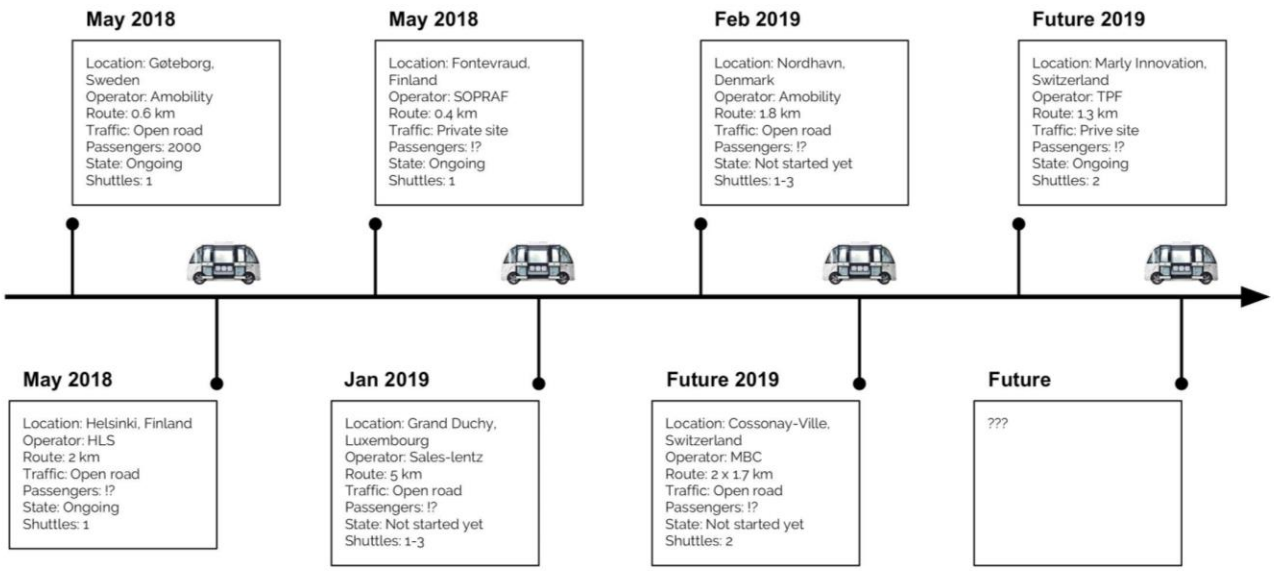
3.4.2 End-Users (not existing yet for AV's) Here we will describe the today available passenger services – these are existing services used for buses, taxis etc, which have a relevance and use to the project. For more details see deliverable "D2.5 - *Definition of AVENUE services*"

- Online life information of vehicle arrival at a bus stop (existing busses)
- Online reservation of taxis and information where they are and when they arrive (we can see on the mobile phone the taxi arriving)
- Online payment and ticketing (by sms, operator app etc).
- Live information about traffic issues and delays to the passengers in and out of the vehicle.

3.5 Autonom Shuttle in operation

Since the launch of Autonom Shuttle in 2015, the vehicle has been deployed in many pilot projects on private sites and on open road. This report draft provides an overview of the projects with the purpose of visualising the experience that NAVYA has gained from the deployment of Autonom Shuttle and to indicate the operators from each of the pilot projects. This overview indicates the number of shuttles deployed during the projects and each project is currently under investigation to identify the number of passenger, the drived km and so forth. The complete data will be included in the next SoA deliverable - indicating more in detail the experience from each pilot.




May 2018
Location: Gøteborg, Sweden
Operator: Amobility
Route: 0.6 km
Traffic: Open road
Passengers: 2000
State: Ongoing
Shuttles: 1
May 2018
Location: Fontevraud, Finland
Operator: SOPRAF
Route: 0.4 km
Traffic: Private site
Passengers: !?
State: Ongoing
Shuttles: 1
Feb 2019
Location: Nordhavn, Denmark
Operator: Amobility
Route: 1.8 km
Traffic: Open road
Passengers: !?
State: Not started yet
Shuttles: 1-3
Future 2019
Location: Marly Innovation, Switzerland
Operator: TPF
Route: 1.3 km
Traffic: Prive site
Passengers: !?
State: Ongoing
Shuttles: 2
May 2018
Location: Helsinki, Finland
Operator: HLS
Route: 2 km
Traffic: Open road
Passengers: !?
State: Ongoing
Shuttles: 1
Jan 2019
Location: Grand Duchy, Luxembourg
Operator: Sales-lentz
Route: 5 km
Traffic: Open road
Passengers: !?
State: Not started yet
Shuttles: 1-3
Future 2019
Location: Cossonay-Ville, Switzerland
Operator: MBC
Route: 2 x 1.7 km
Traffic: Open road
Passengers: !?
State: Not started yet
Shuttles: 2
Future
???

3.6 Consortium experience

Within the AVENUE consortium, there are 4 operators, operating autonomous vehicles in 4 different countries. Switzerland, Denmark, France and Luxembourg. The four operators have prior to the project experience with deployment of autonomous vehicles in either experimental operation or regular operation. As a part of defining the baseline of the AVENUE project - the technological experience startpoint - the four operators and their experience is highlighted in the figure 5.

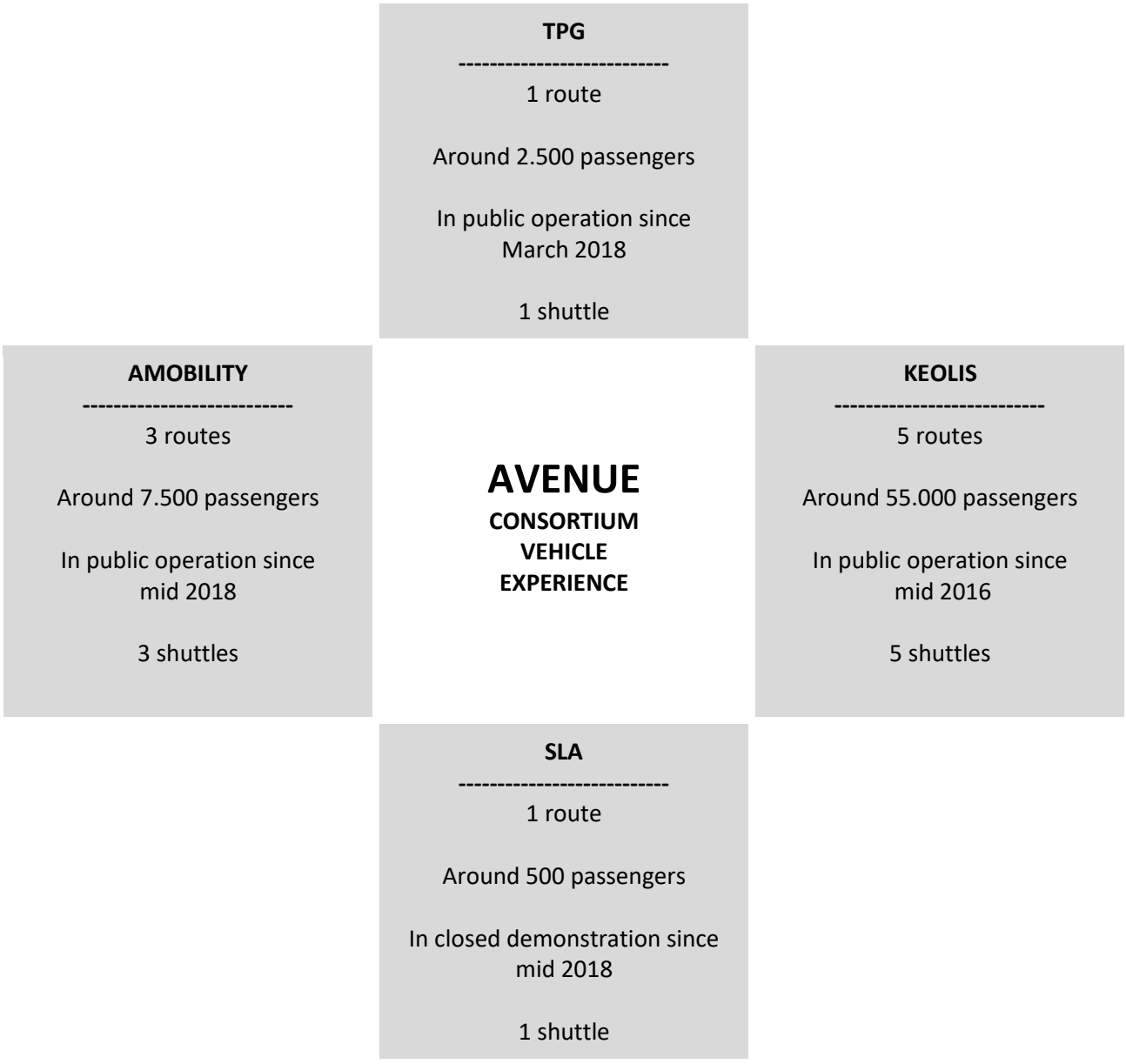


Figure 5 - AVENUE operators

3.7 What can we learn from other projects and operators

As a part of the SoA it is necessary to look into what others have done before the AVENUE project, ensuring that mistakes made in the past, can be avoided in the future. Two major projects related autonomous vehicles operation in EU were completed within the past couple of years: CityMobil2 and UK Autodrive. The two projects are briefly described and the major learnings and recommendations from the projects are extracted and summarized.

CityMobil2[5]

CityMobil2 is an EU funded project with the main purpose of removing barriers and obstacles regarding deployment of fully-automated shuttles. The total budget of the project was 15 M€, where 9.5 M€ came from EU and the rest from the consortium partners. The project ran for 48 months (2012-2016). The two autonomous vehicles deployed during the project was Robosoft Robucity and Easymile EZ10.

The CityMobile2 project had three different pilot setups as follows:

- Showcase: 2-3 day exhibits
- Small demo: 1-4 busses up to 4 months
- Large demo: 1-6 busses up to 6 months

The project included demonstrations in the following 10 cities:

- León, Spain: Showcase (2014)
- Bordeaux, France: Showcase (2015)
- Warsaw, Poland: Showcase (2016)
- Oristano, Italy: Small Demo (2014)
- Vantaa, Finland: Small Demo (2015)
- San Sebastian, Spain: Small Demo (2016)
- Sophia Antipolis, France: Small Demo (2016)
- LaRochelle, France: Large Demo (2014/15)
- Lausanne, Switzerland: Large Demo (2014/15)
- Trikala, Greece: Large Demo (2015/16)

Lessons learned from the CityMobil2 project:

- It is important to limit the initial ambition of the route and to be aware of the limits of the system to be implemented. The reality is very often more demanding in practice.

[5] http://www.citymobil2.eu/en/Downloads/Overview/

- A very clear and identifiable marking of the ARTS route would contribute to a better interaction with pedestrians and cyclists, making it possible for road users to get accustomed to the idea that a part of the road will be restricted for use by the ARTS only or that the ARTS has priority on a given part of the road.

- The presence of hosts on-board was needed to cope with the limitations of the system in some operating environments

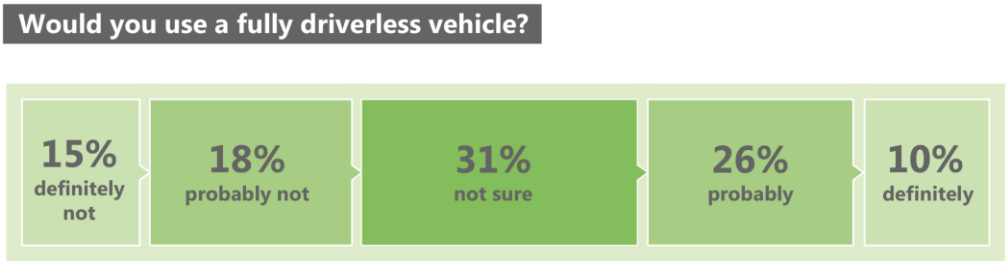
- Enforcement of the laws applied to car/truck drivers is necessary to make sure that the operation of the ARTS vehicles was not detrimentally impacted by illegal parking, etc.

These findings/learnings from the CityMobil2 project are not directly relevant for the AVENUE project, since the technological development within the field allows the AVENUE consortium to operate the autonomous shuttles beyond the learnings from the CityMobil2 project. The learnings are though still interesting to include in the SoA since they contribute to sketching out the technological development of the application of AV's through time. Furthermore some of these learnings contradict with the AVENUE goals, for example to eliminate the safety driver during the project.

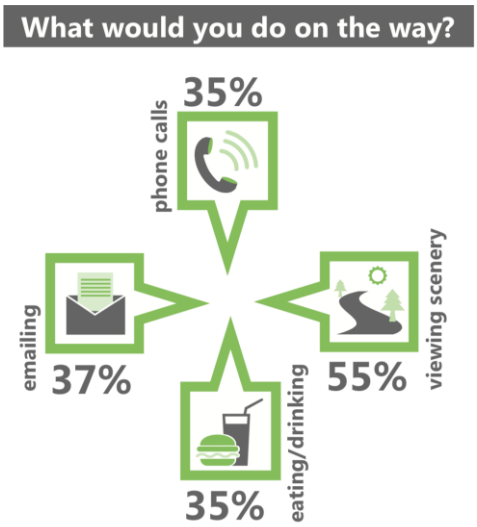
UK Autodrive[6]

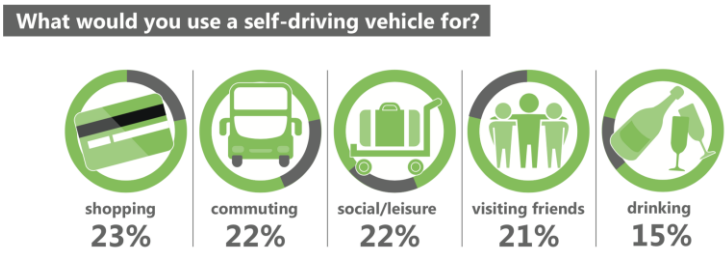
UK Autodrive is the largest of three separate consortia that are currently trialling automated vehicle technology in the UK. All three consortia projects are part of a government-backed competition that supports the introduction of self-driving vehicles into the UK. The project will run for three years (until October 2018) with several major milestones along the way, including the start of the vehicle trials – the first of which took place at the HORIBA MIRA Proving Ground in October 2016. In the last year of the programme, autonomous and connected cars and pods will become a regular sight in Milton Keynes and Coventry

During the UK Autodrive project, the University of Cambridge was asked to carry out a national survey of public perceptions towards self-driving (autonomous) vehicles. The survey conducted in November 2016 and included around 3000 participants. The results from the survey is summarized below.



[6] http://www.ukautodrive.com





The results from the survey reflects user opinions about self driving technology at the time of the conduction, and it will be interesting and necessary to investigate how this technology is perceived in the four operating countries during the the AVENUE project. This will be analyses and presented in "D2.2 - *Passenger needs analysis and specifications"* during the AVENUE project.

4. The initial gap

First a description of the gap between the current state (SoA) and the proposed state (Avenue goals) will be provided. This will lead to a list of technological, and legal recommendations for AVs for public services. Secondly a description of obstacles that hinder the large-scale adoption and deployment of AVs for public transport will be given and prioritised. It will focus on the legal, social and technological barriers.

The gap can be defined as the space that stand between the current state of the AVENUE project and the proposed state - the aim of the project. The current state and the desired state is briefly described with focus on highlighting the gap.

Current state (what are we capable of doing so far):

- SAE level 4 vehicle driving
- Public and shared transport
- Solve real mobility needs
- Drive safe under the right conditions with low speeds
- First step towards more sustainable transport has been reached: electrically driven vehicles

Proposed state (what do we want to be able to do):

- SAE level 5 driving
- Drive fully on demand
- Drive off routes (door to door transport)
- Drive without safety drivers
- Drive with higher speeds (50 km/t)
- Integrate with existing public transport systems
- Drive with multiple vehicles in fleet mode
- Be fully sustainable (green electricity - positive rebound effects)
- Reach a more competent economic setup (no operators & easier application processes)
- Personalised transport
- Automatic vehicle changes

This gap can be described by three factors standing between reaching the AVENUE goals. These factors are legal, social and technological barriers that need to be taken into account when defining the objectives of the AVENUE project. The three factors are shortly described - while emphasising that they will be further defined during the development of the project.

4.1 Legal barriers - AV setup

A simple legal overview of the four operating sites can be seen in the following 4 tables, indicating some of the barriers. Following the 4 tables a short overview of other barriers, affecting full scale deployment of AV's, are presented.

Sales-Lentz moving people	Luxembourg
Route	Luxembourg City (Pfaffenthal) & Contern
Operator presence	The presence of a safety driver is mandatory during trial phases
Seat belt	Sitting passengers have to wear a seat belt when driving
License place	License plates are mandatory for Autonomous shuttles - similar to normal vehicles
Vehicle taxation	Registration taxes are the same as normal vehicles

Table 3 - SLA

tpg	Switzerland
Route	Geneve
Operator presence	The presence of a safety driver is mandatory during trial phases
Seat belt	Sitting passengers have to wear a seat belt when driving
License place	License plates are mandatory for Autonomous shuttles - similar to normal vehicles
Vehicle taxation	Registration taxes are the same as normal vehicles

Table 4 - TPG

AUTONOMOUS MOBILITY	Denmark
Route	Nordhavn, Copenhagen
Operator presence	The presence of a safety driver is NOT mandatory during trial phases
Seat belt	Sitting passengers does NOT have to wear a seat belt when driving
License place	License plates are mandatory for Autonomous shuttles - similar to normal vehicles
Vehicle taxation	Registration taxes are NOT the same as normal vehicles

Table 5 - Amobility

Keolis	France
Route	Décines-Charpieu, Lyon
Operator presence	The presence of a safety driver is mandatory during trial phases
Seat belt	Sitting passengers does NOT have to wear a seat belt when driving
License place	License plates are mandatory for Autonomous shuttles - similar to normal vehicles
Vehicle taxation	Registration taxes are NOT the same as normal vehicles

Table 6 - Keolis

4.1.1 Approval process

The approval process of each of the four operators is elaborated on and can be seen in D2.10: “First report on regulatory requirements and compliance plan”. This draft also highlight the general legal setup regarding each operation country.

4.2 Social barriers

Social barriers are to be elaborated after the insights from initial interviews has been processed in D2.4: “First passenger needs analysis and specifications".

4.3 Technological barriers

- The vehicle is not technologically mature enough to drive in SAE level 4 & 5 without a safety driver
  - On demand off routes not possible
  - Need for manual (safety driver) resets and controls when driving
- The vehicle does not accommodate wheelchair users (without a helper)
  - The automated ramp angle is too steep
  - The vehicle does not include a seatbelt solution for wheelchair users (required by law)

5. Recommendations

Below a list of recommendations are proposed to give further directions for the AVENUE project. These addresses three topics - technical, legal and service requirements. The technical recommendations defines the areas of development that needs to be improved in order for the AVENUE project to reach its technical goals.

5.1 Technical recommendations

Road behavior:

- Overtaking static and moving objects > This is key to operating the shuttle in a live environment at all times.
- Better brake algorithm > Enabling the shuttle to smoothly break in context to surroundings and will improve the comfortability of the ride.
- The ability to detect fire on route

- Better LIDARs with higher resolution > Enabling the shuttle's computer to actually see the actions from other road users. Are pedestrians walking or standing? Are other vehicles overtaking the shuttle or staying behind?

Vehicle management:

- The ability to detect a flat tire
- Weight/load measuring > An essential part in removing the driver is to be able to remotely read the actual and live load in the shuttle.
- Product Improvement Programme (PIP) and bug reporting > By setting up a systematic approach to error reporting by enabling the customers of Navya will greatly improve the empirical data.
- Hardware release notes, software release notes and individual shuttle configuration catalogue > This will greatly improve the dialogue with each authority in the different countries by making it easier to identify which shuttles have a dual braking system, washer fluids, are bi-directional and other hardware and software configurations that will vary from VIN to VIN.
- Live remote access and live remote control of the full feature set of the shuttle > This is key to remove the driver from the shuttle and enabling a supervision centre to overview several vehicles.
- 5G connectivity > Live delivery of video feeds and data feeds to both statistics and a remote supervision centre.
- Documentation standards > Raising documentation standards to automotive grade level, increasing the acceptance rate from authorities.
- Spare parts catalogue, spare part prices and maintenance SLA's > A shared catalogue of all parts used in the shuttles will improve re-ordering parts.
- Hardware release notes, software release notes, hardware and spare parts catalogue

In-vehicle options:

- Automated passenger counting
- More (and easier) customization options (changing graphics on screen in bus, changing sounds in the bus, routing emergency button to our phone number etc.)
- Sound enabled when doors close

5.2 Legal recommendations

- Overall more similar legal legislation across EU (in order to learn more directly from each operation).
- AV specific vehicle type approval - the vehicles is currently being approved in the same framework as normal vehicles.
- AV specific vehicle category at the Road Safety Agency

5.3 Service recommendations

Regarding service recommendations please refer to the delivery D2.13: “First definition of AVENUE services”. This presents a provisional list of AVENUE services, which is further detailed in line with the needs and feedback form the demonstrator cities.